

Transmission & Substations Area Review



Transmission and Substations Area Resources

EPRI's resources are available for more information about the Transmission and Substations website, EPRI|U for Transmission, and Field Guide Apps.



Visit the **Transmission and Substations** Website for the latest research results and project information.



Download on the
App Store

Access to the **Mobile Field Guide App** can be found by scanning the QR codes.

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To find training that meets your needs, scan the QR code above to visit the **EPRI|U for Transmission** website.



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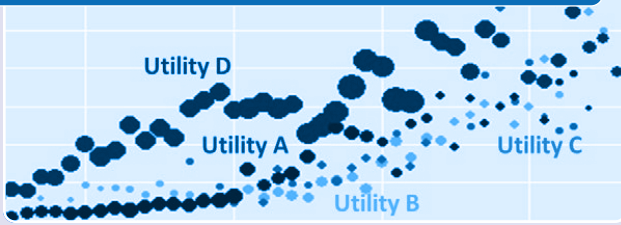


Introduction

EPRI's transmission asset R&D programs address the broad range of challenges facing transmission system owners and managers. These research programs aim to help asset owners manage the existing fleet of transmission assets while keeping an eye to the R&D needed to enable the grid of the future. Implementation of the results produced by these teams will enable transmission system owners to improve safety, reduce costs, improve environmental performance, increase reliability, and meet demand needs of the future.

Drew McGuire Director, Transmission and Substations, dmcguire@epri.com

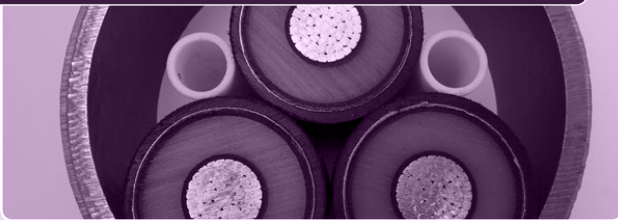
P34 Asset Management Analytics



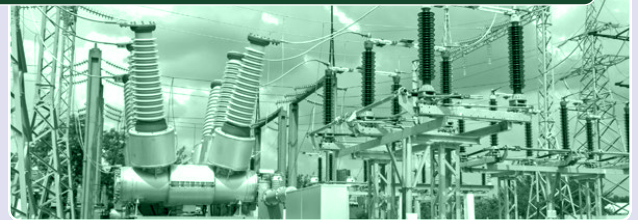
P35 Overhead Transmission



P36 Underground Transmission



P37 Substations



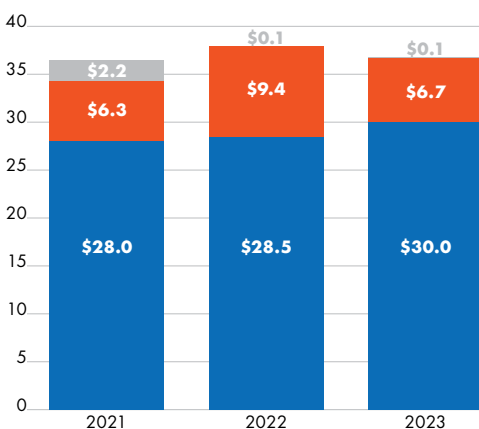
P51 T&D Environmental Issues



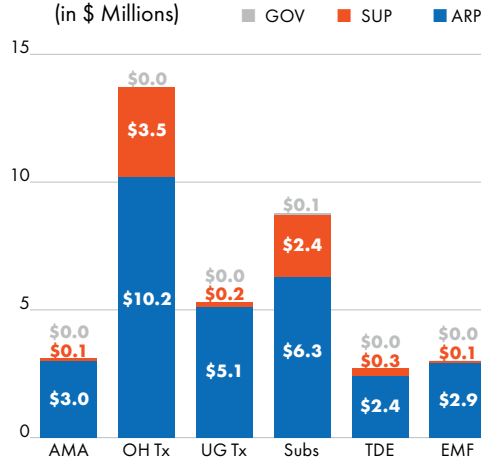
P60 EMF and RF Health Assessment and Safety



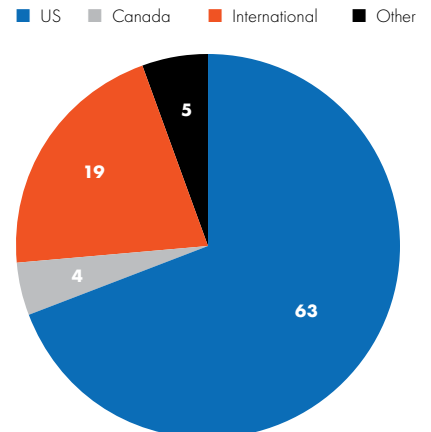
Funding (in \$ Millions)



Funding by Program (in \$ Millions)



Participation - 91 Participants



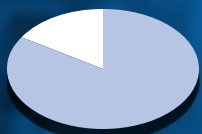


Asset Management Analytics – Program 34

This program focuses on developing asset knowledge enablers, such as failure rates and tools to help utilities make better lifecycle decisions. There are four projects in this program, each with multiple research tasks and technology transfer activities.



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PARTICIPATION
 42 US 8 International

Research Portfolio

Asset Management Analytics:
 Principles and Practices **34.001**



Substations Asset Data
 Analytics **34.002**



Overhead Transmission
 Asset Data Analytics **34.003**



Underground Transmission
 Asset Data Analytics **34.004**



PROJECT

P34.001

Asset Management Principles and Practices

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P34.002

Substations Asset Analytics

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P34.003

Overhead Transmission Asset Analytics

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P34.004

Underground Transmission Asset Analytics

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2023 Accomplishments & Key Deliverables

- Delivered two data analytics training sessions emphasizing how equipment subject matter experts, asset and maintenance supervisors/managers can work effectively with individuals astute in analytics and vice versa.
- Surveyed 22 worldwide Transmission Utilities and documented the impact of supply chain constraints and activities on Power Transformer Asset Management.

3002026801 *Metrics for Managing & Assessing Transmission Asset Performance*

3002027728 *Success Story: EPRI Model Informs Utility Wood Pole Fleet Management*

3002027509 *Success Story: EPRI Circuit Breaker Ranking Tool*

- Significant Improvements in accuracy of Natural Language Processing Algorithms to categorize Circuit Breaker maintenance Work Orders.
- Significant growth in industry wide circuit breaker data (22 utilities, 110,000 maintenance records) enables statistically valid actionable maintenance trends, for e.g., leak rates, annual average corrective maintenance, mechanism problems etc.
- Developed experimental set up with operational load tap changer to produce data that can be leveraged in development of advanced analytics to detect rapidly evolving load tap changer (LTC) incipient faults.

3002026874 *Using Industrywide Data to Better Understand Circuit Breaker Performance*

- Developed an analytical model that uses historical inspection & demographic data to relate lattice tower population age to the likelihood of being in a heavily corroded state. Applied the model to a utility's fleet to aid maintenance & replacement decisions.
- Developed new metrics based on analysis of historical inspection and maintenance data. Applied metrics to rank overhead transmission lines at a utility.
- Significant growth in the performance assessment of wide wood pole, conductor & shield wire based on industry wide data.

3002026887 *Overhead Transmission Steel Structure Fleet Management Analytics*

- Developed algorithm that can automatically classify descriptive maintenance records for Self-Contained Fluid Filled Cable Systems into meaningful categories e.g., oil leaks, joint defects etc. Applied the algorithm to a utility's fleet & used categorized data to develop metrics to inform the utility's risk assessment method.

3002026895 *Using Readily Available Data to Better Understand Underground Transmission Component & Subsystem Performance*

2024 Plan

- Deliver training sessions on new topics: statistical modeling, time-series data analysis and effective use of public data.
- Evaluate late-stage analytical techniques such as Generative Artificial Intelligence, Computer Vision & Large Language Models and their potential applications in Transmission Asset Management Analytics.
- Catalog industry-wide asset management practices & metrics to allow transmission utilities to stay abreast of global trends to maintain or potentially improve equipment reliability & maximize reliability without incurring additional costs.

- Develop advanced analytics to detect rapidly evolving load tap changer (LTC) incipient faults.
- Continue to evaluate of the application of: Natural Language Processing for substation equipment, maintenance record categorization.
- Generative Artificial Intelligence based Large Language Models for text summarization.
- Develop tools for computer assisted maintenance /outage records categorization and information retrieval.
- Develop data extraction & analysis techniques to derive actionable insights from online monitors, digital relays, systems operations historians and SCADA/digital fault recorders.
- Deliver new versions of asset health & risk management software for power transformers and circuit breakers.

- Develop new metrics based on industry wide data to better understand the useful life of wood poles, lattice structures, conductors & shield wire based on readily available data.
- Demonstrate overhead transmission line risk ranking framework.
- Develop tools for computer assisted defect classification and information retrieval.
- Assessment of how utilities can leverage computer vision for fleetwide component health assessment and asset identification.
- Investigate how spatial information and remote sensing can enhance the power of analytics in helping utilities better understand overhead transmission component and system performance.

- Develop new metrics based on industry wide data to better understand the useful life of underground transmission components based on readily available data.
- Develop an underground transmission line risk ranking framework.
- Continue development of analytics for defect classification and information retrieval.
- Explore innovative ways to utilize expert knowledge to better understand component performance (for example, dominant failure modes of terminations, their failure causes, and failures by manufacturer) in analysis-based decision making.

Examples of Member Application of Results

Value Obtained

American Transmission Company

Applying EPRI's Wood Pole Data Analytics Approach to Enable Analysis Based Decisions

Nearly 2/3rd of ATC's transmission structures are wood poles (90,000).

ATC wanted to better understand how inspections & treatments can impact the life of wood poles. However, the lack of an analytical methodology posed a challenge.

EPRI analyzed readily available inspection & demographic data from 90,000 wood poles to better understand population survivability and the influence of various factors e.g., species, treatment type, contractors etc.

The analysis results helped ATC in:

- Justifying maintenance & replacement
- Comparing fleet performance with the rest of the industry
- Developing awareness of vendor results for consistency
- Implementing standard for groundline inspection form



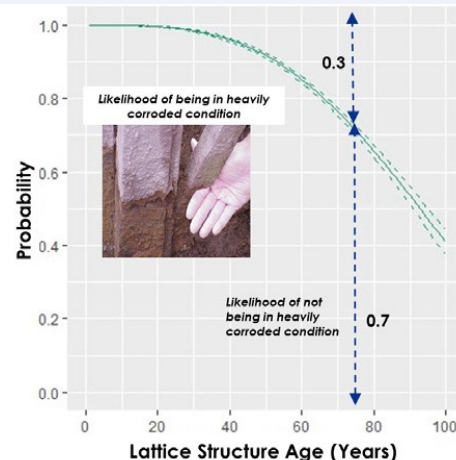
Tennessee Valley Authority

Using Data to Make Smarter Steel Structure Maintenance & Replacement Decisions

TVA wanted to use historical inspection data to develop a better analytical basis to support maintenance & replacement decisions.

EPRI developed analytics that relates age to the likelihood of being in a heavily corroded state for the TVA lattice tower fleet.

Results provide technical basis for developing budgets and prioritizing maintenance and replacement.



ISA Colombia

EPRI's Circuit Breaker Replacement Ranking (CBRR) Software Aids Replacement Planning

ISA wanted to challenge the actual methodologies and rules to prioritize transmission live tank SF6 circuit breakers to identify candidates for replacement & maintenance.

EPRI applied CBRR to prioritize 538 breakers at 110 kV or higher voltages. Identified:

- Replacement & maintenance candidates
- Specific models that are performance outliers

The results provide technical basis for replacement, maintenance decisions. The analysis also identified outliers that inform circuit breaker selection.





Overhead Transmission – Program 35

The program offers a portfolio of tools and information focused on components (such as conductors, insulators, compression connectors, and composite structures) and system issues (such as lightning and grounding, live working, transmission capacity, inspection and assessment, and high-voltage direct current [HVDC] lines).

The program addresses the research needs of transmission asset owners and operators.

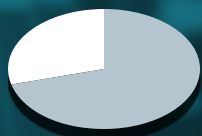
Key drivers of this are:

- Reduced operation and maintenance costs
- Extending asset life
- Improved reliability and resiliency
- Improved safety



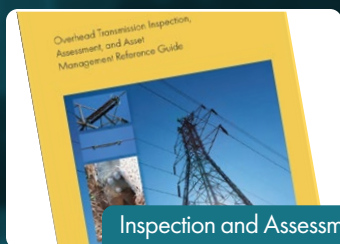
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44 US 18 International

Research Portfolio



Inspection and Assessment
35.001



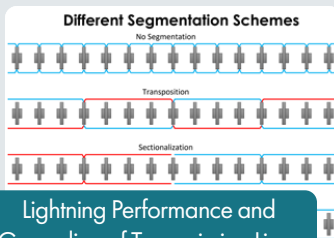
Conductor, Shield Wire and Hardware Corrosion Management
35.002



Structure and Subgrade Corrosion Management
35.003



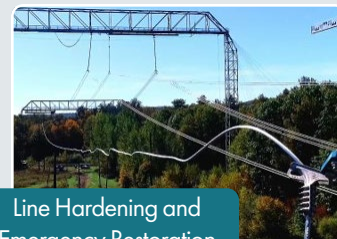
Connector Management
35.004



Lightning Performance and Grounding of Transmission Lines
35.006



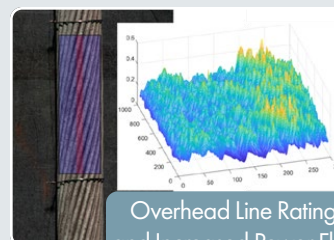
Line Design Tools and Practices for Construction and Maintenance
35.007



Line Hardening and Emergency Restoration
35.008



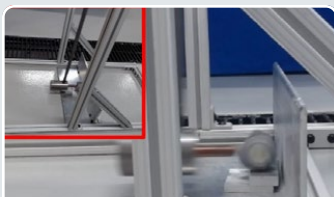
Ductile Iron and Composite Structure Management
35.005



Overhead Line Ratings and Increased Power Flow
35.013



Live Working Research
35.010



Polymer and Composite Overhead Transmission Insulators
35.011



Porcelain/Glass Insulator Integrity Assessment
35.012



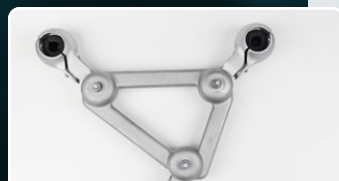
Qualification, Selection & Maintenance of Advanced Conductors
35.015



Line Switch Management
35.018



HVDC Lines
35.019



High Temperature Operation of Overhead Lines
35.014

PROJECT

P35.001

Inspection and Assessment

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2023 Accomplishments & Key Deliverables

- Documented the proceedings of two information sharing sessions on inspection and assessment practices and online monitoring systems.
- Developed a new test plan and setup to evaluate transmission line insulator testers.
- Created a prototype of a new method of delivering inspection field guides.

3002026924 *Best Practices for Integrating Online Monitoring with Inspection Fleet Management Guide*

- Updated the Fleet Management for conductors with corrosion resistance as a function of elevated temperature.
- Developed a methodology for conductor selection in highly corrosive areas. Updated lessons learned from conductor and hardware forensics.
- Development of the atmospheric corrosivity maps.
- Delivered a Corrosion Fundamentals and Control Workshop

3002026928 *Conductor Selection and Application for Corrosive Areas*

- Coating System Selection and Application summarizes performance of more than 80 coating systems.
- Fleet management study of the effects of soil chemistry on structure corrosion rates and an additional 400 soils added to the GIS based maps.
- Documented the benefits and limitations of conductive concrete backfills for structural applications.
- Delivered a Corrosion Fundamentals and Control Workshop

3002026949 *Designing Engineered Backfills to Reduce or Arrest Corrosion*

- Updated the inspection guide with information on mechanical strengths of improperly installed compression connectors.
- Provided guidance on connector management, including utilizing software for connector management, and methodology for developing an end-of-life models for connectors.
- Performed characterization testing on four commonly used joint compounds.

3002026952 *Guidelines for Connector Inspection: Update on Mechanical Effects of Improper Installation of Two-Stage Compression Connectors*

- Completed testing to failure of composite pole samples subjected to accelerated aging for various durations and compared results with "new" properties to evaluate rate of degradation.
- Performed simulated wildfire testing of composite pole and crossarm samples to determine relative benefits of fire protection sleeves vs. intumescent coatings.
- Developed methodology for selection of appropriate composite pole types for installation in line of wood poles to terminate cascading failure events.

3002026959 *Evaluation of Wildfire Protection Methods for Composite Utility Structure Materials*

2024 Plan

- Continue testing of insulator inspection tools.
- Develop an updated method for delivering the field guides.
- Host an Inspection and Assessment workshop.

- Continuation of the atmospheric corrosivity maps development.
- Evaluate a corrosion inhibitor that may be applied to ACSR and ACSS conductors.
- Evaluate the effects of temperature on conductor corrosion rates.
- Initiate work on a web based Conductor End of Life tool.
- Evaluate the effects of bird streamers on shield wire corrosion.

- Start development of an online coating selection tool and application.
- Continued development of the soil corrosivity map.
- Development of a cathodic protection design, installation and management web based tool.

- Initiate accelerated aging of conductor-connector systems with insufficient joint compound.
- Expand the inspection guide to include more types of connectors such as bolt-on fittings, jumper NEMA pads, and t-taps.
- Continue to perform failure/performance analysis on connectors from the field.
- Evaluate a temperature probe for use on high voltage lines for connector inspection.

- Project scope expanded to include evaluation of ductile iron as alternative material for utility poles.
- Investigate options for recycling of composite poles and crossarms at end of life.
- Conduct Composite Structures Testing Workshop at the EPRI Lenox laboratory.

P35.002

Conductor, Shield Wire and Hardware Corrosion Management

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P35.003

Structure and Sub-Grade Corrosion Management

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P35.004

Compression Connector Management

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P35.005

Ductile Iron and Composite Structure Management

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PROJECT

P35.006

Lightning Performance of
Grounding of Transmission Lines

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P35.007

Line Design Tools and
Practices for Construction
and Maintenance

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Line Hardening and
Emergency Restoration

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P35.010

Live Working: Research,
Techniques, and Procedures

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P35.011

Polymer and Composite
Overhead Transmission Insulators

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P35.012

Porcelain/Glass Insulator
Integrity Assessment

Tim Shaw
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2023 Accomplishments & Key Deliverables

- Performed tests to evaluate the mechanical performance of a new surge arrester lead design.
- Updated the benchmark of the TFlash module with lightning related outages by adding results of simulations showing the impact of trees on the sides of the right of ways on the lightning performance
- Updated the Lightning Performance and Grounding Reference Book with new information about lightning impulse strength of transmission lines

3002026972 Resistive Power Losses on Shield Wires: Comparing Segmentation Schemes to Reduce Losses Using TLW-Gen2

- Hosted workshop on resolving under-clearance spans.
- Hosted in-person Red Book Seminar.
- Optimal Pole Foundation Selection Guide completed with improved installation cost and practical applications.
- Experimentation to verify efficacy of bolt loosening prevention methods.

3002026986 Optimal Pole Foundation Selection: 2023 Edition

- Completed initial report on Effect of Seasonal Moisture Variation on Helical Guy Anchor Reliability.
- Significant updates to Learning from Failure - Case Studies.
- Completed tests evaluating impact of stiffness and heavy conductor on the Dynamic Impact Test Line.

3002027002 Learning from Failure - Case Studies in Improved Engineering

- Completed first set of UV aging tests on Live Working Rope.
- Held a Temporary Protective Grounding (TPG) Workshop at the EPRI Lenox Laboratory.
- Finalized the Temporary Protective Grounding Guide.
- Converted Minimum Approach Distance (MAD) software to the Unity 3D graphical engine.

3002027012 Guide for the Temporary Protective Grounding of Overhead Transmission Lines

- Evaluated several polymer insulator failures.
- Held the Transmission Line Insulator Workshop in Lenox, MA.
- Completed round 1 of impact testing of polymer insulators with the new test platform.
- Completed the new mechanical chapter in the Insulator Reference Book.

3002027344 Insulator Reference Book

- Performed thermal shock testing of glass insulators.
- Evaluated the internal strain of glass insulators possible means to assess quality.
- Completed additional quick flashover testing of RTV coated glass insulators.

3002027069 A Study of Aging Porcelain Insulator Performance**2024 Plan**

- Develop guidelines on applying shield wire insulators.
- Develop an educational video on lightning attraction models for transmission lines.
- Develop tool for selecting transmission line surge arresters.

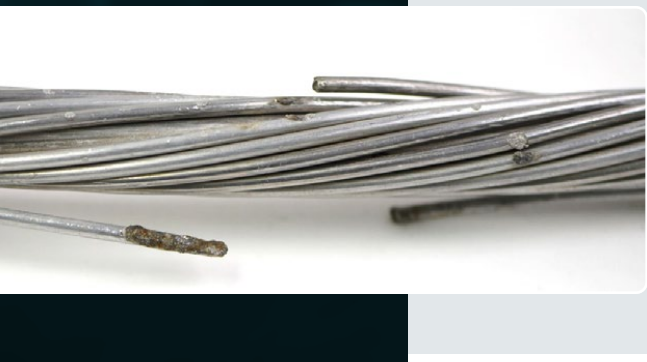
- Complete significant revision to Red Book Chapter on Lightning and grounding.
- Testing on fretting fatigue resistance of annealed versus hard drawn aluminum wire.
- Initiate new project quantifying the real cost for different pole material options.

- Initiate new project to investigate Transverse Cascading Loads.
- Provide Improved Guidance on Forensic Investigations.
- Test impact of longer spans on Dynamic Impact Test Line.

- Develop a TPG ratings calculator.
- Continue with the live working rope testing.
- Evaluate AC voltage detectors.
- Undertake finite element analysis of the live working flashover events.

- Add new insulators to the full-scale aging chamber and evaluate the insulator being removed.
- Continue more impact testing with adjustments learned from round 1 testing.
- Continue to track in-service performance of insulators.

- Develop a tool to measure the contamination on RTV coatings.
- Further study the quality of glass insulators with steep front impulse flashover testing.
- Continue to monitor the failure rate and modes of in-service insulators.



PROJECT

P35.013

Overhead Line Ratings and Increased Power Flow

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P35.014

High Temperature Operation of Overhead Lines

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P35.015

Qualification, Selection & Maintenance of Advanced Conductors

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Line Switch Management

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P35.019

HVDC Lines

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2023 Accomplishments & Key Deliverables

- Completed a key deliverable on emergency ratings that documents an array of practices used worldwide and demonstrates the strengths and risks of each approach.
- Work was also initiated on algorithms that will help specify where to install DLR technologies to minimize the hardware requirements.

3002027077 *Summary of Existing Rating Practices and Considerations for Emergency Ratings*

- Updated the High Temperature Operation Conductor (HTC) Matrix software.
- Updated the guide additional information on mitigating strategies for high temperature operations.
- Provided example applications of the HTC Matrix Software.

3002027106 *Guide for Operating Overhead Lines at High Temperatures: Mitigation Strategies*

- Completed room temperature and elevated temperature mechanical testing of the Solo Connector on ACSS conductors.
- Initiated short term testing on the TS Carbon Core Conductor.
- Updated the HTLS guide with utility application case studies and updated the section on HTLS standards.

3002027130 *Guide for Selection and Application of HTLS Conductors*

- Published initial results of the laboratory tests on quick break whips.
- Added chapters on auxiliary arc interrupters and siting of new line switches in the Practical Maintenance Guide.
- Created a GIS survey field-collector form for in-field commissioning protocols of new line switches.
- Published the first edition of the line switch vintage guide.

3002027141 *Practical Maintenance Guide for Installation of a Transmission Line Switch: Vacuum Interrupters and Utility Experience*

- Updated the HVDC line design guide with a chapter on AC-DC line conversion.
- Completed an initial report on the key considerations related to HVDC Corrosion.

3002027146 *HVDC Transmission Line Design Guide*

2024 Plan

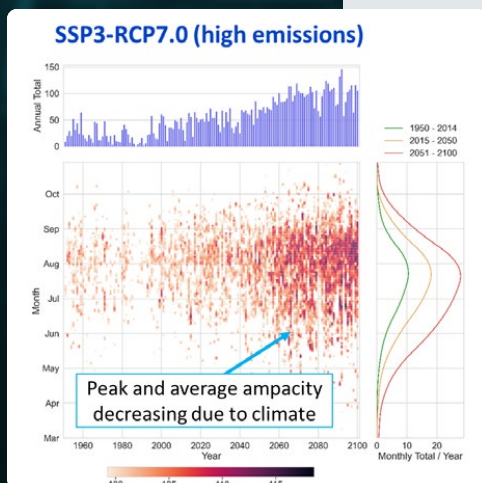
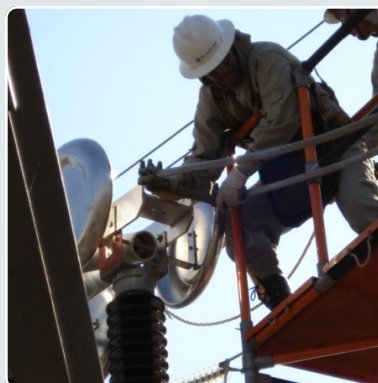
- Aggregate research on FERC Order 881 into a single comprehensive guide on AAR, emergency, seasonal, and forecasted ratings.
- Develop guidance on best practices (in terms of ROI, speed, and reliability) for relieving congestion on clearance limited transmission lines.

- Evaluation of damper characteristics on new and elevated temperature aged spacer dampers.
- Perform test for quantifying corrosion rates at elevated temperature.
- Begin development of web-based versions of the HTC Matrix calculators.
- Perform annealing tests on copper conductor.

- Initiate TS carbon core conductor qualification testing.
- Continue work on the inspection of composite core HTLS conductors.
- Undertake full scale vibration tests to determine safe design tensions for HTLS conductors.

- Conduct additional electrical testing on whip devices from other manufacturers and provide a refined report on the test results.
- Initiate the forensic investigation with root cause analysis to identify the modes and mechanisms of failure and degradation of line switch components.
- Publish the Survey form template on the subscriber website to enable easy access by members.
- Initiate an investigation on inspection and maintenance practices and explore options for near real-time monitoring of line switches.

- Initiate work to republish a reference book specific to HVDC Lines.
- Initiate studies to evaluate anomalous flashovers on HVDC Lines.
- Update the HVDC TLW-Gen2 module.



Examples of Member Application of Results

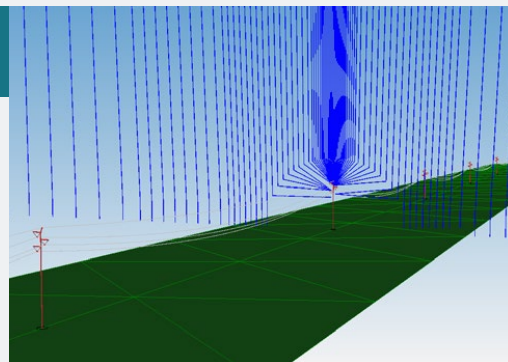
Value Obtained

Lower Colorado River Authority (LCRA)

TLW-Gen2 TFLASH Training Course

The lightning performance of new structure designs or existing transmission lines can be calculated with the TFlash module part of EPRI's software TLW-Gen2. It can also be used for forensic evaluation of lightning-related flash faults to understand their cause and to study the performance of mitigation measures. LCRA wanted to learn how to use this software to evaluate lightning performance of its existing transmission lines.

Attendees learned the lightning performance fundamentals to understand how models are constructed in TLW-Gen2 and the different calculation options provided by the TFlash module. Several transmission line structure designs from LCRA were studied to learn the modeling process and to make sense of TFlash results.

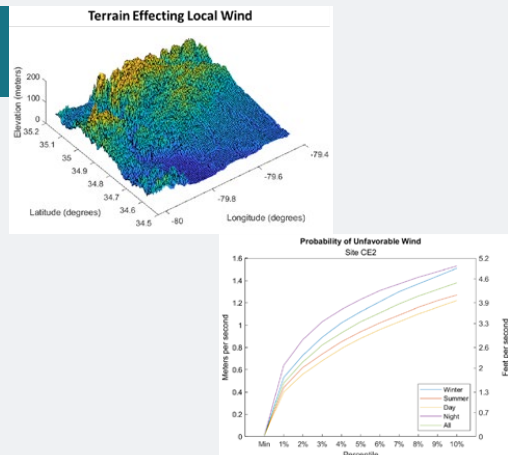


Duke Energy

Development of ratings aligned with FERC 881

Under a new FERC order utilities are required to develop new ambient adjusted ratings, long term (seasonal) ratings, and emergency ratings. These changes can offer ampacity benefits but may also have negative impacts on asset health and reliability. Duke and EPRI began a collaborative effort to improve the balance between risk, complexity, and ampacity gains.

EPRI and Duke engineers assessed how ratings will vary across multiple states using different rating methods. Consideration was given to aged lines, new designs, and coordination with conductors in substations. EPRI applied their risk-based approach to optimize ratings based on conductor strength and line clearances, with support from the Duke team. A range of alternatives were developed and Duke was able to find a suitable solution to increase capacity without increasing risks above their desired level.

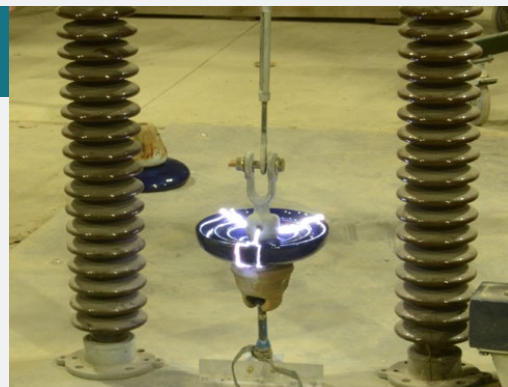


Public Service Electric and Gas

Overhead Line Component Condition Assessment

PSEG initiated a multi-year effort to collect information on aging populations of overhead transmission porcelain insulators, conductors, compression connectors, and associated line hardware to determine when they need replacement.

PSE&G was able to get a better understanding of the current condition of overhead Tx line components and optimize inspection, maintenance and replacement practices based on the data obtained. PSE&G was better able to address their future CapEx budgeting needs and timing, which supported testimony citing the need for new capital investment.



Los Angeles Department of Water and Power

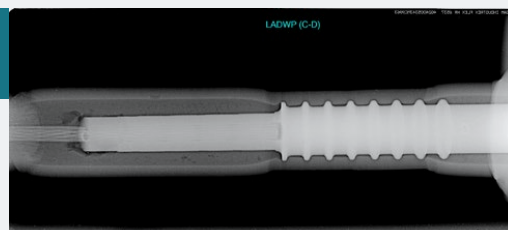
Radiographic Inspection of Compression Connectors

LADWP employed the use of radiography to inspect newly installed ACSS compression deadend fittings as a quality assurance method. During their inspection they found two connectors that appeared to have large pockets of air. To be conservative, the construction company removed the two deadends and replaced them.

Radiography image guidance provided by EPRI was utilized to detect the large void within the connector.

Connectors were sent to EPRI for dissection to better refine radiography analysis.

LADWP was able to verify quality of their newly installed connectors using the EPRI developed guidelines and were able to build upon their understanding of connector radiography.





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PARTICIPATION
22 US 6 International

Underground Transmission – Program 36

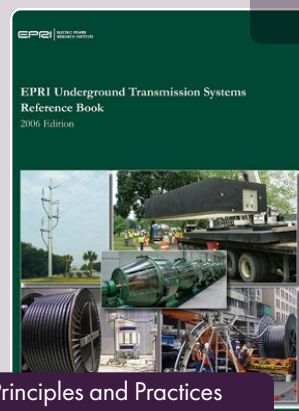
The Underground Transmission Program focuses on assisting utilities in resolving challenges related to design, construction, installation, operation, and maintenance of underground transmission systems consisting of extruded and laminar dielectric cables and accessories. The program develops tools and methods to more effectively design and operate underground transmission systems, gains timely knowledge on asset condition and life expectancy, and acquires strategic intelligence on emerging technologies.



Research Portfolio

Design, Construction, Rating, & O&M

36.001



Principles and Practices
36.006

Extruded Dielectric Cable Systems
36.002



Laminar Dielectric Cable Systems
36.003



HVDC Cable and HVAC
Submarine Cable Systems
36.008



PROJECT

P36.001

Design, Construction, Ratings, and Operation and Maintenance of Underground Transmission Systems

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P36.002

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Laminar Dielectric Cable Systems

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P36.006

Principles and Practices for Underground Transmission

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P36.008

HVDC Cable and HVAC Submarine Cable Systems

Ram Adapa
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2023 Accomplishments & Key Deliverables

- Investigated EPRI pipe-type to extruded cable conversion concept and performed additional tests to evaluate cable and accessory prototype performance.
- Enhanced 138-kV outdoor termination long-term performance test rig and continued termination aging tests.
- Completed demonstrations of EPRI robotic underground vault inspection techniques at two utility sites.
- Enhanced Underground Transmission Workstation (UTW) software and included a new NSPAN module for assisting in thermo-mechanical design.
- Updated EPRI construction and installation practice manual.
- Performed forensic analyses on field aged components.

3002027200 Extruded-Dielectric Pipe-Type Cable (EP Cable) for Installation in Steel Pipe - 2023 Update

- Developed a test protocol and completed the first phase of long-term thermo-mechanical aging tests on a 230-kV cable with copper corrugated sheath.
- Performed mechanical bending aging tests on extruded cables with lead sheaths and reported results.
- Operated the outdoor 138-kV aging test rig with two terminations, a joint, and a cable section and demonstrated cable diagnostic techniques.
- Applied time-frequency domain reflectometry to detect cable faults in AC submarine cables in EPRI Charlotte Underground Cable Laboratory.
- Updated and published Quality Guidelines for Grouting Procedures for Large Casings Used for Transmission Cable Systems.

3002027215 Quality Guidelines for Grouting Procedures for Large Casings Used for Transmission Cable Systems – 2023 Update

- Completed a workshop and updated report on utility experience of in-pipe thermo-mechanical bending events on pipe-type cables.
- Reported additional results of buried steel pipe corrosion study.
- Updated pipe-type cable vintage guide by including information on cable and accessory storage and spare.
- Updated guideline documents on dissolved gas analysis and on cable insulation paper and fluid testing by including more case studies.

3002027224 Utility Experience of In-pipe Thermo-mechanical Bending (TMB) Events on Pipe-type Cables – 2023 Update**3002028687 Success Story: Underground Transmission Cable Condition Assessments**

- Published final report on EMF Management User's Guide for Underground Transmission Systems – 2023 Update.
- Published a new Edition of EPRI Underground Transmission Systems Reference Book (The Green Book) – Completing a comprehensive update on Chapter 6 – Self-contained Fluid-filled Cable Systems.
- Provided training on pipe-type cable thermo-mechanical bending.

3002027229 EMF Management User's Guide for Underground Transmission Systems – 2023 Update

- Updated report on HVAC and HVDC array and export power cables for offshore wind farms.
- Enhanced UTW-DC software for HVDC cable rating calculations.
- Updated EPRI High Voltage Direct Current (HVDC) Transmission Reference Book (Olive Book).

3002027236 EPRI Guide on HVAC and HVDC Array and Export Power Cables for Offshore Wind Farm: 2023 Edition**2024 Plan**

- Continue investigating pipe-type to extruded cable conversion, focusing on performing verification tests on EPRI cable design concepts and field demonstrations.
- Continue operations of outdoor termination test rig in EPRI Lenox Laboratory.
- Enhance EPRI robotic inspection techniques for underground vaults and perform more demonstrations.
- Continue enhancements to Underground Transmission Workstation (UTW) software.
- Perform forensic analysis on components provided by utilities.

- Continue thermo-mechanical aging tests on a 230-kV cable with copper corrugated sheath.
- Perform mechanical parameter tests on a 345-kV laminate sheath cable.
- Perform mechanical bending aging tests on cables of different designs.
- Evaluate emerging cable diagnostic techniques with the 138-kV test rig.
- Initiate development of EPRI guideline document to assist in cable system condition monitoring and assessment.
- Continue and update studies in underground transmission vault component corrosion inspection, assessment, and remediation.

- Continue study on buried steel pipe corrosion.
- Plan to apply developed corrosion and protection monitoring system at member sites.
- Include more case studies on cable insulation paper and fluid testing and dissolved gas analysis to the guideline documents.
- Update pipe-type cable vintage guide.
- Report more results related to failure root cause studies of laminar dielectric cables.

- Continue updating select chapters of the Underground Transmission Systems Reference Book (The Green Book).
- Update EPRI report Underground Cable Fault Location Reference and Application Guide.
- Update EPRI Increased Power Flow Guidebook.
- Provided training sessions on special topics selected based on member interests.

- Perform bending tests on a submarine cable using test rigs in EPRI Lenox Laboratory.
- Update EPRI guide on HVAC and HVDC array and cables for offshore wind farms.
- Enhance UTW-DC software for HVDC cable rating calculation.
- Update EPRI High Voltage Direct Current (HVDC) Transmission Reference Book.

Examples of Member Application of Results

Value Obtained

American Electric Power, Public Service Electric and Gas, and Dominion Energy Underground Transmission Vault Inspections

EPRI demonstrated a robotic tool set developed by EPRI for underground transmission vault inspections at ground level while the underground cable circuit is still energized.

The results of the demonstrations showed the effectiveness of using such tools in improving worker safety and inspection productivity. EPRI research results in vault component corrosion, optimized cable support design, and cable sheath bonding system design can be utilized to address issues as part of the inspection results.



National Grid

Condition Assessment of Self-contained Fluid-filled Systems

EPRI assessed conditions of National Grid's underground circuits of self-contained fluid-filled type. EPRI research and development results were applied along with the EPRI approach. The assessment results can be used to better understand system conditions and to develop operation, maintenance, and replacement strategies.

Results of the assessment helped to better understand life expectancy of the underground systems and to develop operation, maintenance, and replacement strategies. Effective management of such systems can increase reliability and save costs.



Southern Company

Condition Assessment of Pipe-type Cable Systems

EPRI assessed conditions of a pipe-type transmission cable system of Southern Company. The assessment focused on corrosion, coating conditions, and corrosion protection of the buried steel pipes of the underground system. EPRI approach and research results were applied for the assessment.

Results of the project can be used to better understand the conditions of the buried steel pipes of the pipe-type cable system, enhance the current operation and maintenance practices, and extend the life of the system.



New York Power Authority

Evaluation of Recent Failures of Pipe-type Cable Systems

EPRI worked with New York Power Authority and evaluated the failure history of a critical transmission pipe-type cable system, especially in the area related to thermo-mechanical design and performance of the cables within steel pipes. The common approach for cable condition assessment, building on prior EPRI research, was applied.

The results of the project can help better understand laminar dielectric cable aging mechanisms and end-of-life criteria. The results would also help develop a maintenance and replacement strategy to minimize system outages, increase system reliability, improve public safety, and reduce system operation cost.



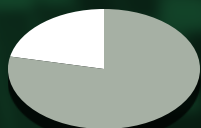


Substations – Program 37

This program focuses on tools, techniques, and methodologies that help improve maintenance specifications and inspections and assessments. There are ten projects in this program, each with multiple tasks and tech transfer opportunities. The research is strongly supported by EPRI laboratories on multiple campuses, including the full scale 138kV Research Substation in Lenox, MA.



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PARTICIPATION
42 US 8 International

Research Portfolio

Transformer Life Management
37.101



Substation Corrosion Management
37.104



Polymer Bushing Life Management
37.113



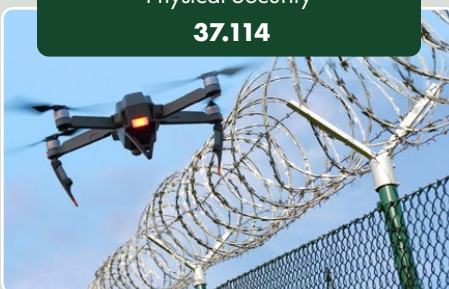
Circuit Breaker Life Management
37.102



Balance of Substation
37.105



Physical Security
37.114



Protection and Control
37.103



Gas Insulated Substations
37.108



HVDC Converter Stations and
FACTS Technologies **37.116**



Using Voltage and Current Measurements
for Monitoring Asset Conditions **37.117**



PROJECT

P37.101

Transformer Life Management

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2023 Accomplishments & Key Deliverables

- On-line monitor evaluation of a wide range of transformer monitors in EPRI's 138kV research substation.
- Extensive research on alternative fluids (both natural and synthetic esters).
- Significant advances in how to dry oil continuously using Peltier technology.
- Important yearly updates to the Transformer Guidebook (the Copper Book).
- Significant expansion of EPRI research substation to add additional monitors.
- Breakthrough in new concepts for low maintenance on-line dehydration.
- 5 deep technical webinars on topics in the Copper Book.

3002026941 *EPRI Power Transformer Guidebook (Copper Book) 2023 update*

P37.102

Circuit Breaker Life Management

Bhavin Desai
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- Conducted first demonstration of novel SF₆ leak sealing technique application to seal flange leaks in live tank circuit breakers.
- Developed "how-to" guide that utilities can use to implement the silicon tape & putty method for sealing flange leaks.
- Evaluated six online breaker monitors based on manufacturer specifications and other published literature.
- Developed a new chapter on onsite installation, test, and commissioning.

3002027018 *Advances in Novel SF₆ Leak Sealing Techniques Development & Field Testing*

P37.103

Protection & Control

Yuchen Lu
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- Significant expansion of EPRI protection and control lab by adding new testbed systems and testing capabilities.
- Research and lab testing identified potential failure modes in the new P&C designs relying on Process Bus technologies.
- Successfully delivered a technology transfer workshop to advance new P&C designs and overcome the challenges in field deployment of the IEC 61850 standard.

3002027061 *Application Guidelines for Protection System Maintenance*

P37.104

Substation Ground Grid Management

Neal Murray
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- The first chapter of the EPRI Ground Grid Inspection was completed and guidelines have been published.
- The Corrosion Monitoring System has expanded capabilities in both atmospheric and subgrade environments to measure corrosion rates and monitor environmental factors.

3002024603 *Inspection and Assessment for Substation Ground Grids*

P37.105

Balance of Substations: Batteries, Arresters and Ratings

Jessica Bock
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- Continued testing of the 2 battery monitoring systems in the test facility.
- Arrester testing and monitoring in our Lenox, MA facility including research and evaluation into the EPRI RF monitors.

3002027114 *EPRI RF Monitor Surge Arrester Development, Laboratory Testing and Field Demonstration*

2024 Plan

- In 2024 Alternative fluid research will expand to examine higher temperature fluids and solid insulation.
- New on-line monitoring technologies will be added to the research substation.
- Field pilots will provide new learning on the new on-line dehydration developments.
- 2024 updates to the Transformer Guidebook (the Copper Book).
- In 2024 we will host 5 deep technical webinars on topics in the Copper Book.

- Perform research to find commercially available adhesives that have fast curing times and can be applied at lower temperatures.
- Continue research and demonstration to apply leak sealing techniques to various geometries.
- Advance development of novel SF₆ leak sealing techniques through laboratory tests and field trials.
- Evaluate efficacy of noninvasive diagnostics – X-Rays, Acoustics.
- Implement test plan & initiate evaluation of on-line monitors.
- Develop and deliver training webcasts based on guidebook content.

- Conduct lab testing of new protection and control designs using fiber-optic communication, process bus technologies, IEC 61850 standard, and precision time protocol.
- Conduct lab testing to evaluate relay performance under stable or unstable power swings.
- Provide hands-on technology transfer at EPRI P&C lab for training and knowledge preparation.

- Survey funders to identify significant corrosion control needs in a substation.
- Continue developing the EPRI Three Tier Ground Grid Inspection Guidelines.
- Selection and application of coating systems.
- Screening a population of substations for soil corrosivity.

- Additional assessment and evaluations of battery monitoring systems.
- Robotics – Testing of an additional robotic chassis that has not been previously tested as a means for substation inspections.
- Continued research into Ratings for Substations including additions to the Power Flow Guidebook.

PROJECT

P37.108

GIS (Gas Insulated Switchgear) and GIL (Gas Insulated Lines)

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P37.113

Polymer Bushing Life Management

Tim Raymond
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P37.114

Substation Physical Security.

Erika Willis
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P37.116

HVDC Converter Stations and FACTS Technologies

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P37.117

Voltage and Current Measurements for Monitoring Asset Conditions

Colleen Konsavage
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2023 Accomplishments & Key Deliverables

- Industry knowledge on leak detection and location.
- Significant expansion of the EPRI GIS laboratory to answer important questions for the industry.
- EPRI's GIS/GIL Guidebook was almost doubled in size in this 2nd edition of practical guidance based on laboratory testing.
- SF₆ leak detection testing in the laboratory using both Optical and Acoustic techniques significantly extended the industry knowledge.
- Advances in one-line Partial Discharge monitoring of GIS and GIL using EPRI's RF Monitoring suite.

3002027117 EPRI Guidebook on GIS and GIL – 2023 Edition

- Continued testing of ABB O plus Dry RIS bushings in the 138kV Research Substation in Lenox, MA.
- Investigated accuracy of Doble T1 bushing monitor applied on RIS bushing.
- Completed construction of environmental chamber facility to accommodate bushings to 69kV.

3002024620 Performance of Dry-Type Bushings Under Extreme Environmental Conditions: 2023 Update – Results from Full-Scale Laboratory Tests

- In 2023, Physical Security was a supplemental and not part of the ARP. With that, there was still some key research that occurred.
- Ballistic Compendium – This was a full report of all previous EPRI testing.
- Cross cutting research that pertains to physical security including IEMI and ISOC.
- Collaboration on enchaining security and decision making across the members.

3002028197 Compendium of 2014–2021 EPRI Ballistic and Blast Testing Technical Reports

- Performance and cost comparison of different Flexible AC Transmission System (FACTS) technologies – Completed a technical and economic comparison of Unified Power Flow Controller (UPFC) with Interline Power Flow Controller (IPFC). The results will provide guidance to utility engineers for applying these technologies.
- Updates to the HVDC Transmission Reference Book (the Olive Book) with the latest information and providing technical webinars. The Olive Book was updated with new information on Voltage Source Converter (VSC) technologies and HVDC cables. Provided technical webinars to utilities including TERN and Manitoba Hydro.

3002027143 Technical and Operational Comparison of UPFC and IPFC

- Continued evaluation of the new transformer monitoring technology.
- Equipment moved from 138kV Lenox Substation deployment to Charlotte lab for reconfiguration and new suite of testing.

3002027138 Using Voltages and Currents to Monitor Equipment Health: Applicable Assets**2024 Plan**

- SF₆ Alternative experiences from the field and the laboratory
- UAV inspections of SF₆ leaks for hard-to-reach detection and location of emission.
- Research into the Life Cycle Analysis of SF₆ and SF₆ Alternatives.
- Continued expansion of the GIS/GIL guidebook to include valuable insights on SF₆ reduction.

- Continue multi-year test plan of RIS bushings.
- Engage members in review of Guidelines on Specification and Maintenance of Polymer Bushings to capture industry operating experience.
- Investigate means for accelerating research objectives.
- Investigate sensitivity of RIS/RIP bushings under overload conditions.

- Continued research on robotics technologies and the ability to use for physical security and becoming more situationally aware.
- UAS Detection Technologies – Testing on new technologies and understanding of the effectiveness.

- Development of life extension guidelines for FACTS controllers - SVC and STATCOM.
- Technical performance and cost comparison of FACTS controllers – comparing Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC) with other series and shunt FACTS controllers.
- Continue to update the Olive Book with latest information.
- Continue to provide HVDC & FACTS tech transfer to utility engineers – technical webinars on HVDC & FACTS.

- Continued evaluation of the new transformer monitoring technology with dynamic inputs in Charlotte lab.
- The results will guide the industry on the specification on understanding of these online monitors.

Examples of Member Application of Results

Value Obtained

Manitoba Hydro

Application of HVDC Converter Life Extension Guidelines

Manitoba Hydro is planning to upgrade the existing Bipoles 1 and 2 and studying various options using the information in the EPRI HVDC Reference Book and EPRI Life Extension Guidelines.

EPRI HVDC Converter Life Extension Guidelines were developed surveying many utilities' converter stations. These guidelines will provide optimal selection of converter components based on their life expectancy either to repair or replace with new components ultimately reducing outages and O&M costs.



AEP, CenterPoint, and Duke Energy

Application Online Monitoring

Numerous utilities have been able to directly apply the In the EPRI 138kV Research Substation monitor evaluation results into their monitor specifications and selections.

Fact-based insights into the performance of on-line monitoring technologies provides significant value in specifying monitors. This is especially true given the large numbers of monitor deployments fleet-wide. Optimal selection has an important role in reducing O&M costs associated with monitor maintenance and optimal selection also improves the probability of detecting an issue in a substation asset prior to failure



Xcel Energy, GTC, PNM, HydroOne, Southern, Duke Energy, and Dominion

Application RF Monitoring

The industry need is for rapid deployment and low cost deployment of continuous partial discharge monitoring for transformers. This need was met with the development of the EPRI RF Monitors and the utilities took the next vital step of successfully piloting the monitors in the field.

At the highest level the benefit for society is more reliable electricity supply. This is achieved through increased reliability of a key component in the grid: The power transformers. In each of the nominee substations the specific value was the cost effective application of EPRI technology to address unique transformer challenges.



NYPA, Con Edison, BC Hydro, SEC, and UKPN

Application of Novel SF6 Leak Sealing Techniques

Utilities are in the need of SF6 leak sealing techniques that utilize adhesives that are easy to procure, apply & remove. Utility personnel can apply these techniques without relying on outside vendors. Furthermore, the desire is to apply the techniques without requiring outages or the need to reducing pressure. The need was met by developing three novel approaches through extensive laboratory research. The techniques have been successfully applied at seven different utility substations across the world.

The technique provides utilities with the ability respond quickly without having to rely on outside vendors and expensive repairs. The resulting value comes from reduced O&M, improved reliability and reduced SF6 Emissions.



Examples of Member Application of Results

Value Obtained

Southern Company

Application of IEC 61850 and Process Bus Technologies

Southern company is applying IEC 61850 and emerging process bus technologies in new P&C design for EMP (Electromagnetic Pulse) hardening, cost saving, and advancing condition-based maintenance.

Through extensive lab testing and investigation, EPRI research was able to identify certain hidden vulnerabilities in the new design that otherwise could lead to protection system failure in the field. Southern Company and EPRI are collaborating on developing effective solutions for the success of new P&C design.



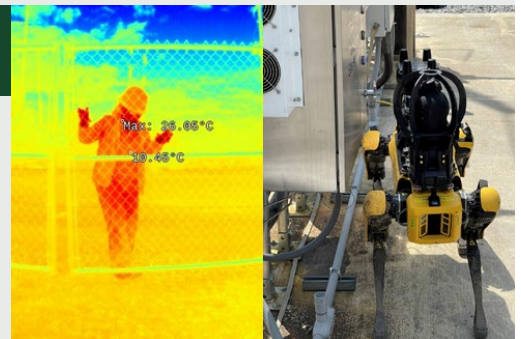
Nebraska Public Power District (NPPD)

Physical Security

Security of assets and the personnel who operate this critical infrastructure is a high priority. For substations these threats are intentional threats against the system such as vandalism, theft, drones, and sabotage. EPRI's research seeks to reduce these potential disruptions and/or damage.

The project has been able to increase situational awareness of the potential threats by leveraging R&D on various cross cutting topics: ballistics, robotics, Drones, Counter-UAS. In addition, there is value in the knowledge of the available and soon-to-be available detection technologies.

3002027520 *Improving Physical Security*



ConEd, National Grid, Entergy

Substation Robotics

Investigate the use of mobile autonomous robots to inspect substation assets 24/7, preventing outages and improving electricity supply reliability.

Collaborating with EPRI has enabled utilities to proactively embrace robotics within their operations, resulting in safer work environments, cost savings, and accelerated learning. EPRI's research and collaborative approach have allowed utilities to confidently explore and implement robotics, ultimately improving worker safety and operational efficiency while making informed decisions based on lessons learned from others in the industry.



AEP, Southern Company, Ameren, CPE, Central Hudson, ConEd, Cooperative Energy, CPS, Exelon, FE, GTC, Heco, H1, NG, NPPD, NYPA, PGE, PSNM, PSEG, SRP, NG, SEC

Application Substation Corrosion Control Workshop

Corrosion control course on methods to inspect, assess and mitigate corrosion on substation assets in atmospheric and subgrade exposure.

The course provided new learning for substation asset managers, engineers and maintenance personnel in best practices for corrosion control within a substation.





Program 51 – T&D Environmental Issues

Focused on enhancing the safe and reliable delivery of electricity while protecting environmental and cultural resources, as well as supporting corporate reliability, resilience, sustainability, and conservation goals.

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PARTICIPATION
22 US 2 International

RESEARCH TOPIC

Vegetation Management & Remote Sensing



Wildlife Interactions with T&D Assets

Substation Environmental Issues

Environmental Aspects of T&D Lines

2023 Accomplishments & Key Deliverables

Delivered a video highlighting utilities' integrated vegetation management (IVM) and conservation programs. Performed field studies to assess eDNA as a biodiversity monitoring tool. Started research to better understand (i) how rights-of-way ROWs can benefit bats and (ii) if satellite data can be used to add a temporal component to LiDAR data.

- 3002026829** *Can eDNA be Used to Detect Pollinators*
- 3002024726** *Assessing the Quality of Native Pollinator Habitat for Management and Biodiversity Monitoring*

Published a guide to help utilities better manage and mitigate issues with bird nests in power system structures. Developed utility surveys to be distributed among participants next year.

- 3002026830** *Successful Nest Management Techniques*

Created educational material about retrofits options that can improve sustainability, resilience, and reduce nuisance conditions in substations.

- 3002026826** *Overview of Sustainable Retrofit Options for Substations*

Provided an overview of the types of equity and justice (E&J) that may be applicable to T&D siting projects and identified methods by which utilities may be able to incorporate E&J into their siting procedures.

Evaluated seed mats for postconstruction revegetation. Seed mats were installed under different site preparations to identify best practices.

Continued yearly soil and porewater samples in Charlotte's outdoor laboratory setup. The data collection aims to assess the fate and transport of DCOI from treated wood utility poles in soil and groundwater.

Assessed alternative options for circular economy of utility wood poles using wood pole generated biochar.

- 3002026828** *Environmental Justice Considerations for Power Delivery Siting in Rural and Suburban areas*
- 3002026833** *Evaluating Seed Mats for Postconstruction Revegetation*

2024 Plan

- Continue investigation on how ROWs can support bat populations.
- Continue research to identify how satellite imagery can leverage LiDAR data over time.
- Create a template for integrated vegetation management (IVM) progress and reporting.

- Drone installed line markers demonstration in Lenox Laboratory
- Establish leading practices for use of UAVs around protected birds.

- Assess effectiveness of vegetative screens to reduce substation nuisance conditions without creating wildlife impacts.
- Study the feasibility of using waste heat and stormwater from substations to support small-scale agriculture.

- Evaluate the feasibility of using remote sensing data and machine learning algorithms to detect cultural resources. This approach can help reduce the time and effort required for surveys that are necessary for new infrastructure siting projects.
- Prepare an overview of current practices for 3rd party construction environmental compliance.
- Continue yearly soil and porewater samples from DCOI treated wood poles.
- Explore considerations for using Airepel to prevent woodpecker damage in utility poles.



Program 60 – Electric and Magnetic Fields and Radio-Frequency Health Assessment and Safety

Focuses on addressing the potential health effects of EMF and RF on humans and non-human biota and provides exposure management tools and resources to address impacts to workers and the public.



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PARTICIPATION
13 US 4 International

RESEARCH TOPIC

60A: Health Studies and Risk Communication

2023 Accomplishments & Key Deliverables

Updated TransExpo Multi-National Childhood Leukemia Study to include data from the Netherlands.
Accepted peer reviewed journal publication of alternative risks for childhood leukemia from pesticide exposures and plant nurseries situated near powerlines.
Created FAQ Information Briefs on Smart Meters and 5G to facilitate risk communication.
Completed evaluation of health and environmental impacts from HVDC and Hybrid overhead lines.
3002027316 *Pesticides as a Potential Childhood Leukemia Risk Factor and Confounder for EMF Exposures*
3002027321 *Environmental and Potential Health Effects of HVDC and Hybrid Transmission Lines*
3002028428 *5G FAQ Information Brief*
3002028427 *Smart Meter FAQ Information Brief*

2024 Plan

- Complete and submit manuscript for TransExpo epidemiology study to a peer reviewed journal.
- Conduct feasibility study to evaluate other agents/factors near powerlines that may influence risk for childhood leukemia.
- Create additional FAQ information briefs on key EMF or RF exposure topics (e.g. microshocks).
- Begin software development of a Public Exposure Database.
- Begin development of a resource for EMF risk communication.

60B: Exposure Characterization and Management

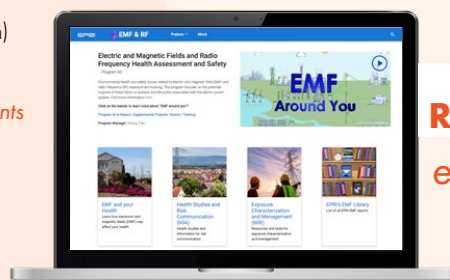
Accepted peer reviewed publication of RF exposures near 5G new radio small cells.
Completed assessment of EMF impacts to marine life from HVDC submarine cables and developed an EMF assessment framework to facilitate utility environmental impacts analysis
Completed EMF measurement protocol for residential dwellings.
Began review of potential EMF impacts from grid level energy storage technologies.
Began development of a resource for EMF considerations for public use of transmission line easements.
3002027319 *RF-EMF Exposure near 5G NR Small Cells*
3002028429 *EMF from HVDC Submarine Cables*
3002028430 *EMF Residential Measurement Protocol (joint with 60A)*

- Conduct EMF characterization study of grid-level battery energy storage sites.
- Conduct EMF characterization of select electrification technologies.
- Develop handbook of EMF calculations.
- Begin software development of a Public Exposure Database.
- Begin migration of EMFast to the web.
- Complete resource for EMF considerations for public use of transmission line easements.

EMF-RF Knowledge Transfer

Conducted four technical webinars:
- EMFast Practical Applications (Part 1 and Part 2)
- Utility Experiences with Public Meetings
- EMF Risk Communication.
Disseminated twelve editions EMF Now.
Updated the EMF/RF Resource Center (emf.epri.com) with an EMF Library and interactive graphic.
3002027323 *EMF Now – 2022 Compilation*
www.epri.com/research/programs/025025/events

- Conduct technical webinars to facilitate knowledge transfer and peer-to-peer exchange of experience.
- Disseminate monthly editions of EMF Now.

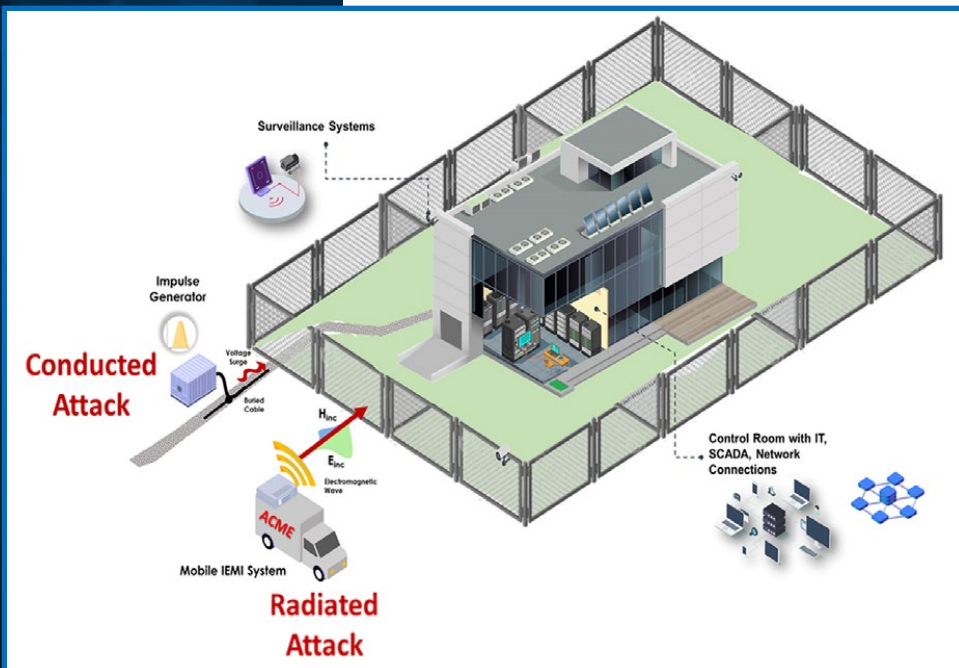


ONLINE RESOURCES
emf.epri.com

EMP Update

In 2023, EPRI's electromagnetic pulse (EMP) research, development and demonstration (RD&D) efforts focused on assessing the potential impacts of early-time high-altitude electromagnetic pulse (E1 HEMP) on distribution systems, generation facilities and telecommunications infrastructure and applying hardening technologies in transmission and distribution substations. Several U.S. government-sponsored EMP projects were also completed or are ongoing.

EPRI's EMP laboratory in Charlotte, NC was also expanded in 2023 to include an indoor testing facility for performing high-voltage direct injection testing of equipment. The picture below shows a EMP test of a medium-voltage distribution insulator, an example of some of the EMP testing that was performed in this new facility.



Later in 2023, intentional electromagnetic interference (IEMI) became a new R&D area for the program due to the increasing physical security threat resulting in the launch of a new two-year supplemental project. The figure below illustrates how a transmission control center can be attacked using IEMI.

To find out more information contact Randy Horton at rhorton@epri.com or (205) 515-7303.

EPRI | U for Transmission

The “EPRI | U for Transmission” project has been delivering high-quality, technically based training for three years now. Aimed at engineers and other technical staff, it continues to provide content on transmission assets, operations and planning through various delivery methods, including videos, live webinars, and computer-based training courses.

EPRI staff achieved approval from NERC for six courses to granting continuing education hours (CEH) to NERC Certified System Operators (NCSO). This includes two brand new courses designed and created by EPRI staff: Transmission 201, and Power Systems Dynamics: System Restoration.

In 2024 a return to face-to-face workshops, and new content for this year is planned.

For any questions related to EPRI | U for Transmission, please reach out to Robert Haromszeki at rharomszeki@epri.com or (650)-855-1050.



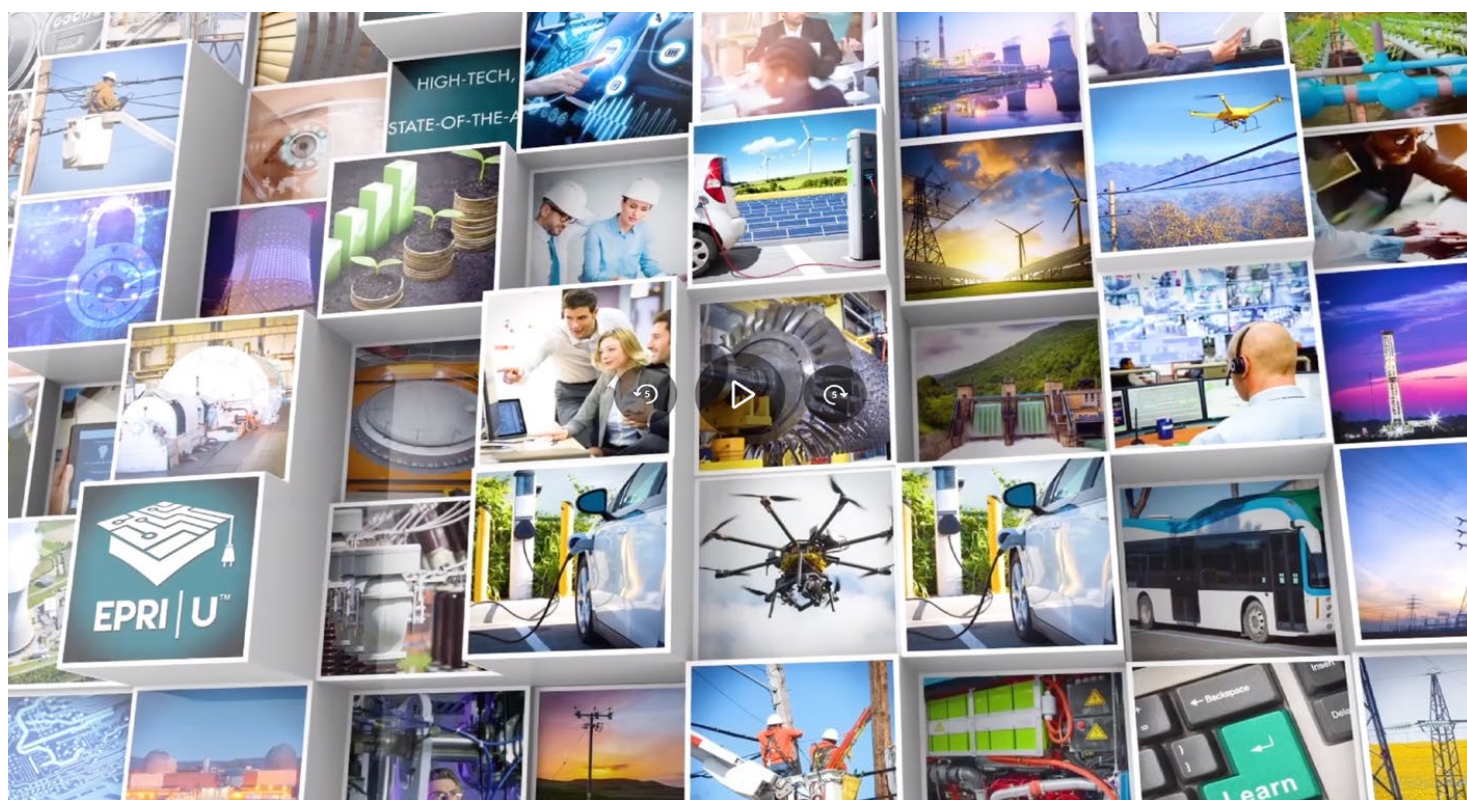
EPRI | U™

EU4T



Learn more about EPRI | U for Transmission by scanning the QR code above.

| | |
|-------------|--|
| 5456 | Touchpoints with learners |
| 2876 | Professional Development Hours |
| 72 | Videos & CBT Available |
| 24 | Utility Project Participants |
| 5 | Computer-based training courses NERC-approved for NCSO |
| 9 | New Interactive CBT Designed and Created |



THE EPRI RADIO FREQUENCY (RF) MONITOR SUITE

The **EPRI Monitoring Application** combines the RF monitoring hardware, actionable information visualization and world class SME consulting service.

The Hardware: The EPRI Radio Frequency (RF) monitoring suite is a collection of 18 purpose built wireless RF sensors. The sensors collect data, internally processes the data into actionable information, and wirelessly transmit (to a base station) this information which correlates to the health condition of a range of transmission line and substation assets e.g., insulators, structures, conductors, and transformers. The base station relays this information typically via cellular modem to a utility or EPRI servers.

As many as 44 EPRI battery or power harvesting sensors can be combined and wirelessly communicate real-time information to the solar/battery or 110v powered base station. The base station also collects ambient weather information: wind, rain, temperature, and relative humidity.

Actionable Information: Stakeholders can view (via an EPRI web interface or on their own asset health system) a graphical representation of real time parameters; current, temperature, movement, strain, or acoustics, associated with asset condition, degradation, security, or failure modes for each asset type.

Expert consulting: In parallel EPRI experts also monitor the information and provide guidance. Alerts and alarms to action can also be set up to prompt local utility action if warranted.

The Value: The proactive monitoring of transmission and substation asset health information allows utilities to make actionable maintenance or replacement decisions to avoid costly unplanned service interruptions and to intelligently plan/procure for future resiliency.

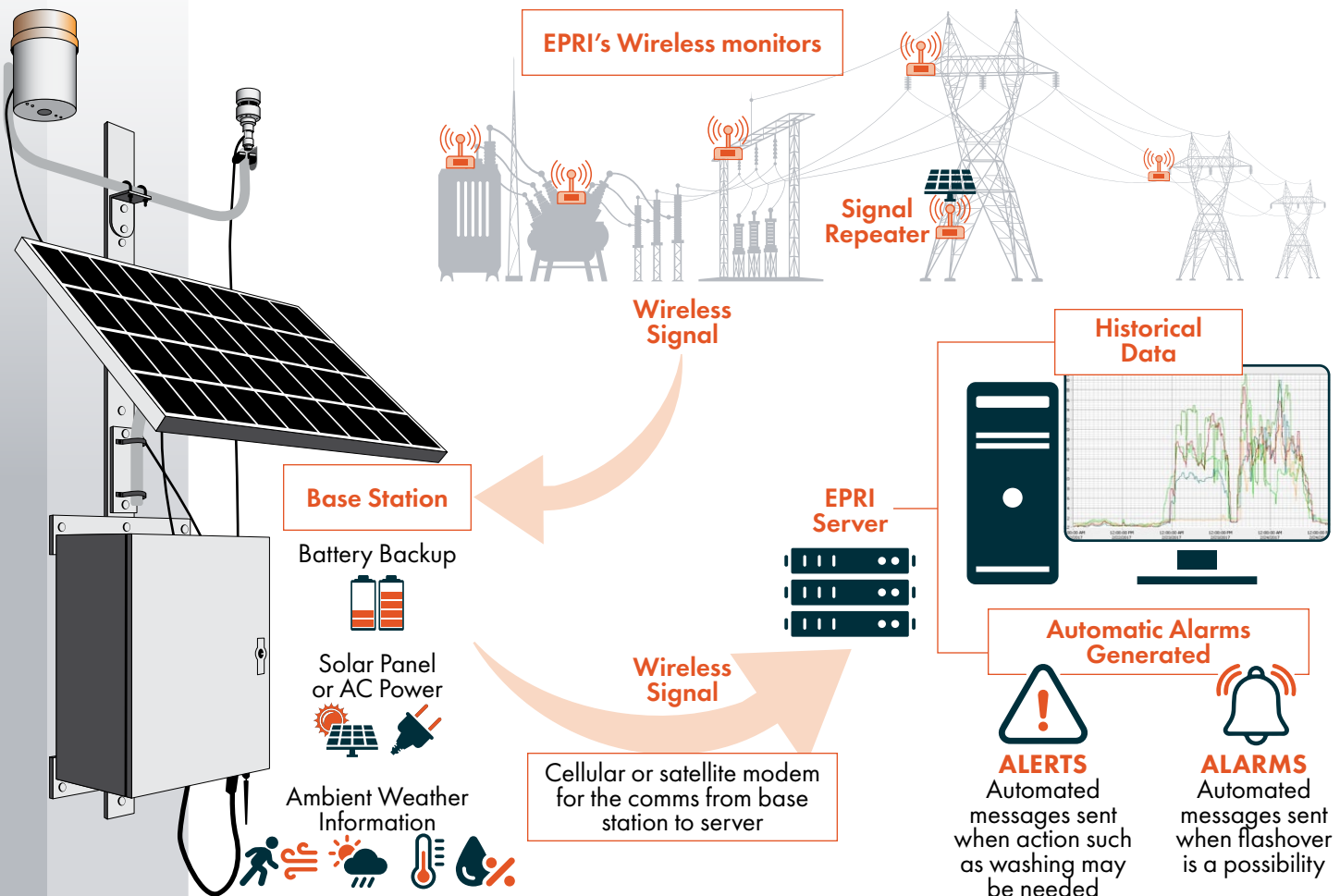
For more information on the EPRI Radio Frequency (RF) Monitor Suite, please reach out to Rich Menar at rmenar@epri.com or (650) 855-8707.

3002028174 Insulator Contamination Monitoring

“The EPRI RF Monitors not only inform us of insulator contamination, but also of the need for replacement or recoating. We plan to install EPRI RF Monitors on different insulator designs and sizes within a substation to help identify designs that perform better and thus support design and procurement decisions.”

~ MIKE KOKOSZ
Consultant Engineer
CenterPoint Energy

EPRI currently actively monitors over **60 sites** utilizing over **1000 sensors** in the US and **5 other countries.**



| Title | Project Manager | | Deliverable # |
|---|-------------------|----------------------|---------------|
| RED BOOK EPRI AC Transmission Line Reference Book – 200 kV and Above, 2023 Edition | Pierre Marais | jmarais@epri.com | 3002026982 |
| ORANGE BOOK EPRI Transmission Line Reference Book: Conductor and Structure Motion, 2023 Edition | Pierre Marais | jmarais@epri.com | 3002026983 |
| YELLOW BOOK Overhead Transmission Inspection, Assessment, and Asset Management Reference Guide - 2023 | Daniel Malan | dmalan@epri.com | 3002026920 |
| BLUE BOOK EPRI Transmission Line Reference Book: 115– 400 kV Compact Line Design, 2022 Edition | Pierre Marais | jmarais@epri.com | 3002024409 |
| OLIVE BOOK EPRI High Voltage Direct Current (HVDC) Transmission Reference Book – 2023 Edition | Ram Adapa | radapa@epri.com | 3002027330 |
| TAN BOOK EPRI Live Working Reference Book - 2023 | Gary Sibillant | gsibillant@epri.com | 3002027031 |
| GRAY BOOK Overhead Transmission Line Lightning & Grounding Reference Book - 2023 | Camille le Mauff | clemauff@epri.com | 3002026976 |
| VIOLET BOOK EPRI Insulators Reference Book - 2023 | Tim Shaw | tshaw@epri.com | 3002027344 |
| PLATINUM BOOK Increased Power Flow Guidebook - 2023 | Justin Bell | jbelle@epri.com | 3002027331 |
| GREEN BOOK Underground Transmission Systems Reference Book – 2023 Edition | Tom Zhao | tzhao@epri.com | 3002027228 |
| BLACK BOOK EPRI Switching Safety and Reliability Reference Book – Sixth Edition | Robert Haromszeki | rharomszeki@epri.com | 3002023251 |
| MAROON BOOK Fault Current Management Guidebook | Ram Adapa | radapa@epri.com | 1024227 |
| COPPER BOOK EPRI Power Transformer Guidebook Development | Luke Van der Zel | lvanderz@epri.com | 3002026941 |
| GOLD BOOK Power Electronics-Based Transmission Controllers Reference Book | Ram Adapa | radapa@epri.com | 1020401 |
| Electric and Magnetic Field Management Reference Book: Second Edition | Phung Tran | ptran@epri.com | 3002024734 |

Field Guide: Corona Rings for Polymer Insulators
Selection, Inspection, and Assessment
3002005631



Field Guide: Visual Inspection of Wood Structures
3002005632



Field Guide: Inspection of Transmission Line Foundations
3002005619



Field Guide: Visual Inspection of Porcelain and Glass Disc Insulators
3002005628



Field Guide: Visual Inspection of Avian Issues on Transmission and Distribution Structures
3002005626



Field Guide: Inspection of Conductors for Overhead Transmission Lines
3002005633



Field Guide: Live Working Rope
3002007706



Field Guide: Smart Ground Meter
1024555



Field Guide: Switching Safety and Reliability



| Title | Project Manager | | Deliverable # |
|--|-------------------|----------------------|---------------|
| PROGRAM 35 | | | |
| Visual Inspection of Polymer Insulators | Tim Shaw | tshaw@epri.com | 3002027261 |
| Visual Inspection of Steel Structures | Neal Murray | nmurray@epri.com | 3002027247 |
| Visual Inspection of Wood Structures | Neal Murray | nmurray@epri.com | 3002027250 |
| Inspection of Transmission Line Foundations | Neal Murray | nmurray@epri.com | 3002027244 |
| Inspection, Maintenance, and Troubleshooting of Sacrificial Anode Cathodic Protection Systems for Transmission Line Structures | Neal Murray | nmurray@epri.com | 3002007677 |
| Visual Inspection of Porcelain and Glass Disc Insulators | Tim Shaw | tshaw@epri.com | 3002027264 |
| Visual Inspection of Avian Issues on Transmission and Distribution Structures | Tim Shaw | tshaw@epri.com | 3002027243 |
| Corrosion Assessment of Weathering Steel Transmission Structures | Neal Murray | nmurray@epri.com | 3002025667 |
| Corona Rings for Polymer Insulators | Tim Shaw | tshaw@epri.com | 3002027259 |
| Tier 1, Above and Below Grade Corrosion Assessment of Weathering Steel Transmission Structures | Neal Murray | nmurray@epri.com | 1023499 |
| Inspection of Transmission Line Grounding Systems | Tim Shaw | tshaw@epri.com | 3002027254 |
| Inspection of Conductors for Overhead Transmission Lines | Gary Sibilant | gsibilant@epri.com | 3002027267 |
| Construction and Inspection of Compression Connectors for Overhead Transmission Lines | Gary Sibilant | gsibilant@epri.com | 3002027252 |
| Infrared Thermography for Overhead Transmission Lines, Overhead Distribution Lines, and Substations | Gary Sibilant | gsibilant@epri.com | 3002027253 |
| Daytime Discharge Inspection of Transmission and Distribution Overhead Lines and Substations Guide with Video Product | Tim Shaw | tshaw@epri.com | 3002027269 |
| Transmission Line Aerial Marking & Lightning | Pierre Marais | jmarais@epri.com | 3002027256 |
| Live Working Rope | Gary Sibilant | gsibilant@epri.com | 3002027271 |
| PROGRAM 37 | | | |
| Lubrication of High-Voltage Circuit Breakers (HVCBs) | Bhavin Desai | bdesai@epri.com | 3002025468 |
| Compressors for High-Voltage Circuit Breakers | Bhavin Desai | bdesai@epri.com | 3002010228 |
| Did That Transformer Really Fail? | Bhavin Desai | bdesai@epri.com | 1024553 |
| Smart Ground Meter | Erika Willis | ewillis@epri.com | 1024555 |
| Field Guide for Switching Personnel: EPRI Switching Safety and Reliability | Robert Haromszeki | rharomszeki@epri.com | 3002023250 |
| Substations Physical Security | Erika Willis | ewillis@epri.com | 3002015698 |



Access to the mobile field guide app can be found by scanning the QR codes.



| Title | Project Manager | | Deliverable # |
|--|------------------|--------------------|---------------|
| PROGRAM 34 | | | |
| Circuit Breaker Maintenance and Replacement Ranking Software – version 10.0 | Arshpal Gill | agill@epri.com | 3002026882 |
| Power Transformer Expert System Software v9.0 | Tim Raymond | traymond@epri.com | 3002026877 |
| PROGRAM 35 | | | |
| Foundation Analysis & Design (FAD) v. 5.1.19 | Pierre Marais | jmarais@epri.com | 3002005097 |
| Insulator Calculation Engine (ICE) v. 10.0 | Tim Shaw | tshaw@epri.com | 3002027343 |
| Transmission Ratings Workstation | Justin Bell | jbell@epri.com | 3002027088 |
| Minimum Approach Distance Calculator (MAD Calculator) | Gary Sibilant | gsibilant@epri.com | 3002027023 |
| Overhead Transmission Inspection and Sensing Technology Database (OTIS) | Tim Shaw | tshaw@epri.com | 3002026923 |
| High-Temperature Conductor (HTC) Matrix v. 13.0 | Rachel Moore | ramoore@epri.com | 3002027104 |
| Aging Chamber Report Tool (ACRT) v. 15.0 | Tim Shaw | tshaw@epri.com | 3002024440 |
| Transmission Line Workstation – Gen 2 (TLW-Gen2) v. 11.0: HVDC Electrical Effects | Gary Sibilant | gsibilant@epri.com | 3002027149 |
| Transmission Line Workstation – Gen 2 (TLW-Gen2) v. 11.0: Design Module (incl. Electrical Effects, LCC & Vibration calculations) | Pierre Marais | jmarais@epri.com | 3002026991 |
| Transmission Line Workstation – Gen2 (TLW-Gen2) v. 11.0: Lightning & Grounding | Camille le Mauff | clemauff@epri.com | 3002026979 |
| Polymer Insulator Population Assessment Tool (PIPA) v. 12.0 | Tim Shaw | tshaw@epri.com | 3002027042 |
| Cascading Failure Risk Assessment Tool v. 3.1 | Pierre Marais | jmarais@epri.com | 3002021504 |
| Increased Power Flow Wizard (IPFWiz) v. 2.2 | Justin Bell | jbell@epri.com | 1021704 |
| AC to DC Line Conversion - DC Convert Software | Ram Adapa | radapa@epri.com | 1020651 |
| PROGRAM 36 | | | |
| Underground Transmission Workstation (UTW) v. 7.9 | Tom Zhao | tzhao@epri.com | 3002027199 |
| Underground Transmission Workstation – DC Ampacity (UTW-DC) v. 4.0 | Tom Zhao | tzhao@epri.com | 3002027233 |
| PROGRAM 37 | | | |
| AC vs DC Wizard 2.0 – Software for Comparing AC and DC Options | Ram Adapa | radapa@epri.com | 3002000854 |
| Circuit Breaker Lubrication Selection (CBLS) v. 5.0 | Arshpal Gill | agill@epri.com | 3002015675 |
| Electronic Information Tool for Transmission Line and Substation Sensor Systems (SCMID) v 6.0 | Erika Willis | ewillis@epri.com | 3002019682 |
| PROGRAM 51 | | | |
| Mineral Oil Spill Estimation Software - Multiphase (MOSES-MP) v5.0 Beta | Lea Millet | lmillet@epri.com | 3002027599 |
| PROGRAM 60 | | | |
| EMFast v1.5.1 | Phung Tran | ptran@epri.com | 3002022505 |
| Electric and Magnetic Fields Occupational Exposure Database (EMF-OED) v1.0 | Phung Tran | ptran@epri.com | 3002024850 |



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