EPRI | ELECTRIC POWER RESEARCH INSTITUTE

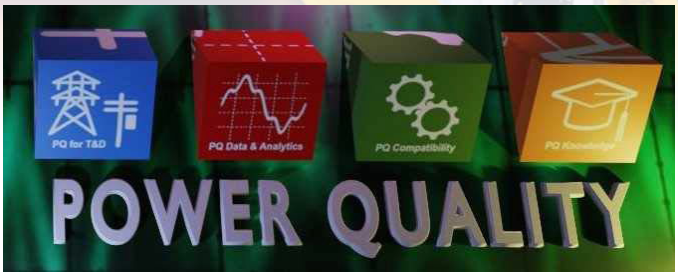
EPRI Power Quality (P1) Program Annual Review

WHAT MAKES US DIFFERENT

Proactive vs. Reactive PQ Management Strategies

The utility industry has, historically, taken an almost entirely reactive approach to power quality (PQ)—waiting for things to go wrong, equipment to malfunction or fail, or for customers to complain before acting. The customer base serves as the utility's Quality Control (QC) department with valuable PQ data resources and trained staff expertise brought in after the fact. This needs to change. One of the hallmarks of Smart Grid and Big Data strategies is to make use of data streams in near or real-time. Based on input from participating utilities, coupled with hard work, the Power Quality Program (P1) strives to enable the continuous use of PQ data in order to dramatically increase its value.

Examples include looking for indications of incipient equipment malfunction or failure, continuous benchmarking of PQ performance, and automated recognition and categorization of PQ waveforms and events. Tennessee Valley Authority (TVA) in the U.S. has been the most aggressive in applying these techniques. In their initial round of implementation, performance issues were detected with three transmission-level capacitor banks that would have, absent intervention, led to costly failures. This activity saved TVA over $1 million in avoided repair costs, not to mention the avoided outages and possible related safety issues. Based on this initial success, TVA's GridOps has budgeted $5 million for their PQ team to put in hundreds more PQ monitors—increasing the ability of their PQ team to provide proactive value. And this is just scratching the surface of what is possible via additional research.



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By participating in PQ Knowledge Development and Transfer, Central Hudson uses a foundation of knowledge regarding the latest PQ products and expert insights into power quality—and access to world-class PQ resources via the PQ Hotline. With the latest PQ information and resource tools, Central Hudson is able to minimize economic losses and more effectively provide service to its customers in today's marketplace.

Overview and 2020 Research Agenda

The Electric Power Research Institute (EPRI) is a U.S.-based and internationally recognized not-for-profit collaborative research organization for the electric utility industry. EPRI conducts about US $700 million in research each year with a team of 900+ employees. This document is intended to provide a concise overview of EPRI's Power Quality research program (Program 1 in the EPRI portfolio, or P1 for short) beginning with some over-arching issues and/or opportunities in the industry that are influencing PQ research at EPRI, and what makes the EPRI PQ research program a unique resource. Following will be specifics of the P1 research program and how we are working to address industry needs in 2020. Power Quality has evolved to become a critical enabler of operation and economic excellence for modern electric utilities. Electric utilities worldwide consistently report that power quality (PQ) is a fundamental component of three key utility business performance metrics:

- Grid system performance
- Utility economic performance
- Customer satisfaction

Driving a resurgence of interest in electric power quality performance:

- The need to increase the economic performance of existing infrastructure
- Reduce the cost of grid operations and repairs
- Manage and respond to increasing grid complexity
- Retain existing and attract new load with excellent PQ performance and related customer support

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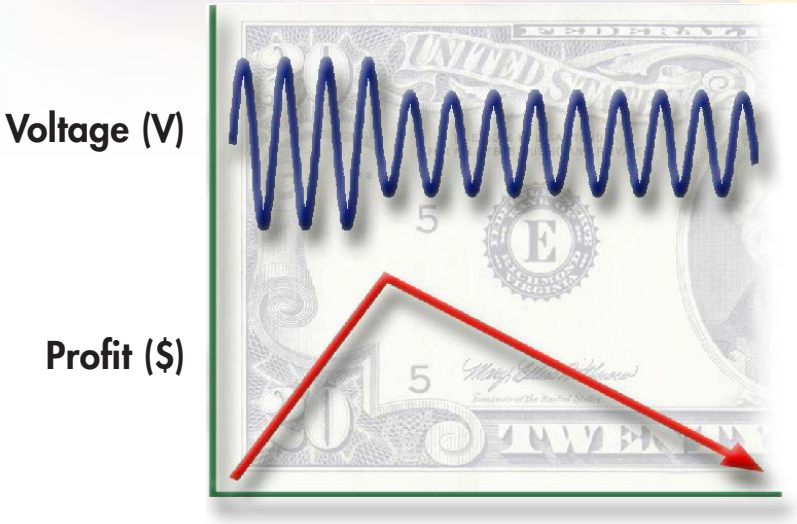
Key among these are R&D imperatives to use PQ expertise and knowledge to improve utility performance and management, maximize the proactive value of PQ data, and address increasing PQ issues that are inevitable with increasing edge-of-grid complexity.

Leading the way...

With this program, members can access research results that can help them achieve the public benefits associated with enhanced PQ. The Power Quality research program provides fundamental insights on electrical grid power quality and compatibility— improving the value of electricity service for society, and contributing to the overall public benefit of reliably supporting and integrating increasing levels of DER.

The Power Quality research program actively and continually seeks member input and industry knowledge to identify research priorities—producing a variety of expertise, software, analysis tools, and knowledge.

Created over 30 years ago, the Power Quality program has created and cataloged what may be the greatest concentration of PQ expertise in the world. EPRI regularly represents the interests of its funding utilities on IEEE, CIGRE, and IEC standards working groups—participating in almost all the



IEEE PQ working groups and often with official roles: another way EPRI brings value to our funding utilities in the area of PQ.

EPRI utility/funder meeting participants tend to be subject-matter expert who bring direct and personal experience to the table: one of the "secrets" making EPRI research so effective… the ideas, vetting, and implementation are all done by the same people in those planning meetings.

Accomplishments and Looking Ahead

The Power Quality program has delivered valuable research over the years that has helped its members, the industry, and society:

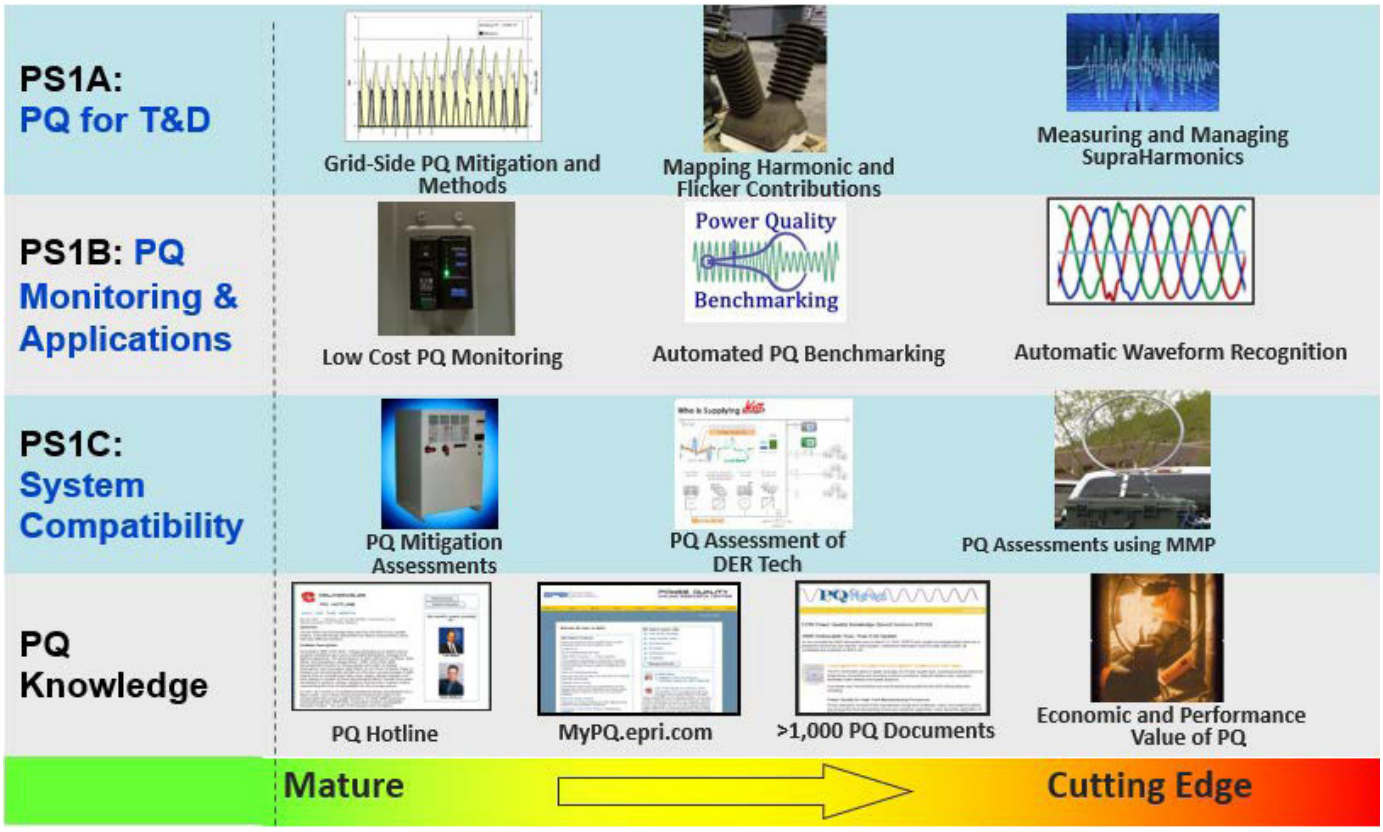
- Utilities reported US$ millions in cost savings from avoided grid-connected equipment failures—by using PQ data for detection of incipient equipment failure and mis-operation.
- EPRI's best-in-class PQ Investigator software, integrating U.S. $2M in end-use device testing and facility investigation results and expertise, allows funders to conduct expert-level facility assessments.
- EPRI's first-of-its-kind Grid-IQ software platform estimates future PQ performance levels based on changing loads, grid configurations, and operational practices, including an open-source-based grid model database allowing quick and low-cost analyses—most prominently, the Harmonic Evaluation Module (HEM) and Flicker Evaluation Module (FEM), tools. These allow analysis of current conditions and modeling of future conditions based on changes in grid configurations and end-use loads.
- EPRI's laboratory testing enabled the development of a detailed load model library for new and changing loads such as compact fluorescent lamps (CFLs), light-emitting diode (LED) traffic lights, hybrid electric vehicle chargers, and rooftop photovoltaics (PVs).
- EPRI's PQ Dashboard, a low-cost, easy-to-deploy, open source platform, allows visualization of PQ and other data—and integration with other data resources including Geographic Information System (GIS) information.
- Many of EPRI's past research developments have been implemented over time into PQView®, a multi-component software system for building and analyzing databases of power quality and energy Measurements (jointly owned by EPRI and Electrotek Concepts).
- EPRI's Power Quality Online Resource Center, a member-focused website deployed on MyPQ.epri.com, features more than 1,000 EPRI-authored PQ case studies, technology briefs, and other authoritative documents—available from no other source.

Current Year Activities:

- Develop readily deployable data analysis modules for near-time assessment using PQ data of the health and detection of incipient failure for common grid-connected equipment.
- Automation of data analysis methodologies so that assessment of PQ data can occur in real- or near-time rather than only on a post-mortem basis.

- Perform laboratory testing for accuracy, precision, and usability of the PQ monitoring capabilities of grid-connected devices incorporating PQ measurement capabilities, such as switches, relays, reclosers, breakers, and other devices.
- Evaluate the PQ sensitivities and contribution of new advanced manufacturing technologies as well as new DER technology such as smart inverters.
- Assess the PQ contribution, integration, and management challenges of DER, including rooftop PV, energy storage, and smart inverters.
- Assess the impact on common end-use devices of the complex PQ environment created by increasing DER integration.
- Enhance search capability for the MyPQ.epri.com website, including additional technical resources for the PQ Online Resource Center comprising more than 1,000 documents.

P1 Power Quality Program Summary Overview



EPRI Power Quality Project Set A: Analytics and Opportunities for Transmission and Distribution

Power quality is a key electric grid performance metric, and through improved understanding of PQ performance, this project set seeks to maximize the value of grid investments by helping to manage the inevitable consequences of increasing grid complexity.

Project Set 1A (PS1A) develops and supports unique tools for improving PQ management and analysis, including the Harmonics Evaluation Module (HEM) and the Flicker Evaluation Module (FEM). Both of these tools enable unique scenario-analysis capabilities that not only help in understanding today's PQ challenges, but also—through expert analysis—help to prevent future PQ issues.

In addition, PS1A seeks to leverage PQ expertise—employing advanced data analysis techniques—to monitor the health and performance of grid-connected assets and to detect problems using PQ data streams before they become costly failures.

The PQ Analytics and Opportunities for Transmission and Distribution consists of three base area subsets:

2020

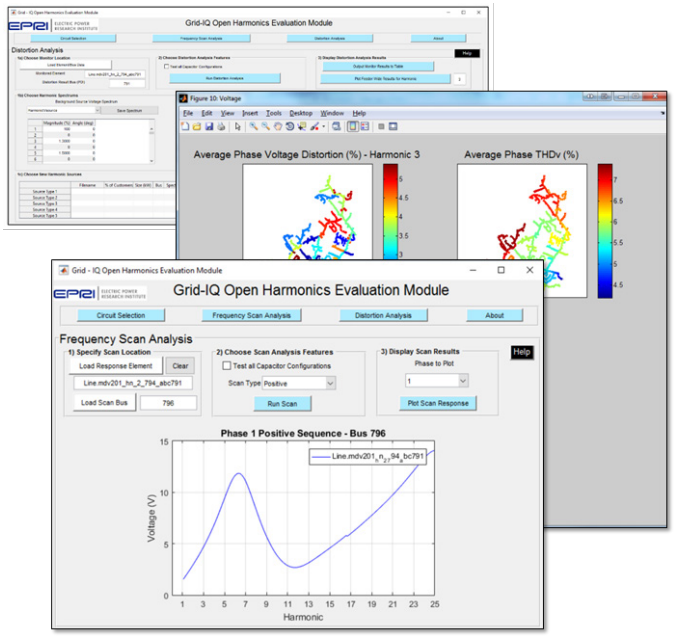
- PQ Issues and Solutions for Transmission and Distribution
- PQ Benchmarking, Standards and Advanced Applications
- Support and Development of PQ Analysis Tools

2021

- PQ Phenomena and Grid Performance
- Advanced PQ Analytics and Applications
- PQ Analysis Tools and Predictive Applications

How Can Analytics and Opportunities for Transmission and Distribution Help You...

- Develop and support tools for PQ management
- Offer one-of-a-kind analysis to understand and prevent PQ disruptions
- Subject Matter Experts in advanced data analysis and performance of grid-connected assets
- Detect any incipient failure



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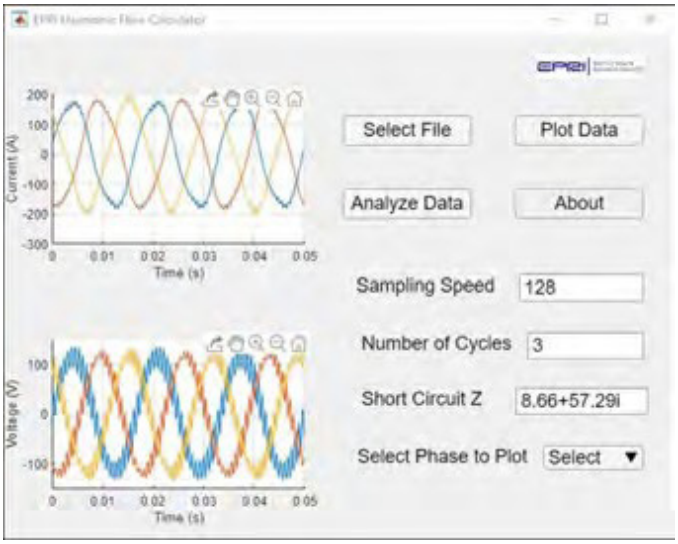
Accomplishments and Looking Ahead

2019 ACCOMPLISHMENTS

P1A – Harmonic Flow Calculator (HFC)

In 2019, P1A produced a Harmonic Flow Calculator (HFC) v1.0 Beta with this deliverable (3002015472). This software allows the user to combine monitored load data (voltage and current waveforms) with system impedance data—at the point of common coupling—to determine if the load is a source or a sink to harmonic current flow. Understanding the direction of harmonic current flow is important for problem cause-and-resolution studies addressing standard compliance issues or adverse conditions caused by harmonics.



Assessment of Best Practices for Measurement of Higher-Order Harmonics: For Medium and High Voltage

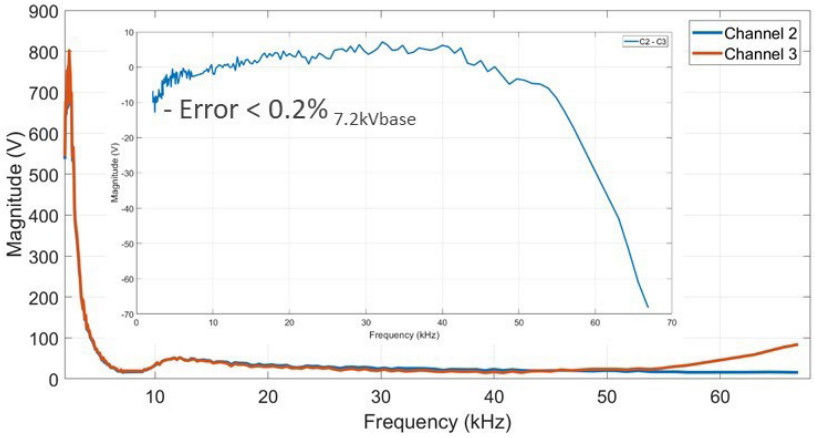
This report (3002016597) examined the capabilities of existing sensors for measuring signals above 2 kHz along with off-the-shelf monitoring equipment. The report presents an off-the-shelf method for acquiring voltage waveforms from the test or voltage tap found at the bottom of High-Voltage bushings on substation transformers—using a relatively low-cost sensor with an existing substation asset normally used only during periodic testing and maintenance.

Assessment of an Optically-Based, Medium-Voltage, Voltage and Current Sensor: Harmonic and Supra-Harmonic Performance

This research (3002016598) assesses the sensor system's harmonic signaling performance for both voltage and current—up to the 50th harmonic—and as a potential platform for supra-harmonic measurement (2 kHz to < 150 kHz), including a brief review of the sensor's response to voltage sag and capacitor switching wave shapes. The report includes an off-the-shelf method for acquiring voltage waveforms from the test or voltage tap found at the bottom of high-voltage bushings on substation transformers—using a relatively low-cost sensor with an existing substation asset that is normally used only during periodic testing and maintenance.

2020 Plan

P1A is developing a software tool to help determine the probability of a load being the source of a flicker problem—important where multiple loads on a power system may be potential flicker sources. The tool should help PQ engineers rule out or confirm the contribution of a potential flicker source. This year has seen efforts at perfecting the methodology for producing harmonics from 120 Hz to 150 kHz—required for sensor testing on a medium-voltage system—into a repeatable, standards-based process.

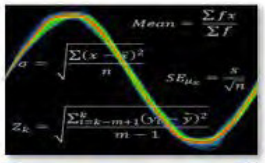


EPRI Power Quality Project Set B: PQ Monitoring and Intelligent Data Applications

Project set 1B (PS1B)—through program members' guidance—has focused on the needs of utilities and their customers to gather, process, and report power quality data.

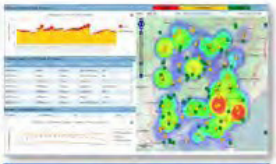
Gather

- Assessment of Low Cost PQ Monitoring for Edge of Grid Applications
- PQ Capabilities from Grid Management Resources
- Sensors/Transducer Assessments
- Open Source PQ Monitoring Hardware Support
- Meter Placement Strategies



Process

- Statistical Process Control of PQ Data for System Health
- Waveform Signature Analytics
- Data Quality and Validation Methods
- Continuous Waveform Analytics
- Fault Location
- Aggregating and Consolidating Varying Data Sources



Report

- Open Source PQ Monitoring Software Development
- New Wide-Area Data Visualizations for Large Deployments
- Data Dissemination
- Federated Data Integration
- Automating Power Quality Benchmarking

Gather

PS1B has contributed to the PQ metering industry by assessing new technologies of meters, sensors, and designs—giving guidance on needs for best practices. Realizing that the cost of PQ monitors can be a significant barrier for some applications for improving grid operations, EPRI engineers focused on low-cost PQ monitoring technologies, and their capabilities for cost versus benefit assessment. Assessment, deployment, and especially development in new open-source hardware platforms are advancing PS1B's capabilities to deploy research—thus contributing to the industry.

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Process

Signatures of power quality waveforms and parameter trend data can alert PQ Managers to power system health. However, monitoring systems may collect waveforms and trends too numerous for personnel to watch! Therefore, PS1B focused on the needs of automated analysis to assist a PQ staff. Recent analytical methods focus on:

- Using statistical process control methods on PQ data for alarming on abnormal trend variations,
- Growing a waveform signature library for machine learning, and
- Continuous waveform analysis to enhance monitoring capabilities for incipient faults.

Report

Some utilities might have multitudes of PQ data sites to monitor. One PS1B motto: "less eyes on raw data, more eyes on meaningful results." To that end, EPRI developed an open source PQ monitoring software platform called the Open PQ Dashboard. The dashboard allows effective deployment of analytics and the development of wide-area visualizations and summaries to guide utility personnel—not just the PQ staff—to problematic areas quickly. PQ Mark is another software service developed by PS1B to help utilities benchmark

their quality of power delivery—not just to compare to other utilities, but to communicate PQ expectations to customers. The PQ Monitoring and Intelligent Data Applications consist of these base area subsets:

2020:

- PQ Waveform Signature Analytics and Repository
- Dynamic SPC Tool for PQ Data
- Full-time Waveform SPC

2021:

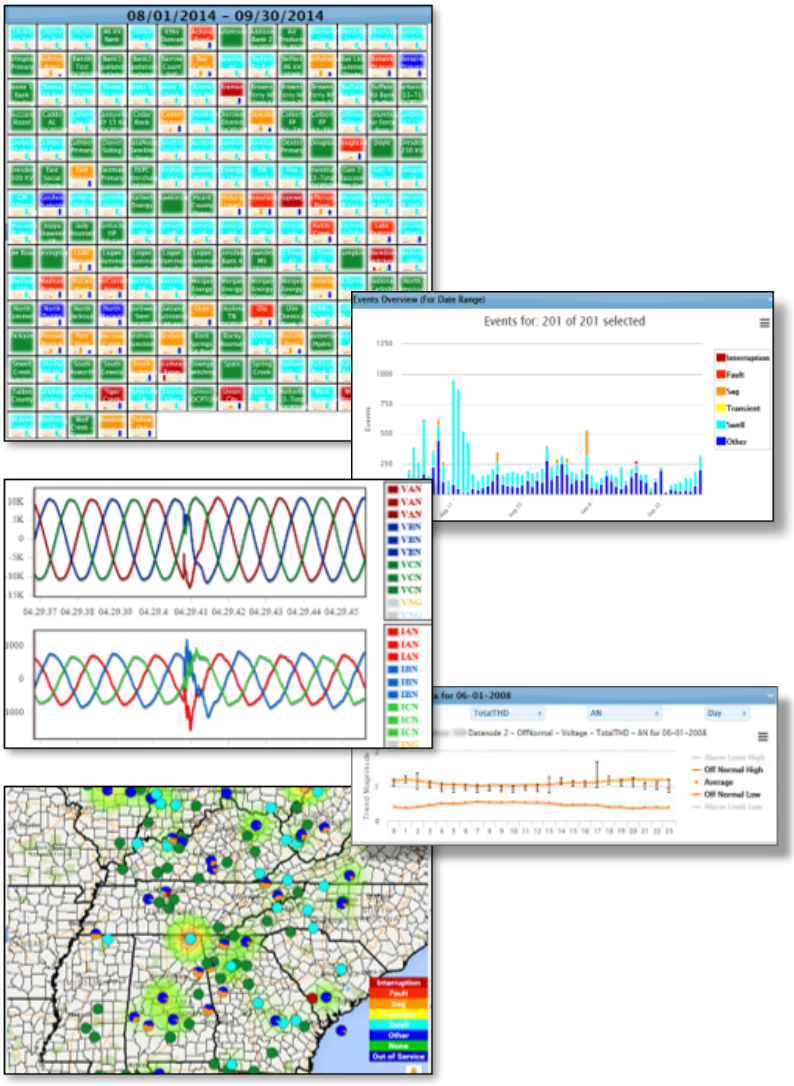
- Development of Advanced Visualization, Reporting, and Validation Methods for PQ Data
- Advanced Applications for Monitoring Systems
- Monitoring System Development and Management

The PQ Dashboard Software has enhanced our ability to proactively respond to events impacting our customers.

—Dominion Energy South Carolina

openFLE (fault location engine), and later enhanced by GPA through openXDA (eXtensible Data Analytics).

TVA integrated the Open PQ Dashboard into their operation center and has reported significant value from its deployment. When system events occur, departments within TVA automatically receive an email with information important to their response. Line crews regularly use the provided fault location details as guidance in locating downed structures or similar issues. This automation shortens lag time for line-teams to respond and restore reliable power—improving



Accomplishments and Looking Ahead

Open PQ Dashboard

The Open PQ Dashboard provides visual displays that quickly convey the status and location of power quality (PQ) anomalies throughout the electrical power system. This software suite was born from utility participation in EPRI's Power Quality Research Program (Program 1). The objective: to build a more comprehensive wide-area visualization tool for utilities with growing fleets of PQ monitors and fault recorders. Collaborating with the developers at Grid Protection Alliance (GPA), EPRI and individual utilities guided functional design requirements and development. One automated analytic feature within the dashboard is the fault location engine, created from an EPRI open-source component called

speed in locating, and repairing—thus, reducing costs and improving reliability performance metrics.

Sample cases:

- Asset Management Monitoring and Fault Analysis
- PQ Investigator integration for proactive notification of customer susceptibility to recorded events
- One-line overlay integration from analysis models

Recently added features:

- Event wide-area view time scaling improvement
- Characterization of events consolidation
- Analytic extension tab
- Extension drill down
- Disturbance tab enhancement
- Statistical process control/automating alarm configuration

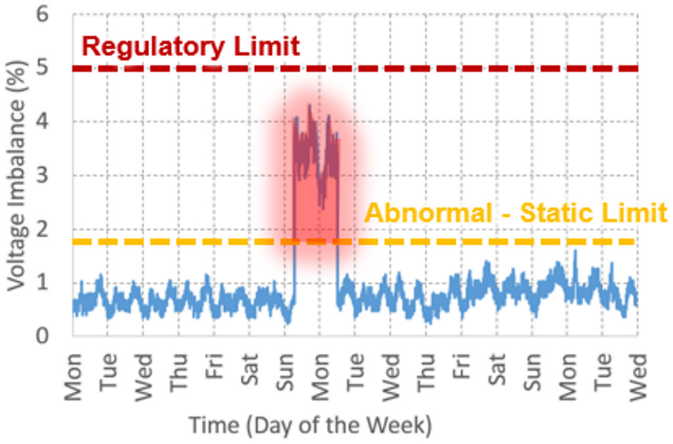
TrenDAP
open-source trending-data analytics platform

TrenDAP

A typical PQ monitor may provide 50 to 150 parameters as performance metrics. These metrics, collected over time, form individual trends with variances that can reveal system health. To understand this data and make informed decisions, many of these variances require analysis by power system engineers. Much of this analysis occurs in separate software systems incapable of being integrated into one comprehensive reporting tool—significantly slowing the analysis process.

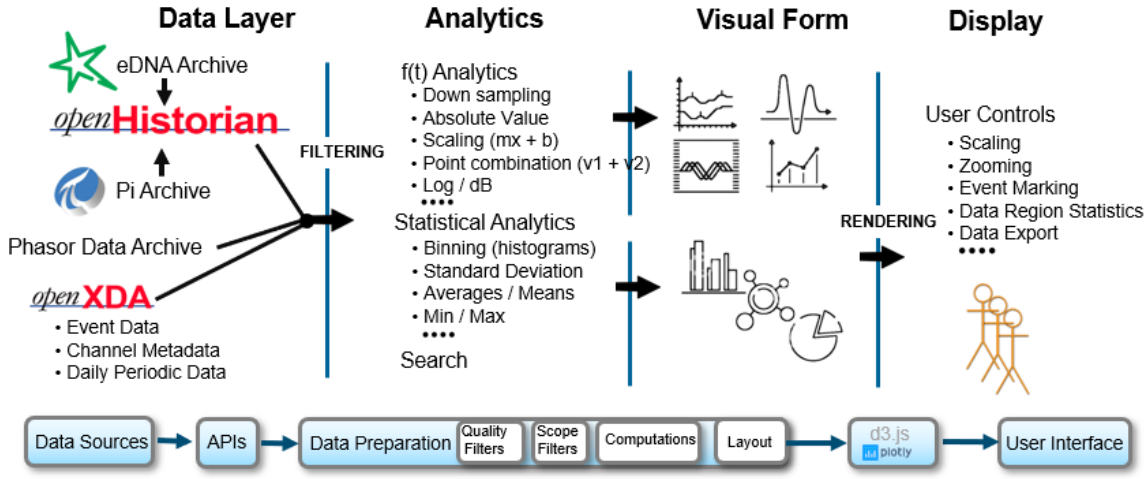
The objectives of the TrenDAP project:

- Determine what PQ analytics and data sources are required from utilities
- Develop an open-source software platform meeting those combined requirements plus allowing the integration of the aforementioned separate systems into one comprehensive reporting tool—providing trending-data, analytic visualizations and reports.



TrenDAP is an open-source software component—part of the Open PQ Dashboard suite of products. The objective of the tool is to integrate, analyze, and visualize trend data from a multitude of PQ and other data parameters to enable informed decision-making. (3002018148)

PQ Trends – Data Flow

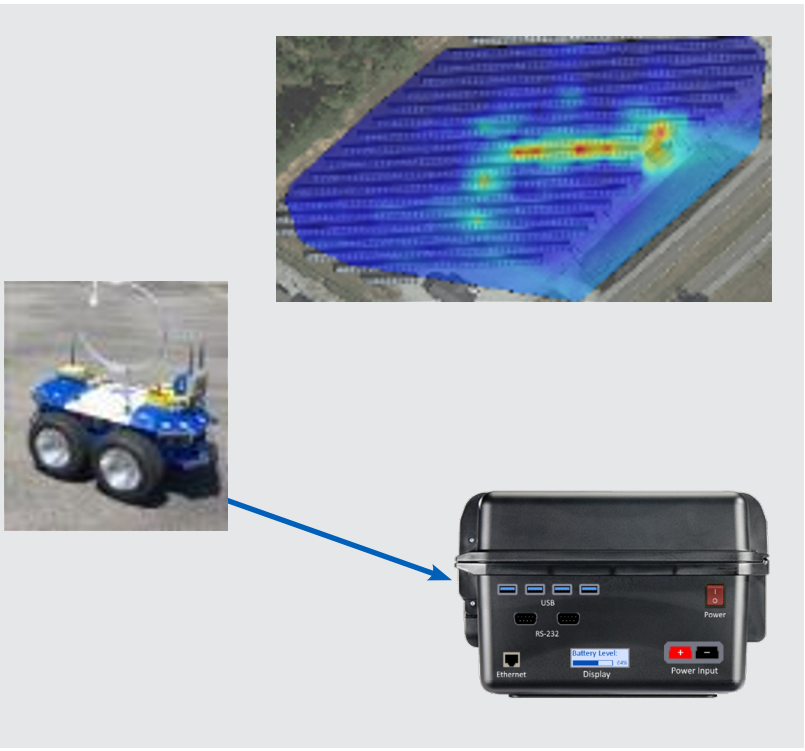


EPRI Power Quality Project Set C: Achieving Cost-effective Edge-of-Grid PQ Compatibility

Project Set 1C (PS1C) helps EPRI members achieve electrical compatibility between the power system and edge-of-grid equipment—including that owned by end-use customers. Power quality mitigation solutions significantly reduce electrical disturbances at the transmission, distribution, and end-use levels by integrating advanced energy-storage technologies with power electronics. This work includes detailed examination and understanding of the PQ implications of distributed energy resources (DER) and microgrids, as well as other edge-of-grid innovations. PS1C is also creating a library of end-use load and DER models—which may allow assessment of the PQ impact of different and changing load configurations.

Key research questions for this project set are:

- How can utilities understand, influence, and anticipate the sensitivity to common PQ phenomena of new, changing, and emerging loads?
- What will be the impact on grid PQ of new loads?
- Can the PQ impacts of emerging end-use loads, DER, and microgrids be modeled and evaluated under a variety of load configurations to predict future grid PQ conditions?
- What are the PQ benefits and vulnerabilities of advanced grid applications?
- How can utilities best prepare for the inevitable PQ-related compatibility and operational issues that will emerge from an increasingly complex grid?



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PS1C: Achieving Cost-Effective Edge-of-Grid PQ Compatibility consists of three base areas:

- System Compatibility Research
- PQ Impact Assessment and Sensitivity of Grid-Connected Loads
- DER Resources, and Strategies and Tools for Maintaining and Integrating Problem Loads (2020)
- Edge-of Grid PQ Detection, Measurement, and Analysis Strategies and Methods (2021).

Power Quality Monitoring and Diagnostic Tools

EPRI developed many PQ Monitoring and Diagnostics tools (PQView, PQWeb, PQ Investigator, and others) that can be deployed by utilities. Through these tools:

- Grid performance is improved through use of PQ data by near- and real-time assessment of equipment performance, detection of incipient equipment failure, and early identification of mis-operation
- Availability of near- and real-time PQ data fosters increased customer satisfaction, reductions in man-hours required to troubleshoot issues, and better understanding of PQ problems and potential solutions.

EPRI created the best-in-class PQ Investigator software that integrates end-use device testing and facility investigation results and expertise, allowing utilities to conduct expert-level facility assessments.

Southern Company makes significant use of PQView—to analyze power quality data from hundreds of sites across Southern Company at both substations and customer sites. Analysis of this data can identify the cause of events as well as provide near real-time notification of power quality events to key account personnel—allowing for quick response to customer issues. Similarly, PQI has been used by the operating company PQ engineer to conduct PQ audits.

Power Quality Investigator (PQI) (3002004287)

The Power Quality Investigator is an online tool provided by EPRI to help the user understand a facility's processes and potential power quality sensitivities. The PQI allows for the methodical investigation of a plant by someone working inside the facility or even remotely from a desk. Information about a facility—such as individual area and equipment details—can be entered into the PQI.

Once this has been done, potential mitigation solutions can be researched and applied to equipment, and economic information such as net annual return, internal rate of return, net present value, and simple payback can be calculated effortlessly. The PQI also provides an expansive knowledge database for both new and experienced power quality engineers to leverage—PQ concepts for over 14 industries, 48 processes, and hundreds of equipment assemblies. Information such as component cut sheets and ride-through

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curves—for over 160 adjustable speed drives—help determine the overall effectiveness and practicality of a solution. This information, along with the Investigator module of the PQI, can quickly generate reports—ultimately for delivery to a customer. These reports can automatically include facility details, historic power quality events, economic analysis, and potential mitigators.

Participants gain:

- Access to latest PQ Investigator software releases
- Quarterly web training on new features
- Use case findings based on field investigations with the PQ Investigator
- Access to collaboration forum for uses to inform potential enhancements
- Software support via telephone and email
- PQ Investigator User Group meetings, workshops and webcasts.

AEP actively uses the EPRI PQ Investigator expert software tool to bring very specific and actionable EPRI PQ Research results to their industrial client base—ranging from demonstrating the expected vulnerabilities and potential solutions to their customers in face-to-face meetings, to solving vexing power quality issues for the customer from their office desk, to conducting in-depth power quality audits using the tool—providing specific and actionable reports to the customer to improve the power quality performance of their processes. AEP has emphasized that through using EPRI's PQ Investigator they are able to transfer EPRI's PQ research and knowledge directly to their customer base in a very efficient and interactive way—solving many of their customer power quality problems internally.

Providing customers with this knowledge and these solutions:

- **Reduces unexpected and costly downtime—even up to millions of dollars per event**
- **Saved losses can be repeated several times per year**
- **The utility improves their relationship with the customer and increases customer satisfaction**

Power Quality Knowledge Development and Transfer (PQK)

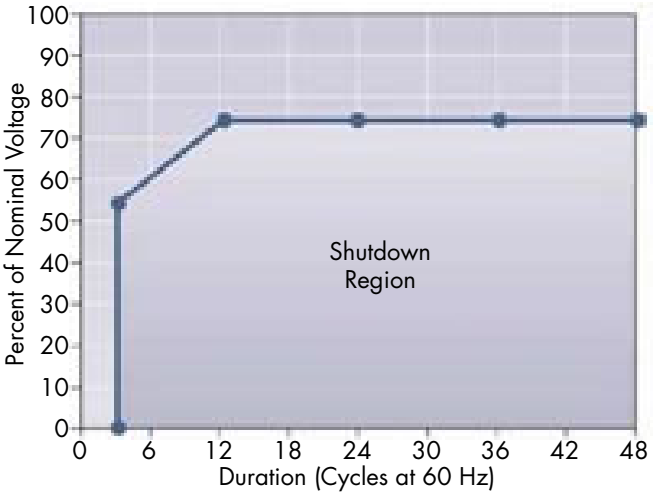
The EPRI Power Quality Knowledge Development and Transfer supplemental project provides a wealth of high-impact resources in well-designed, readable, and accessible format—numerous and highly readable documents covering a wide range of PQ topics. Written not only for use by busy PQ professionals, but these documents also expedite problem solving and education of important end-use customers and internal utility management. The EPRI PQ Knowledge Development and Transfer supplemental project (PQK) is pleased to announce the completion of 25 new documents, online resources, and PQ Hotline Calls of the Month for the 2019 deliverable year. In 2020, the EPRI PQ Knowledge Development and Transfer supplemental project will continue to provide vital support for the base-funded EPRI Program 1, Power Quality.

PQ Knowledge will continue in 2020 to offer:

- A wealth of new and insightful documents
- Online resources
- Access to the EPRI PQ Hotline and Call-of-the-Month articles
- Events and other resources essential for busy PQ professionals.

PQ Knowledge is one of the most highly leveraged offerings in the EPRI portfolio because of the large number of utility and government funders. We look forward to working with you in 2020. For more information about PQ Knowledge for 2020, please download the brochure.

For more information about the EPRI PQ Portfolio in general, please visit EPRI.com to see the new 2020 EPRI PQ Research Portfolio, or contact: Bill Howe, PE, at email: bhowe@epri.com, or tel: 720-565-6888.

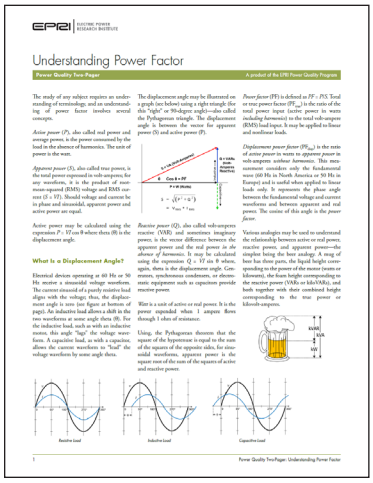


PQ TECHWATCHES

The PQ TechWatch gives in-depth coverage of a power quality topic, including practical advice for diagnosing, preventing, and resolving common problems. Reports feature easy navigation, illustrative case studies, and quality graphics.

PQ TWO-PAGERS

The PQ Two-Pager provides a short-format treatment of a single, important PQ topic in a concise, readable format—intended to help utilities educate end-use customers on complex subjects, but in a non-intimidating way.



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Training Videos

Understanding Voltage Imbalance (3002016732)

This EPRI PQ Training Module video examines voltage unbalance, methods to calculate line voltages and the degree of voltage unbalance, and mitigation techniques.

Understanding Distribution Harmonics (3002016733)

This EPRI PQ Training Module video is intended to help distribution and industrial engineers understand the origin of distribution power line harmonics and figure out how to deal with it when it occurs.

Understanding Electromagnetic Compatibility and Power Quality (3002016734)

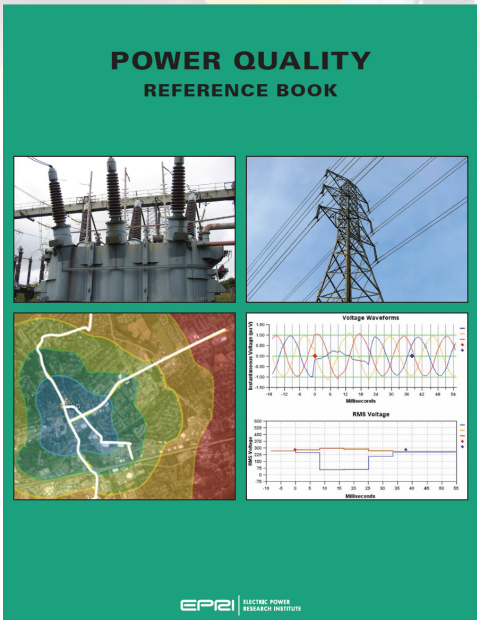
The increased complexity due to the introduction of monitoring, control, communication, and data processing systems in the operation of the grid poses new challenges for the design, maintenance, and issuance of standards. This PQ Training Module video outlines the correlations between the field of electromagnetic compatibility (EMC) and that of power quality (PQ) in reference to present fast-evolving power grid technology

Accomplishments and Looking Ahead

EPRI PQ Color Book

Updated in 2019, the EPRI PQ program published its comprehensive PQ ColorBook (**3002016841**), comprising the 24 chapters of the PQ Encyclopedia in one continuous, integrated volume. The current edition contains over 600 pages, including the following chapters:

- What is Power Quality?
- The Economics of Power Quality
- Understanding Voltage Sags
- Mitigation Techniques for Power Quality
- Understanding Harmonics



- Understanding Voltage Flicker
- PQ Standards for System Compatibility
- Grounding: A Broad-Spectrum Requirement for Power Quality
- Facility Design for PQ: Voltage Quality and Regulation
- Conducting a Power Quality Audit
- Electromagnetic Shielding: A Power Quality Engineering Perspective
- Power Quality and Energy Efficiency
- Adjustable-Speed Drive Technology and Power Quality Considerations
- Power Quality Monitoring: Concepts, Equipment, and Applications
- Understanding Power Factor
- Understanding Voltage Unbalance
- Transient and Temporary Overvoltage Protection
- Facility Design for PQ: Introduction and Equipment Needs
- Facility Design for PQ: Power Conditioning and Mitigation
- Electromagnetic Compatibility for Power Quality Engineering
- Understanding Stray and Contact Voltage
- Application of Small Interruptible Power Supply (UPS) Systems
- Distribution Harmonics: Impacts, Management, and Practical Considerations
- Electromagnetic Interference of Power Lines with Co-Located Telephony and Communications Cables

Central Hudson uses EPRI's extensive collaborative research in power quality to provide a wealth of easy-to-use, informative PQ resources for utility staff as well as materials to support and inform their end-use customers. In addition, Central Hudson used the EPRI PQ Hotline inquiry service offered to funders of the PQ Knowledge Project.

PQ Hotline and PQ Hotline Calls of the Month

Every year, dozens of inquiries from participating PQ Knowledge utilities pour into the EPRI Power Quality Hotline—all manner of PQ issues including measurement concerns, equipment performance and compatibility, electrical system configurations, management issues, and more. Experience timely responses to your individual concerns and access to over 60 PQ experts at EPRI.

Access to the PQ Hotline is an exclusive benefit of PQ Knowledge participation and is available 24/7. Most questions are addressed within a single business day.

Each month, one call received by the Power Quality Hotline is explored in detail by the EPRI staff and shared with PQ Knowledge members via email in the very popular PQ Hotline Call of the Month.

Email: PQHotline@epri.com

Online: mypq.epri.com

Online Catalog of EPRI PQ Reports

Find the research you need—the first detailed catalog of previously created EPRI reports is available to PQ Knowledge funders. Available from EPRI, this catalog of over 600 documents offers intuitive search tools and user-driven results. For the complete archive, visit mypq.epri.com.

MyPQ Power Quality Online Resources Center

The PQ Knowledge subscriber website—MyPQ.epri.com—is rich with content and functions. It features access to over 1,500 authoritative EPRI-authored PQ resources (documents, videos, and other items). The upgrade of MyPQ to Version 4.0 began in 2018, and the new version is planned to be released in early 2020.

New features include:

- Database of grid-side solutions
- A discussion forum
- Free training videos
- Improved Hotline database searching
- Addition of PQ Two-Pagers

Power Quality Services

Facility Assessments for Power Quality

EPRI's Facility Assessment Team specializes in on-site Power Quality evaluations— over 300 conducted through 2019. EPRI's team specializes in reducing process downtime and maximizing production output. Facility assessments may involve a few targeted processes or the entire plant. Our experience in solving power quality issues is deep and broad.

Combining PQ and Energy Efficiency

When requested, EPRI's Industrial Team can combine the goals of improving power quality performance and energy efficiency during an assessment—including traditional areas of energy efficiency assessment (insulation, waste heat, drive applications, motors, lighting, air leaks, and heat recovery). In addition, EPRI can provide initial energy-management system (EMS) activities for determining significant energy uses (SEUs), determining or verifying a plant's key performance indicators (KPIs) and energy performance indicators (EnPIs), and creating a plant baseline model that considers energy use, production, and relevant variables per ISO 50001 and the Superior Energy Performance Certification requirements.

Training

EPRI offers training in all aspects of power quality at its location in Knoxville, Tennessee, at off-site locations around the world as requested, and even online through its video series on power quality topics.

Autonomous Robotic Site Surveys

Having issues with electromagnetic interference or electric fields? These can be characterized and isolated with the EPRI "PQ Robot" (the Big Autonomous Mobile Measurement Platform, or BAMMP) to get to the root of the issue. Navigating with high-precision (±2 CM) GPS (outdoors) or LIDAR (indoors), the BAMMP autonomously measures several parameters, including electric fields, radio frequency interference (RFI), the lighting spectrum, and even the presence and emissivity of radioactive materials or residues. The data obtained may be visualized as a heat map on aerial imagery or a map. Characterizations can be done before and after remediation. Additional information about the BAMMP can be found at:

- Journal R&D Quick Hits – https://eprijournal.com/a-rugged-rover-in-search-of-electromagnetic-interference/
- BAMMP in Action at Nuclear Site (YouTube) – https://www.youtube.com/watch?v=4R6QPVqEcOo

Mark Stephens
Principal Project Manager
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Design Consulting

EPRI offers its knowledge of component, equipment, and process PQ sensitivities as a service to original equipment manufacturers (OEMs) through a review of process-control designs prior to manufacturing. Thus, equipment and process designs may be robust to variations in power quality as built, requiring no PQ mitigation after installation.

Testing: EPRI maintains comprehensive test laboratories and mobile test tools which enable expert power quality testing (voltage sags, line transients, and electromagnetic interference), both in the lab and onsite. We pioneered the technology behind the EPRI voltage sag generator (the PortoSag) and routinely test industrial equipment loads that require three-phase power (up to 200 amps of current).

Voltage Sag Standard Certification: EPRI can quickly certify that a process component or machine complies with IEEE 1668 and/or SEMI F47. EPRI established a certification program to test manufacturer equipment per established power quality standards. PQ Star certification is available for suppliers of semiconductor equipment.

Additional P1 Supplemental Projects

Supplemental Projects are research, development, or demonstration projects offered outside of the annual research portfolio. These projects are often spearheaded in response to an immediate need by an individual or group of members. Supplementals are supported either through Tailored Collaboration or pooled member funds.

Trend Data Analytics Platform (3002018148)

EPRI plans to work with participating utilities to collect requirements and architectural designs for software platform development and to develop Beta software accordingly.

Will produce TrenDAP, an open-source trending-data analytics platform (as well as other open PQ Dashboard suite of components, if not in place).

- Design & Development: by end of 3Q2020
- Beta Deployment: by end of 4Q2020
- Assessment Period: by end of 2Q2021
- Software Delivered: by end of 4Q2021

System Compatibility Requirements for the Semiconductor Industry (3002016943)

This project intends to methodically investigate the potential factors that continue to cause semiconductor plant downtime in a post-SEMI F47 environment. These factors include:

- Three-phase voltage sag events
- Repeated voltage sag events due to recloser operations
- Events outside SEMI F47 scope of magnitude, duration, phase-shift, or point-on-wave
- Voltage sag testing methods utilized during certification tool software, design, or configuration differences; or
- Electrical system differences between the certification environment and the actual fab environment.

Working through EPRI, utility members can work with their semiconductor site clients to investigate SEMI F47 requirements against specific site electrical environments and identify potential gaps against tool shutdown data. It is planned that SEMI F47 certification documents be reviewed for the sensitive tool sets, and characterization of this equipment be accomplished through additional analysis and testing. The aim is also that specific design and mitigation strategies, including related cost-benefits, be determined and documented. The general, non-confidential findings from these partnerships will help inform the overall collaborative effort through workshops, white papers, and the final report. The overall effort intends to include participation in project web-meetings and workshops, inclusion in engagement with SEMI, and involvement in any proposed standards modifications.
Will be approximately 24 months start to finish.

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Contact and Stray Voltage Assessment (3002009808)

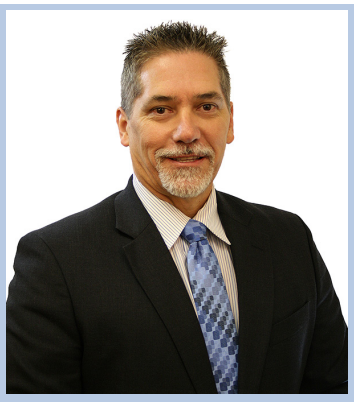
Electric shock complaints associated with the normal delivery of electricity continue to challenge electric utility field investigators when attempting to diagnose and resolve these concerns. Moreover, the standards and code-making bodies charged with human and animal safety rules and regulations require unbiased factual and accurate data for decision making.

The Electric Power Research Institute (EPRI) has taken a leadership role in the investigation and remediation of stray and contact voltage for the past 25 years, and this project is designed to continue the work with a targeted set of activities to enhance public safety and inform codes and standards relative to the subject matter. The research is intended to inform new learning by targeting knowledge and technology gaps associated with three recurring industry challenge areas:

- Investigator diagnostics training and support
- New product testing and evaluation
- Industry documents to support standards, regulations, and unique investigative approaches.

The project has three important learning objectives—all targeted at moving the power industry to the most up-to-date level of knowledge and understanding of stray and contact voltage. These three areas include:

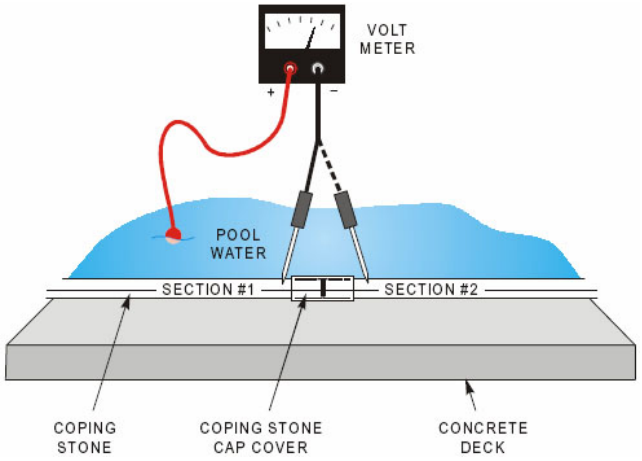
- Technology
- Knowledge base
- Investigations and workshops.



Doug Dorr
Technical Executive
ddorr@epri.com

Research will include but not be limited to:

- Diagnostic equipment assessments
- New mitigation technology evaluation
- Enhanced field investigation capability
- State-of-the-art knowledge repository
- Improved public safety programs.



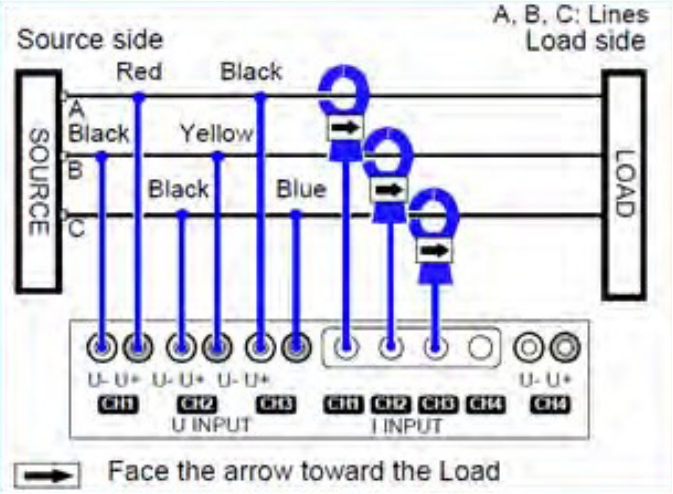
Knoxville Laboratory – What we are doing in the lab...

Matrix Drive testing

Electric motors—the workhorses of industrialized nations for over 100 years—required valves, dampers, and clutches to control variables such as speed and flow during most of that time. After the invention of semiconductor technology enabling adjustable speed drives (ASDs), process engineers controlled many process variables through very accurate control of motor speed and torque.

Recently, a new ASD technology called the Matrix drive has appeared—one with a topology without a DC link and inverter. A "matrix" of IGBT switches supplies each three-phase input connection of the motor directly from any combination of the input phases. The drive controls the speed of the motor by turning on the appropriate IGBT—providing the correct power requirement to each three-phase connection of the motor instantaneously. The matrix drive is also able to control multiple types of motors such as induction and permanent magnet motors. What is its harmonic emissions, power factor, and efficiency compared to traditional inverter drives?

EPRI will test a 5-hp Yaskawa U1000 series matrix drive in EPRI's power quality laboratory located in Knoxville, Tennessee. Per a two-part protocol guiding the planned testing activities, the first task includes measuring the harmonic emissions, efficiency, and the energy intensity of the matrix drive. The second task will document the matrix drive's response to power quality phenomena.



Scott Bunton
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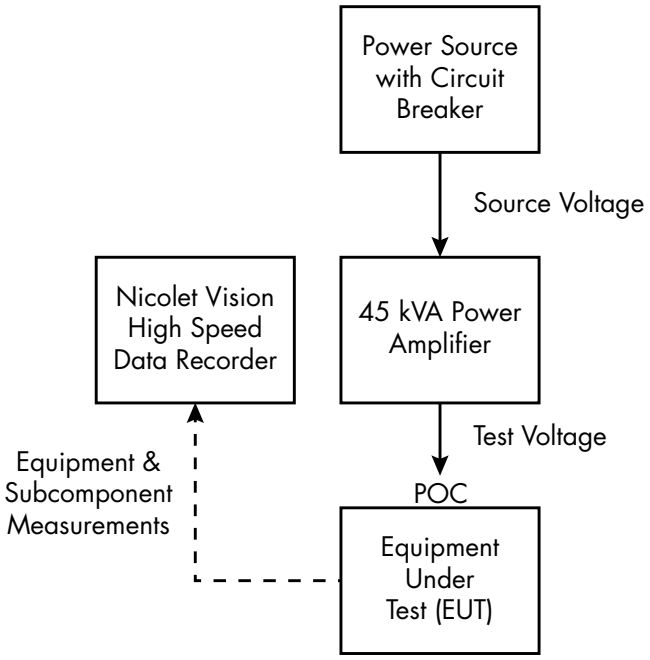


Mobile Measurement Platform (MMP)

P1.009 with project set C of Power Quality continues to develop a more mobile measurement platform that utilities can use to conduct initial site surveys of areas with reported RFI and other issues. This work builds on the development of the Big Autonomous Mobile Measurement Platform (BAMMP), which has helped Utilities with autonomous and repeatable surveys of areas with RFI and E-Field issues. This work will provide utilities a portable measurement system able to survey areas using various sensors, then create "Heat Map" reports indicating levels and affected areas of offending sources.

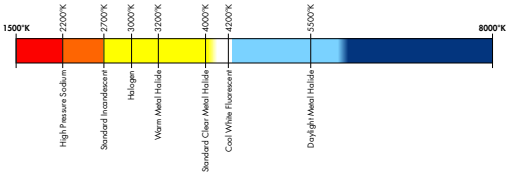
AQI

AIR QUALITY INDEX

Air Quality Index (AQI) Values	Levels of Health Concern
0 to 50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
301 to 500	Hazardous

The platform also can be fitted with other environmental sensors:

1. **Temperature and Humidity**
2. **Light (Lumens)**
3. **Air Quality**
4. **Spectrum Analyzer**
5. **Electric Field Detector**
6. **Nuclide (Radiation) Detector**



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Marine Installation

A chiller manufacturer hired EPRI to conduct three-phase voltage sag testing on their ASD-driven chiller compressors. These chillers are very small in size compared to typical compressors of the same tonnage, making them an attractive option for marine applications. The purpose of these chillers is to cool the critical high-tech navigation equipment. However, when the ship maneuvered quickly, the output voltage of the electrical shipboard generators sagged—causing the chiller to trip and often causing a long delay should the chillers abruptly shut down. Even worse, if the chiller could not restart before the navigation equipment overheated, the ship had to stop at sea and could not resume until the navigation equipment had time to cool.

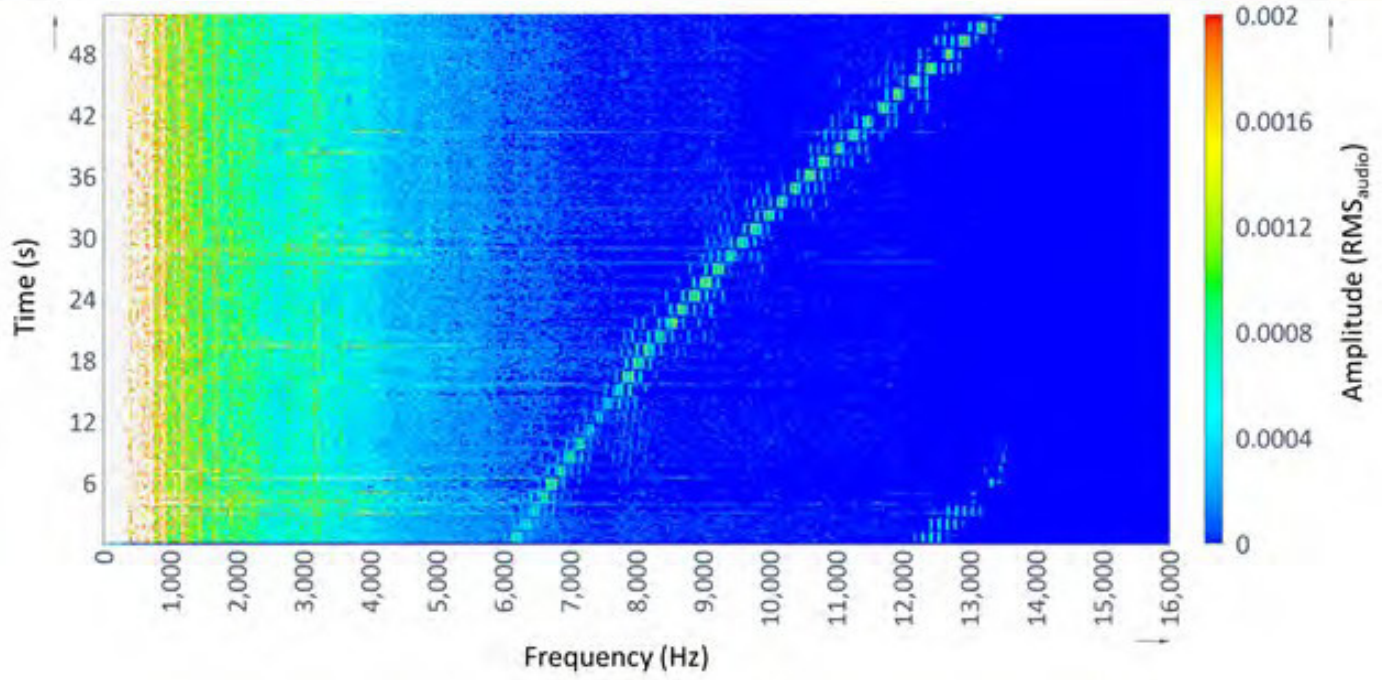
EPRI went to the manufacturer's facility, tested the chiller drive/compressor combination, and successfully repeated the trip condition. EPRI's experience with voltage sag testing in many industries along with its extensive laboratory research of components and voltage sag mitigation technologies allowed EPRI engineers to make recommendations—subject to strict, shipboard space constraints—that helped harden the customer's chiller compressor to voltage sags. After the chiller manufacturer implemented EPRI's mitigation recommendation, EPRI engineers returned to the chiller manufacturing facility, successfully conducted a proof-of-concept test, and left a manufacturing customer happy with the results—and also the chiller manufacturer's customer. EPRI engineers not only solved the chiller down-time problem, but their efforts also resulted in more chiller orders.

Project Lead: Scott Bunton, sbunton@epri.com

Investigation into Supraharmonics (collaboration with Project sets A & C)

The need for higher efficiency, desire for reduced device footprint, and existing regulation on harmonics led to the advent of devices that utilize forced commutation switches such as insulated-gate bipolar translators (IGBTs), metal-oxide-semiconductor field effect transistors (MOSFETs), and gate turn-off thyristors (GTOs). The end result of this develop-

Supraharmonics Test Facility; Knoxville, TN



Audible noise recorded from an LED lamp due to supraharmonics in voltage.

ment was the creation of a new generation of consumer load and Energy resources that employ switched mode power supplies and other power electronic circuits that switch in the multiple kilohertz range. As a result, the spectra of frequencies being emitted by end use loads has changed as well, and more and more devices these days emit frequencies in the 2 kHz to 150 kHz range. The distortion in voltage arising from such frequencies is commonly referred to as "supraharmonics".

Instances of interference observed with energy meters, LED lamps, and other household devices spurred the initial investigation into supraharmonics, mostly in Europe. The EPRI Power Quality program has taken the lead on investigating these issues in the United States as consumer concerns regarding supraharmonics have increased along with the increased integration of distributed energy resources (DER) such as solar PV generation and battery energy storage systems. Further, electric vehicles and other consumer loads promise to exacerbate this PQ issues in future years.

EPRI initiatives are to investigate sources of supraharmonics and to investigate the effects of supraharmonics on end-use loads. To this end, a dedicated testing facility (shown above) has been established, with both industrial and domestic loads being investigated—the results intended to inform industry practice and standards. Of particular interest are the effects of supraharmonics on end-use loads such as LED lamps—observed during testing to produce both audible noise (shown below) and visible flicker. Future research in this area will primarily center around collaborating with educational institutions, industry partners, and other entities to investigate the propagation and distribution characteristics of supraharmonics—particularly in the U.S. distribution grid.

Technology Innovation (TI)

TI projects generally have longer-term goals (greater than five to ten years out) and have higher research risks. Learnings from TI projects can inform and inspire future Research Portfolio (ARP) projects and provide thought leadership for EPRI, its members and other relevant stakeholders. All TI deliverables in a given year are available to all EPRI members investing in an EPRI research program in that year.

Aerial Scanning and Detection of Contact Voltages and Distinguishing Between Normal and Abnormal Sources of Electric Fields

Conceptual Drawing
Method and Apparatus for Aerial Scanning and Detection of Contact Voltages and Distinguishing Between Normal and Abnormal Sources of Electric Fields

US Patent 10,501,181
December 10, 2019

This TI project will serve as proof-of-concept testing for EPRI's recently patented aerial e-field detector. The testing will be accomplished through mock-up scenarios representing at least two of the following safety applications:

Application #1: Detection of Contact Voltage in Urban Areas

Metallic fixtures in urban areas can become unintentionally energized—posing a shock hazard to the public, especially where foot traffic is persistent. Causes of dangerous contact voltage include:

- Failure of wire insulation,
- Improper electrical rework, and
- Water ingress into fixture wiring.

Some utilities are mandated to address the public risk through periodic scanning of publicly accessible areas to identify unintentionally energized objects—commonly accomplished by driving vehicles equipped with electric field sensors along streets in urban areas. The limitation to this approach is the necessity for navigable roads since potential hazards may exist beyond navigable roads: urban parks, playgrounds, golf courses, stadiums, and ballparks, for example.

Application #2: Detection of Live Downed Conductors

A medium-voltage cable can break, falling to the ground without tripping circuit protection—particularly during storms. At greatest risk of electric shock are utility workers and first responders, who might not be aware of the downed conductor.

Application #3: Detection of Arcing Conductors

Underground vaults pose a unique hazard. Utility workers entering a vault are aware that combustible gases can be emitted by chemical decomposition of cable insulation. Within a vault, having a contained volume and restricted air flow, the spark from an arcing conductor can ignite the gases.

Deliverable: *PowerPoint 3002019760*

Enhanced DER Monitoring (TI)

As part of TI project 1-113107 (Enhanced DER Monitoring), program 1 (P1), Power Quality, is assessing an open source hardware platform for power quality measurement. The goal of this project is to develop a low-cost monitoring package for a variety of DER. The project will seek to assess a variety of metering, sensor, and data gateway technologies and compare the accuracies of targeted monitoring packages.

The openZmeter (oZm) is a collaborative project between the University of Almeria and the University of Granada in Spain to create an open and low-cost edge-of-grid meter to meet the needs of the new smart grid. As part of our assessment, P1 is integrating an EPRI developed concept for continuous waveshape analysis to enhance the capability of PQ monitors to detect and predict incipient faults.

Deliverable: *Technical Brief 3002019013*

Value Statements

FirstEnergy on Their 2016 JD Power Award

"During the EPRI Power Quality seminar we hosted for our industrial business customers, we shared with them the latest strategies, technology and equipment to assist them with hardening their facilities from power quality issues. We received positive feedback from the attendees," he said. "The Customer Support team also coordinated communication efforts with our major commercial and industrial customers in reference to the Pennsylvania rate case, and kept customers informed on our storm protocol. This resulted in highly positive feedback from customers."

Gary Grant, Vice President, Customer Service, praises the Customer Service team for contributing to the high rankings.

EPRI PQ Standards Work Helps Central Hudson Semiconductor Customers

In 1997, EPRI successfully convened a group of utilities and semiconductor vendors to work together and build a standard to which wafer-handling equipment could be designed and constructed so that they were less sensitive to common voltage fluctuations. The resulting standard, SEMI F47, provided for more robust equipment in an industry that suffered very large losses due to unplanned downtime. In 2004, EPRI published a report on the impact of the standard on typical manufacturers. According to the report's calculations, a conservative estimate for savings for a SEMI F47-compliant wafer manufacturing plant can range from $2.6M to $3.4M per year. Each compliant fabricator has the possibility to save as much as $26M to $34M in revenue over a ten-year operating period.

To continue to help the semiconductor industry improve their voltage-sag immunity, EPRI began interfacing again with the SEMI organization in 2019 to review the SEMI F47 standard and look for opportunities for improvement. Since Central Hudson has been a leader in supporting this effort (most recent project with EPRI in 2015), EPRI invited them to join in the new SEMI voltage-sag task force. Central Hudson joined the task force and has been an active collaboration partner in this effort. The task force work is ongoing as we are now reviewing events from semiconductor fabs that continue to cause downtime in an effort either to adjust the standards or further improve the semiconductor tool susceptibilities.

Based on the results in the original work, it can be expected that significant savings may again be achieved for this important customer segment for Central Hudson. Of course, it can also be expected that the new work will result in greatly enhanced customer satisfaction.

Consolidated Edison Uses EPRI PQ Team to Improve Subway Service

Consolidated Edison provides electric power to the MTA, which operates the subway system in New York City. System faults from lightning, tree contact, equipment failure, animals, wind, public interference, etc., can cause voltage fluctuations that impact the train control system, sometimes shutting it down. This results in a great deal of consternation with the general public, and a lot of unhappy customers.

EPRI was consulted to help analyze and propose solutions for the problems in 2018. Voltage-sag mitigation techniques were evaluated and compared. The final solution was chosen with the agreement of the MTA and Consolidated Edison engineers. EPRI and several other companies combined to design and implement the solutions in the summer of 2018, resulting in nearly 400 installations of the device as well as additional transformers for voltage matching.

As a result of the solutions, several control stations being monitored showed the same voltage fluctuations on the input, but very little fluctuation at the output. The output voltage was constant and stable enough that there were no more shutdowns of the subway system caused by sag events—helping to solve a very large problem for Consolidated Edison resulting in a significant improvement in customer satisfaction.

EPRI PQ Program Annual Technology Transfer Activities

1 Advisory Meeting
1 Program Meeting
3 Training Courses
6 Workshops (1 international)
10 Webcasts

4750 Member Center Visits
25 Technical Results
14 Technical Reports/Other Deliverables
9 Software Deliverables

Program Chair & P1A Chair: Anthony Murphy, Tennessee Valley Authority
P1B Chair: George Hoxworth, Consolidated Edison
P1C Chair: Brian Gutierrez, CPS Energy
PQ Knowledge Chair: Kristen Citarella, FirstEnergy

Important Links

MyPQ Website:
http://mypq.epri.com

EPRI Member Center:
https://www.epri.com

Power Quality Program:
https://www.epri.com/research/programs/053119

Open PQ Dashboard:
https://github.com/GridProtectionAlliance/PQDashboard

Ask EPRI:
AskEPRI@epri.com, 800-313-3774

PQ Knowledge PQ Hotline Requests:
PQHotline@epri.com

Harmonic Evaluation Module (HEM):
https://github.com/epri-dev/Grid-IQ-Open-Source-Harmonics-Evaluation-Module

Flicker Evaluation Module (FEM):
https://github.com/epri-dev/OS-FEM

Power Quality Investigator (PQI):
https://pqi.epri.com/ASPX/home.aspx

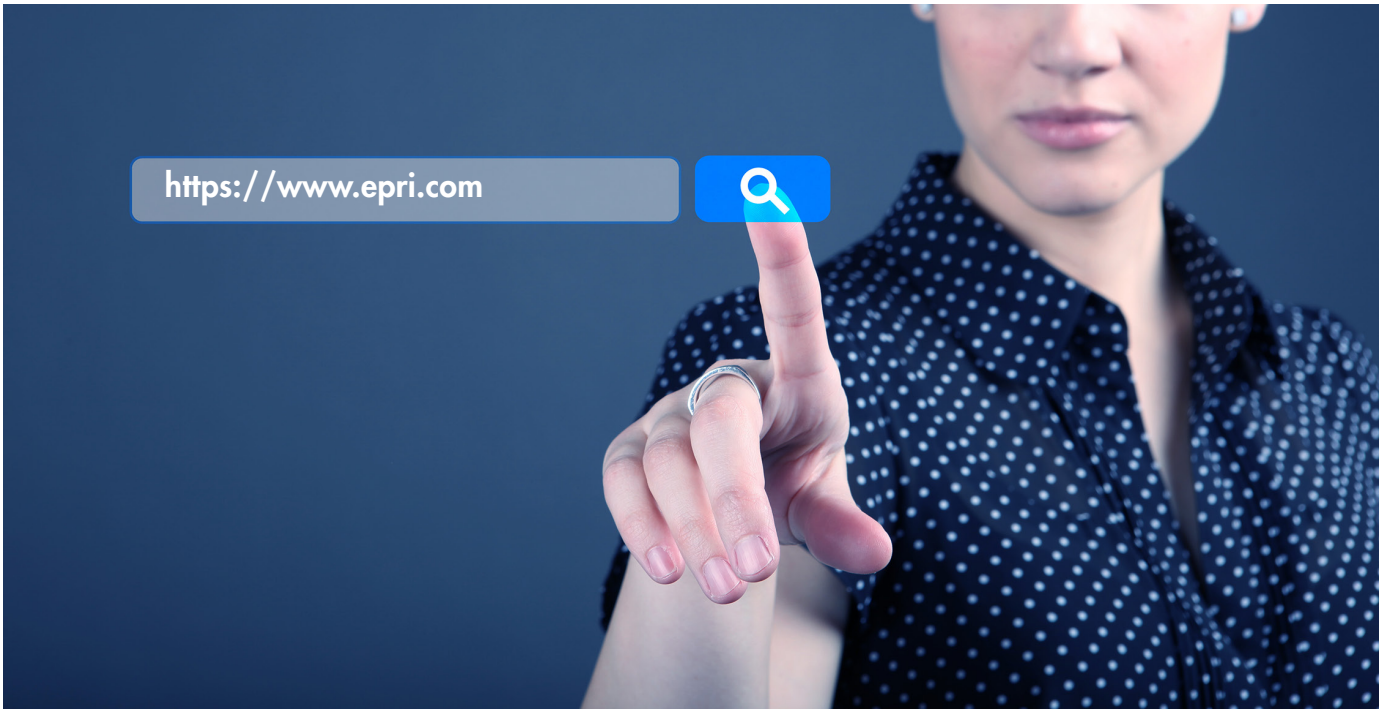
PQ View:
https://www.electrotek.com/

Copyright:
Copyright@epri.com

Facebook:
https://www.facebook.com/EPRI/

LinkedIn:
https://www.linkedin.com/company/epri/

Twitter:
https://twitter.com/EPRINews



EPRI's Technology Transfer Awards

Each year EPRI recognizes the leaders and innovators who transfer research into applied results. The people and companies honored with Technology Transfer Awards exemplify the collaboration and leadership that drive progress in the industry and benefit society. Nominees are an individual or group of individuals from our member companies who have championed the successful use of EPRI-sponsored research results over the previous time period. Awards were selected in the fall of previous year and are presented at the following year February Winter Advisory Meetings.

Nominees are judged on the following criteria:

- Successful application of research results
- Magnitude of the problem solved
- Impact and quantifiable benefits of the application to the company, customers, and/or society at large
- Leadership, innovation, and initiative demonstrated.

Nominees

ComEd (Exelon)

- Russell DeSalvo
- Gregory Mayer
- Nayeem Mohammad Abdullah
- Wahhaj Irfan
- Liuxi (Calvin) Zhang

How Research was Applied

Distribution System Power Quality (PQ) Assessment and Analysis_PQ

Sensitive Loads Distribution System Power Quality (PQ) Assessment and Analysis PQ Sensitive Loads, Commonwealth Edison (ComEd) observed PQ issues with different types of customers with critical PQ requirements, ranging from data centers to manufacturing companies. Using EPRI best practices and analyses, ComEd performed PQ assessments to help improve the power quality of its provided recommendations to help the equipment ride through longer and deeper voltage sags.

Awardees

- Alabama Power (Southern Company): Steve Pierre and Steve Tatum
- American Electric Power (AEP): Brad Martin
- BC Hydro: Scott Merriman
- Dominion Energy: Luis Vega
- Duke Energy: Joe Grappe
- Electric Power Board Chattanooga (EPB): Bob Hay
- Georgia Transmission Corporation: Marlin Browning
- Hawaiian Electric (HECO): Randy China
- SCANA: Joe Hodges and Jeff Inabinet
- Tennessee Valley Authority (TVA): Anthony Murphy

How Research was Applied

Implementation of Advanced PQ Monitoring and Analysis Tools

Each utility demonstrated a more efficient process in managing large waveform and trends data sets and analytical processing using Open PQ Dashboard. Today these utilities are actively using the EPRI PQ Investigator expert software tool with their industrial client base.

Technology Transfer – Video

Onsite Training

Studies have shown that video clips allow for efficient processing and memory recall after viewing. Their audio and visual nature appeals to a wide audience and allows each user to process information in ways more effective for the individual. Several video series created by EPRI and can be found on EPRI.com under the Power Quality Program area (P1).

- ISO 50001 – a series of video modules concerning the implementation of the ISO 50001 standard (Energy Management Systems) across an organization. ISO 50001 uses the total quality management approach pioneered by William Edwards Deming to establish and maintain an energy management system to reduce energy consumption across an organization and continually improve it.
- PQ Encyclopedia Training Modules – an on-going series of brief video modules that provides information concerning various power quality topics found in the PQ Encyclopedia. Topics covered include Grounding and Bonding for PQ, Power Factor, Stray Voltage, and many others.
- Industrial PQ Videos – a series of videos concerning industrial PQ topics such as individual voltage-sag mitigation technologies—the CVT, VDC, Nice Cube, etc.
- PQ Mitigation Technologies – module that provides information concerning various technologies designed to mitigate PQ phenomena such as voltage sags, transients, etc. These technologies apply power electronics, energy storage, the properties of inductors or capacitors—or combinations of several technologies—to mitigate the effects of PQ events.
- Understanding Harmonics – module that provides information concerning the sources and possible mitigation of harmonics in the electrical system.
- Conducting PQ Investigations – module that provides information on how to conduct a facility PQ investigation, including preparations for a PQ investigation, what equipment is required, what should be done in preparation beforehand, and who should be involved in the investigation.

Upcoming Events

Annual events

Meetings

PDU Advisory and Sector Council Meeting – Winter Program 1 Advisory meeting – Fall

GA/PQ conference – Summer

Trainings

PQ Week – Spring PQI – November

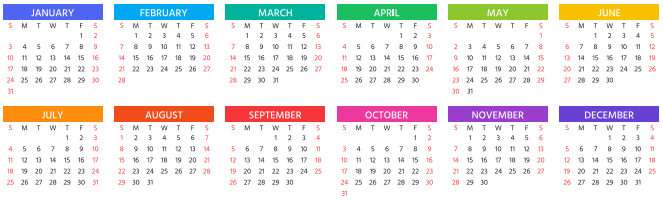
PQ Dashboard – November

WebCasts

3 times a year: April, September, and the Year-End in December

2020

2021



2020 Event Dates

Program 1 Webcast Updates

- April 28 and 30
- July 14 and 16
- December 15 and 17

Program 1 Face to Face Planning Meetings

- February 11–13, Dallas, TX
- September 14–23

PQ Investigator Meetings, Webcasts, and Trainings

- February 20
- March 3
- September 3
- November 17–19

2021-2022 Event Dates

Program 1 Webcast Updates

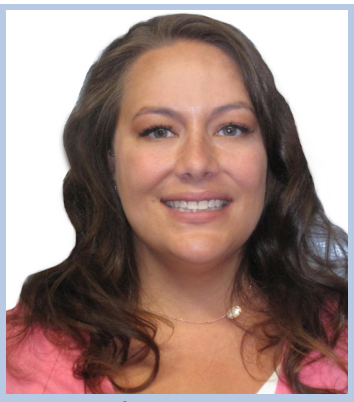
- April
- July
- December

Program 1 Face-to-Face Planning Meetings

- February 21–25, February 22—March 5, 2021
- September 13–16 (Indianapolis, IN @ Marriott)
- February 7—10, 2022 (Austin, TX @ Marriott)
- March 21–24, 2022 (Krakow, Poland @ DoubleTree)

PQ Investigator Meetings, Webcasts, and Trainings

- TBD



Alison Station
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2020 Power Quality Deliverables by project set

Project Set	Deliverable ID	Deliverable Name
PS1A.001	3002018316	Assessment of Existing Practices and Factors Leading to the Establishment of Electric Power Transmission Harmonic Limits
PS1A.002	3002018096	Results of Testing a Medium-Voltage Sensor and PQ Monitoring System: Detection and Reporting of Frequency Distortion Between 2 kHz and 150 kHz
PS1A.003	3002018107	Assessment of Impact and Management Strategies: For Frequency Distortion Between 2 kHz and 150 kHz
PS1A.003	3002018108	Flicker Source Calculator: Proof of Concept Software
PS1A.002	3002018357	Assessment of Testing Methodology for Medium-Voltage Sensor: Detection of Frequency Distortion in the 2 to 150 kHz Range
PS1B.004	3002019329	Power Quality Waveform Signature Analytics and Repository
PS1B.005	3002019330	Dynamic Statistical Process Control Tool for Power Quality Data
PS1B.006	3002019332	Fulltime Waveform Statistical Process Control
PS1C.007	3002019395	Understanding the Economics and Cost of Power Quality
PS1C.007	3002019396	PQ Compatibility of Matrix Type AC Drives
PS1C.008	3002019399	Survey of End-Use Device Harmonics and High-Frequency Distortion
PS1C.009	3002019400	Important Findings from Field Trials of the Mobile Measurement Platform
PQK	3002019374	PQTW – PQ Issues for Electric and PHE Vehicles
PQK	3002019375	PQTW – Understanding the Economic Value of Good Power Quality – Harmonics
PQK	3002019377	PQTW – Needs and Gaps in PQ Monitoring/Data Standards
PQK	3002019378	PQ Color Book Chapter Updates: Chapters 4, 9, and 12
PQK	3002019379	Power Quality Hotline Call of the Month 2020 Compendium
PQK	3002019382	PQ Two-Pager: Understanding Power Factor
PQK	3002019386	PQTW – Review of Existing Software Resources for PQ Monitoring and Data Analysis
PQK	3002019387	PQTW – Guiding End-Use Customers on Mitigation of PQ Phenomena
PQK	3002019388	Power Quality Hotline
PQK	3002019391	Power Quality Training Module: Understanding and Applying PQ Standards
PQK	3002019392	Power Quality Training Module: Understanding Power Factor
PQK	3002019393	Power Quality Training Module: Facility Design for PQ – Power Conditioning

2019 Power Quality Deliverables by Project Set

Project Set	Deliverable ID	Deliverable Name
PS1A.001	3002015457	Assessment of Best Practices AoV
PS1A.001	3002015466	Assessment of Best Practices for Fault-Current Limiting for Grid-Side Voltage Sag Mitigation
PS1A.002	3002016597	Assessment of Best Practices for Measurement of Higher-Order Harmonics
PS1A.002	3002016598	Assessment of Optical Based MV Voltage and Current Sensor
PS1A.003	3002015470	Arrester Incipient Failure Detection
PS1A.003	3002015471	Assessment of Instantaneous Flicker to Load Current Measurement for Determination of Flicker Source
PS1A.003	3002015472	Harmonic Flow Calculator
PS1B.004	3002016682	AI for PQ Waveform Recognition
PS1B.005	3002016683	PQ-Mark Launch and Testing
PS1B.006	3002016717	Performance & Potential Applications from Low-Cost Edge-of-Grid Devices Performing Power Quality Measurements
PS1C.007	3002013150	Evaluation of End-Use Equipment Against DER Induced PQ Issues
PS1C.007	3002016720	IEEE 1668 Workshop Proceedings
PS1C.007	3002016721	IEEE 1668 Video
PS1C.008	3002016722	Mitigating Distributed Energy Resource
PS1C.008	3002016723	DER Power Quality Issues
PS1C.009	3002013155	Field Assessment Protocol for Evaluation of Radiated Emissions at DER Installations
PS1C.009	3002016724	Power Quality Investigator
PQK	3002016842	2019 PQ Hotline Call of the Month Compendium
PQK	3002016732	Power Quality Training Modules: Understanding Voltage Imbalance
PQK	3002016733	Power Quality Training Modules: Understanding Distribution Harmonics
PQK	3002016734	Power Quality Training Modules: Understanding Electromagnetic Compatibility and Power Quality
PQK	3002016735	PQ Two-Pagers: The Economics of Power Quality
PQK	3002016736	PQ Two-Pagers: Protecting Against Transient Overvoltages
PQK	3002016737	PQ Two-Pagers: Facility Design for Power Quality
PQK	3002016377	PQTW – Monitoring for Microgrid and Comparable DER Installations
PQK	3002016770	PQTW – Best Practices for Mitigating Stray/Contact Voltage Conditions
PQK	3002016773	PQTW – Nuisance Breaker Operations: Causes and Prevention
PQK	3002016771	PQTW –Managing Large Fleets of PQ Monitoring and Data
PQK	3002016840	PQTW – PQ Issues and Practices for Remote and End-of-Feeder Loads
PQK	3002016841	PQ Color Book Chapter Updates

Introduction to Electric Power Research Institute (EPRI)

EPRI's wide-ranging collaborative research, development, and demonstrations help guide strategic planning and inform technical and business decision-making. Learn how EPRI is helping to build the knowledge and technology foundation for a future in which consumers have the flexibility to produce and manage their energy. EPRI conducts research and development relating to the generation, transmission, delivery, and use of electricity for the benefit of the public. EPRI's Power Delivery and Utilization sector provides transmission, distribution, and end-use R&D to guide utilities and stakeholders toward a safe, secure, resilient, affordable, reliable, and environmentally responsible, integrated grid.

EPRI's research and development portfolio has a clear vision for electricity R&D today and into the future. Our portfolio addresses the technologies, systems, operations, environmental performance, and workforce as they are today and drives the innovations to shape them for the decades ahead. Through technology scouting, innovation, analysis, and collaboration, EPRI helps meet major requirements and enables energy developments that enhance efficiency, accelerate decarbonization, and deliver societal benefits around the world.

The Technology Innovation Program leads early-stage R&D to maintain a full pipeline of promising concepts, new knowledge, and potential breakthroughs.

EPRI's Core Research and Development

- Efficient Electrification: Accelerating electrification by advancing high-efficiency technologies and grid-interactive systems for the transportation and building sectors and other significant end-use loads.
- Energy Storage: Developing modeling and control technologies to optimize the value of battery installations and exploring innovative concepts for distributed and bulk storage applications.
- Grid Modernization: Building interoperability architecture for the Integrated Grid and developing foundational technologies for more reliable, intelligent, and efficient transmission and distribution.
- Low-CO_2Fossil: Identifying and advancing promising,

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early-stage carbon capture concepts and exploring high-efficiency power cycles to minimize cost-of-energy impacts while reducing CO_2 emissions.

- Next-Gen Nuclear: Creating a technical foundation to focus public/private investment on design, development, demonstration, and U.S. deployment of a commercial Gen IV reactor in the 2030s.
- Next-Gen Renewables: Exploring and testing innovative technologies for increasing the productivity, reliability, cost competitiveness, deployment, and grid support value of renewable generation.

Research Portfolio

- For 2020, we see clearly the pivotal changes and progress across the electricity sector. EPRI's research offerings are shaped by our comprehensive view, based on almost a half-century of research and development. Our R&D portfolio addresses the technology, systems, operations, and workforce as they are today and drives the innovations to shape them for the decades ahead. (300201503)
- 2021 portfolio address the electricity sector's technology, systems, operations, environmental performance, and workforce as they are today and drives the innovations to shape them for the years ahead. EPRI's technology scouting and innovation combine with wide-ranging analysis and collaboration to address also the major requirements and developments across the energy sector for efficiency, decarbonization, and broad areas of social and technological concern. (3002017738)

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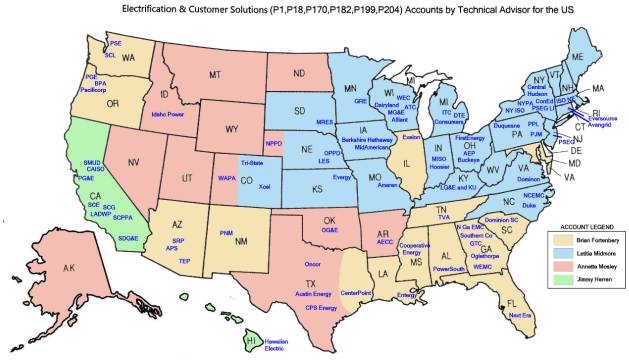

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