

# Transmission & Substations

## Area Review

January 2021

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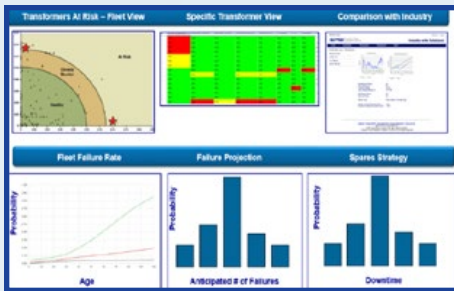
## Introduction

EPRI's Transmission and Substations (T&S) area aims to address the challenges facing transmission asset owners and operators. The area is focused on transmission (overhead and underground) and substation assets, their life cycle, and industry issues. Research is aimed at improving practices and tools used to manage the entire asset life cycle (i.e.: acquire, maintain, operate, and dispose) of transmission and substation assets.

This area review is intended to help members stay informed of our research activities. It quickly reviews the research highlights from 2020, identifies valuable key deliverables and results, and shares information on upcoming work as well.

## What Transmission & Substations Area Does

Performs Research and development to support members with the technical basis and tools for managing their transmission assets to ensure that they can provide Safe, Reliable, Affordable and Environmentally Responsible Electricity to society. The Transmission & Substations Area is comprised of four research programs each with multiple projects, tasks, and technology transfer activities.



### Program 34

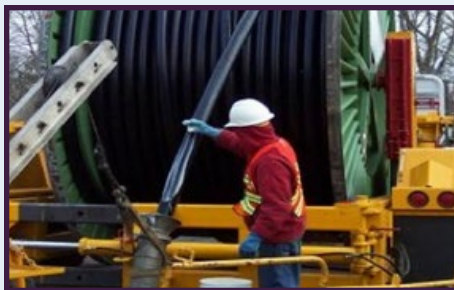
#### **Asset Management Analytics**

Focuses on developing asset knowledge enablers, such as failure rates and asset health assessment algorithms, to help make better asset life cycle management decisions.

### Program 35

#### **Overhead Transmission**

Focuses on tools, techniques, and methodologies for line components and issues related to lightning, live working, and transmission capacity.



### Program 36

#### **Underground Transmission**

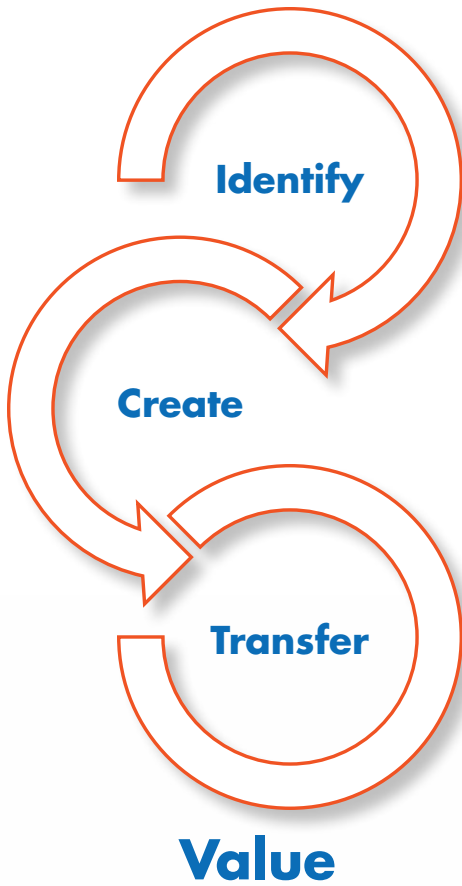
Focuses on new technologies, tools, guides, and practices for design, construction, operation, inspection, and maintenance of safe, cost-effective, and reliable underground transmission systems.

### Program 37

#### **Substations**

Focuses on tools, techniques, and methodologies that help improve maintenance specifications and inspections and assessments.





## How We Do It

- We leverage the shared experience of our utility members, industry engagement, and the expertise of EPRI's Transmission & Substations Team to **Identify** existing research gaps and associated project needs.
- We develop a portfolio of research projects that **Create** independent, fact-based results and effective tools to provide members decision support in managing transmission systems.
- We **Transfer** the research value to members through advisor and task force interactions, topical workshops, user groups, software applications and direct member support.

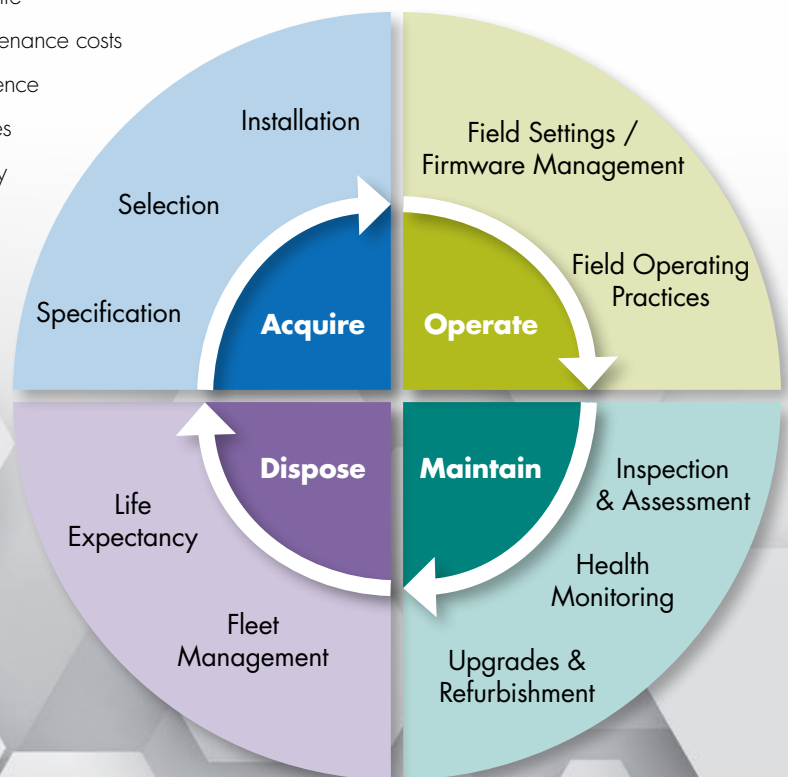
## Approach

- Utilize a portfolio-based approach to develop **short-, medium- and long-term deliverables** which address each asset type or industry issue
- Utilize a collaborative model to **leverage** investment, **identify** issues, **guide** ongoing research and **implement** results
- Utilize a **well defined** member-driven **roadmap** which includes mission, drivers, future states, and gaps. The **action plans** to bridge these gaps are well defined documents listing tasks and the timeline. Action plans are viewed and revised regularly by EPRI member task forces together with EPRI technical leaders
- Utilize continual engagement with members to ensure that the R&D we perform is of **high value, easy to implement and likely to succeed**

## Research Value

The results from Transmission and Substations area should help asset owners:

- Extend asset life
- Reduce maintenance costs
- Improve resilience
- Reduce failures
- Improve safety





## How We Transfer and Apply Research Results



### Equipment Testing

Third-party testing is important when making specification and selection decisions. T&S uses specialized testing to give an objective assessment of equipment performance before it goes into the field.



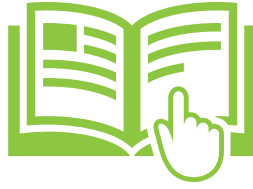
### Laboratory Testing

EPRI's laboratories play an important role in the research. Many projects have multiple experiments and demonstrations in the labs in Charlotte, Knoxville, and Lenox.



### Workshops & Training

Face-to-face meetings and training with EPRI and industry provide opportunities to discuss research results and industry issues.



### Technical Reports

Each year's research is fully documented in technical reports. These reports contain background and technical information on the research projects.



### Forensic Analysis

Understanding equipment failure can be a great way to learn about assets. The EPRI team is equipped to analyze failures to determine the root cause and possible actions for other in-service assets.



### Videos

Throughout the year, project managers provide video updates to keep members informed in a few minutes per video.



### Engineering Software

Each year software tools are updated and developed.



### Subject Matter Expertise

The experts at EPRI are just a phone call or an email away.



### Reference Material

Color books and field guides act as a comprehensive reference for technical T&S questions.



### Webcasts

Each project hosts multiple webcasts throughout the year. These events give updates on existing research, future outlook, and information-sharing opportunities.



**Fabio Bologna** Director, Transmission & Substations  
email: [fbologna@epri.com](mailto:fbologna@epri.com)

## 2020 Asset Focused R&D Initiatives

Research results provide “Knowledge Enablers” & “Tools” to help transmission companies make informed asset management, risk assessment and strategic planning decisions.

Project Name & Manager	2020 Accomplishments	2021 Plan
<b>Asset Management Analytics</b> Bhavin Desai <a href="mailto:bdesai@epri.com">bdesai@epri.com</a>	<ul style="list-style-type: none"> <li>Developed advanced asset performance metrics for circuit breakers, wood poles, conductors, shield wire and underground cables.</li> <li>Expanded integration of EPRI analytics in third party platforms to include circuit breakers.</li> <li>Initiated application of machine learning and natural language processing for understanding capacitor bank and disconnect switch performance.</li> <li>Developed overhead transmission line risk ranking methodology.</li> </ul>	<ul style="list-style-type: none"> <li>Advance asset performance metrics development such as capacitor banks, station and line arresters, ground grid, relays, steel structures, cable joints and terminations etc., apply overhead transmission risk ranking concept at member utilities and utilize artificial intelligence to further advance asset performance analytics.</li> <li>Continue to provide specific guidance to members on what data they should collect (minimize subjectivity) and expand integration of EPRI analytics in third party platform.</li> </ul>
<b>Advanced Sensor Evaluation &amp; Development</b> Luke van der Zel <a href="mailto:lvanderz@epri.com">lvanderz@epri.com</a>	<ul style="list-style-type: none"> <li>Over 30 on-line monitors have been deployed in EPRI laboratories for evaluation against well defined test protocols.</li> <li>EPRI has continued development of a full RF Monitor suite for Overhead, Substations and Underground, with multiple utility pilots deployed in utility sites in 2020.</li> </ul>	<ul style="list-style-type: none"> <li>In 2021 EPRI is expanding its 138kV research substation and adding monitors for other assets such as Circuit Breakers and arresters.</li> <li>EPRI also continues to expand deployment of RF monitors in utility pilots and R&amp;D in 2021 continues on enhanced algorithms for turning data into action – especially in the area of partial discharge detection.</li> </ul>
<b>Application of Artificial Intelligence</b> Bhavin Desai <a href="mailto:bdesai@epri.com">bdesai@epri.com</a> Dexter Lewis <a href="mailto:dlewis@epri.com">dlewis@epri.com</a>	<ul style="list-style-type: none"> <li>Utilized artificial intelligence and machine learning (AI/ML) to analyze T&amp;D asset inspection images (helicopter or unmanned aerial surveillance) for better understanding underlying defects and their severity.</li> <li>Developed taxonomy that can guide how T&amp;D component images can be labeled for use in training AI/ML models.</li> <li>Developed library of curated and well labeled transmission and distribution component images that included healthy as well as defective components.</li> <li>Experimented with alternative image generation techniques.</li> <li>Evaluated the efficacy of AI/ML techniques.</li> </ul>	<ul style="list-style-type: none"> <li>Continue to enhance taxonomy and grow image library, experiment with different labeling techniques, and expand AI/ML technique evaluation.</li> <li>Utilizing AI/ML for T&amp;D asset performance (maintenance and outage data) assessment.</li> <li>Develop guidelines to apply machine learning for transformer asset management.</li> <li>Investigate how AI/ML can be used for analyzing nontraditional data sets such as voltage and current waveforms, breaker timing, SCADA alarms etc. to gain additional visibility into asset performance.</li> </ul>
<b>Unmanned Aircraft Systems (UAS)</b> Dexter Lewis <a href="mailto:dlewis@epri.com">dlewis@epri.com</a>	<ul style="list-style-type: none"> <li>Demonstrated and tested a drone-in-a-box solution for automated substation inspection</li> <li>Completed an industry review and published a whitepaper on UAS fuel options that may support longer UAS flight</li> <li>Launched the UAS Automation Technologies for Transmission Inspection – Phase 2 project</li> </ul>	<ul style="list-style-type: none"> <li>Continue work in UAS automation activities with literature review, lab testing, and field demonstration</li> <li>Expand activities related to artificial intelligence object detection leveraging drone imagery</li> </ul>
<b>NATF Engagement</b> Bhavin Desai <a href="mailto:bdesai@epri.com">bdesai@epri.com</a>	<ul style="list-style-type: none"> <li>Analyzed transformer data and provided non attributable observed failure rates for 27 companies.</li> <li>Wrapped up joint Asset Management Guide development and incorporated two utility implementation examples.</li> <li>Participated and help develop codes for reporting field discoverable substation equipment failures and problems.</li> </ul>	<ul style="list-style-type: none"> <li>Expand industry wide database analysis to include new assets such as circuit breakers.</li> <li>Provide feedback on usefulness of data gathered based on problem codes for asset performance analysis.</li> </ul>
<b>High-Altitude Electromagnetic Pulse (HEMP)</b> Randy Horton <a href="mailto:rhorton@epri.com">rhorton@epri.com</a>	<ul style="list-style-type: none"> <li>Tested EMP conducted and radiated vulnerability of 80+ critical substation electronic devices.</li> <li>Created a highly advanced software tool that has allowed EPRI to perform the most advanced substation EMP coupling analysis available in public space.</li> <li>Testing and modeling efforts enabled completion of EMP vulnerability assessments for 17 transmission substations resulting in the beginning of deployment of EMP hardening technologies.</li> </ul>	<ul style="list-style-type: none"> <li>Continue to support deployment of EMP hardening technologies and construction techniques and evaluate reliability and efficacy.</li> <li>Delve into threat assessment of other critical infrastructure industries such as telecommunications, power generation, and power distribution.</li> <li>Expand EMP related services such as: training, consulting, testing and assessment to support specific requirements of utilities and vendors.</li> </ul>
<b>Robotics</b> Erika Willis <a href="mailto:ewillis@epri.com">ewillis@epri.com</a>	<ul style="list-style-type: none"> <li>Laboratory testing and field trials of the substation inspection robot.</li> <li>Started the project for the substations robot.</li> <li>Laboratory evaluation of the climbing ability of the insulator robot.</li> </ul>	<ul style="list-style-type: none"> <li>Demo in Lenox for the substation robot</li> <li>Enhance porcelain capabilities and electrical integration for the insulator robot</li> </ul>

## EPRI|U for Transmission

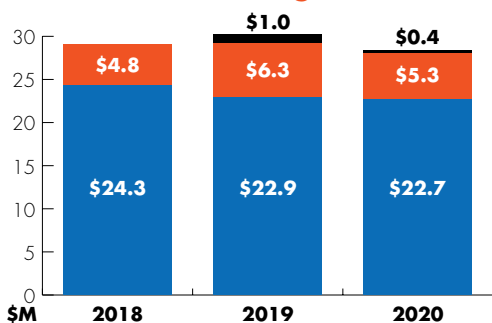
This project launched in 2020 and focuses on the creation, updating, and delivery of high quality training on subjects related to transmission operations, planning, assets, and asset management.

Twenty-three industry organizations collaborated to access and help shape the technically-based training material offered, which by the end of the year included:

- 35 videos
- 7 computer-based training (CBT) modules
- 3 webinar series.

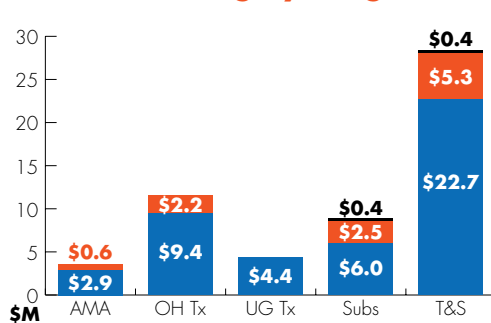
Almost 700 Professional Development Hours (PDH) were earned and are tracked and stored on an individual basis via EPRI's Learning Management System (LMS). New training material is planned for 2021.

### T&S Area Funding - \$28.4 million



- Gov
- Supplemental Projects
- Annual Research Portfolio Projects

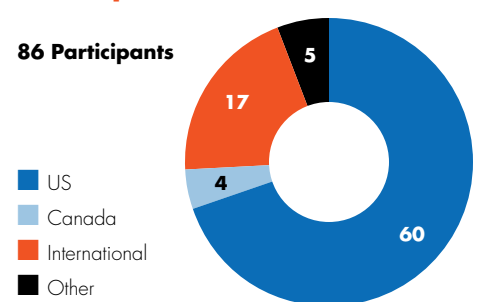
### 2020 Funding by Program



- Gov
- Supplemental Projects
- Annual Research Portfolio Projects

### Participation

86 Participants



- US
- Canada
- International
- Other

### Staff

	#	Added in 2020
Tech	48	4
Admin	3	
Labs	16	2
<b>Total</b>	<b>67</b>	<b>6</b>

Highest Degree	#
PhD	9
Masters	17
Bachelors	36

Numbers do not include lab or admin staff, only technical staff.

### Types of Projects

	ARP	Collab	Demo	Gov	Total
AMA	4	2	0	0	6
OH	16	16	16	0	48
UG	5	1	0	0	6
SUBS	10	13	13	2	38
<b>TOTALS</b>	<b>35</b>	<b>32</b>	<b>29</b>	<b>2</b>	<b>98</b>

### Member Satisfaction Survey

Overall Performance	94.0%
Technical Program Value	92.8%
Ease of Doing Business	90.3%
Overall Satisfaction	92.5%



## Lenox Laboratory

### The Lenox laboratory capabilities includes:

- 5.6 MV outdoor impulse generator
- 230 kV Insulator accelerated aging chamber
- 138 kV Sensor and robotic test facility
- Mechanical test area for poles, insulators, conductors
- Arc flash test area
- Manhole cover explosion test area
- Unmanned Aircraft System (UAS) high voltage test area
- UHV indoor test building
- Composite Structures Testing
- Medium Low Voltage test area
- Stray Voltage sensor test area
- Pole Break test area
- Insulator contamination test area
- 138 kV energized outdoor asset aging test facility
- Mechanical testing of arrestors
- Pole Barn test area
- HVDC yard + or - 700kV
- High Current & Sensor Evolution test area

### New Resources

- Upgrade 138 kV energized outdoor asset aging test facility
- 800 kV impulse generator
- 200 kV hipot tester
- Manhole testing facility upgrade.

### 2020 Accomplishments

138 kV energized outdoor asset aging test facility that provides infrastructure for evaluating novel sensors, monitors, inspection techniques and new technologies such as polymer bushing application at high voltages.

### 2021 Plan

Continue 138 kV energized outdoor asset aging test facility development, initiate development of lab resources for evaluating and demonstrating substation inspection robot and transformer robot.

## Charlotte Laboratory

### The Charlotte laboratory capabilities includes:

- Thermo-mechanical test rig for conductors and accessories
- Sensor suite Development & test area
- Thermal-Mechanical Bending Rig (TMB Rig) for XLPE cables
- Thermal-Mechanical chamber for insulator testing
- 2x 120 kV high voltage test cages
- Lab developed outdoor test transformer
- 110 kV (7.5 MVA) transformer
- Corrosion Lab
- Wind tunnel for conductor and insulator coating tests
- EMP test area
- Relay laboratory for assessing technologies and training
- 230 kV insulator salt fog chamber
- Conductor vibration facility
- GIS and dead tank circuit breaker
- Distribution grid modernization asset lab

### New Resources

- 45 kVA 3 phase supply for advanced sensor testing

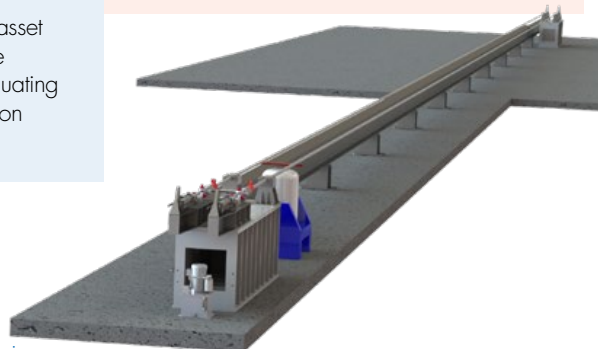


### 2020 Accomplishments

- Startup of conductor vibration facility
- Startup of 230 kV insulator salt fog chamber
- Distribution grid modernization asset lab

### 2021 Plan

- Bushing tests in new GIS test cage



## Knoxville Laboratory

### The Knoxville laboratory capabilities includes:

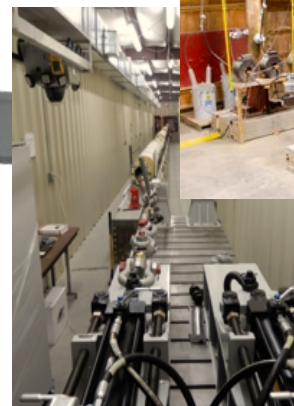
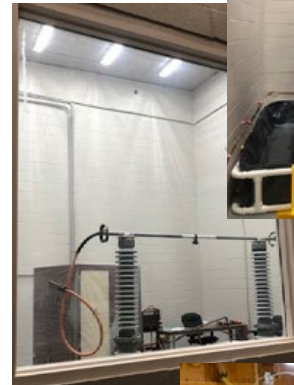
- Direct EMP voltage surge injection testing (up to 300 kV)
- Direct EMP current surge injection testing per MIL-STD-188-125-1 (up to 1000A)
- Shielding effectiveness testing (MIL-STD-188-125-1)

### 2020 Accomplishments

- Direct injection testing (voltage and current) of digital protective relays, merging units, battery chargers, and control cables

### 2021 Plan

- Continued direct EMP injection testing.



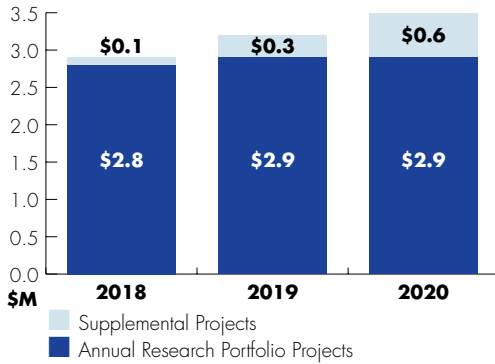




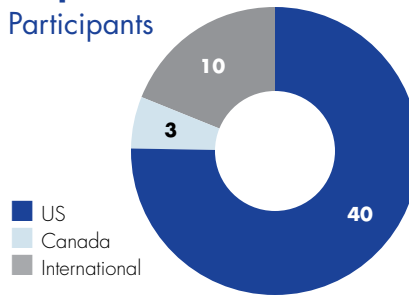


## 2020 Accomplishments & Look Ahead to 2021

### Funding - \$3.5 million



### Participation 53 Participants



**Bhavin Desai**  
Asset Management Program Manager  
[bdesai@epri.com](mailto:bdesai@epri.com)

### Project Number, Name & Manager

### 2020 Accomplishments

### 2021 Plan

P34.001  
**Transmission Asset Management Analytics: Principles and Practices**  
Bhavin Desai, [bdesai@epri.com](mailto:bdesai@epri.com)

Finalized asset management guidebook, incorporated implementation use cases with two member utilities. Delivered asset analytics workshop through series of nine webcasts. Continued development of asset performance metrics.

Continue development of asset performance metrics. Increase emphasis on predictive analytics during asset analytics workshop. Continue to deliver one webcast per month on a technical topic.

P34.002  
**Substation Asset Analytics**  
Bhavin Desai, [bdesai@epri.com](mailto:bdesai@epri.com)

Applied Natural Language Processing to analyze capacitor bank and disconnect switch maintenance and outage records to uncover the most common problems with specific make, model, manufacturer etc. Active development of algorithms for CCVT's, disconnect switches and arresters. Added new algorithms and functionality in Power Transformer Expert System software.

Continue to work with NATF to expand participation in T&S industry-wide database. Enhance substation asset health software. Initiate methodologies to assess substation and bay risk. Investigate AI applications for transformers and nontraditional datasets such as voltage, current, breaker timing, cable alarms etc. Advanced analytics for asset performance and health assessment.

P34.003  
**Overhead Transmission Asset Data Analytics**  
Bhavin Desai, [bdesai@epri.com](mailto:bdesai@epri.com)

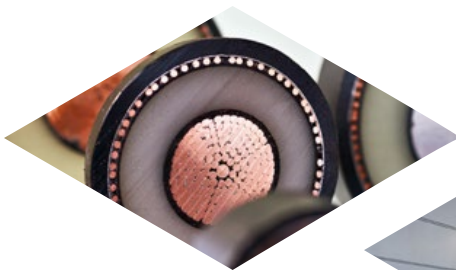
Increased industry-wide database failure data for: conductors, shield wires, line arresters and insulators. Analyzed conductor shield wire data from two utilities and wood pole inspection data from seven utilities to develop performance insights to improve inspection and removal decisions. Developed transmission line ranking index methodology.

Enhancement and application of Transmission Line Ranking Index. Developing wood pole performance metrics and conduct steel structure inspection data analytics. Investigate AI applications for analyzing big data sets to better understand overhead transmission system asset performance.

P34.004  
**Underground Transmission Asset Data Analytics**  
David Kummer, [dkummer@epri.com](mailto:dkummer@epri.com)

Developed methodology to analyze SCADA alarm data to better understand underground transmission system component performance such as cable leak rates, gauge failure rates, circuit performance as a function of alarm type, frequency and location etc.

Active development of underground transmission asset analytics framework. Continue advanced analytics on utility provided data for underground systems. Continue to expand and update asset registry.



## 2020 Deliverables

### Key Deliverables

#### Transmission Asset Management Analytics: Principles and Practices

##### 3002018816

Asset Management Analytics & Asset Health Systems: Webcast Series

##### 3002018819

Power Delivery Asset Management Guidelines – 2021 Update

Provides utilities with guidelines to implement formal asset management processes.

#### Substations Asset Analytics

##### 3002018841

Industrywide Transformer Failure and Performance Database: Data Models, Definitions and Analysis Results

##### 3002018844

Industrywide Circuit Breaker Failure and Performance Database: Data Models, Definitions and Analysis Results

##### 3002019249

Balance of Substation Asset Management Analytics: CCVT's, Disconnect Switches and other substation assets

##### 3002019250

Protection and Control Asset Management Analytics

##### 3002019253

Analytics for Substation and Bay Risk Assessment: Concept Development

##### 3002019254

Analytics Assessment and Comparisons

##### 3002019256

Power Transformer Expert Systems Software Version 7.0

Includes new algorithms for different tap changer models and processing DGA from online monitors. Also includes improved algorithms for main tank, bushing, oil health, analyzing online DGA monitor data and built-in functionality for easy integration with third party systems.

##### 3002019258

EPRI Circuit Breaker Maintenance And Replacement Ranking Software (CBMRR) Version 7.0

#### Overhead Transmission Asset Data Analytics

##### 3002018848

Overhead Transmission Conductor Fleet Management

##### 3002018850

Overhead Transmission Wood Pole Fleet Management

Provides results of investigating different wood species (e.g., reject rates by treatment types). Provides technical basis for capital budgets and prioritizing inspections.

##### 3002018851

Overhead Transmission Steel Structure Fleet Management: Evaluation of Inspection Data

##### 3002018853

Overhead Transmission Lines Ranking Index Development

#### Underground Transmission Asset Data Analytics

##### 3002018855

Underground Transmission System Asset Analytics - 2020 Update

Describes method to analyze SCADA alarm data to better understand underground transmission system component performance such as cable leak rates, gauge failure rates, circuit performance as a function of alarm type, frequency and location etc.





## Examples of Member Application of Results

### Value Obtained

#### American Transmission Company (ATC)

##### Power Transformer and Circuit Breaker Performance Metrics

**Power Transformers:** EPRI developed failure rates for 138 kV/69 kV and 345 kV/138 kV transformer groups using industry-wide and ATC's data and applied them to develop a replacement forecast. EPRI analyzed ATC's transformer fleet historical test data using PTX.

**Circuit Breakers:** EPRI analyzed "gas fill" data provided by ATC to determine if certain breaker types are more prone to higher leak rates.

**Transformers:** PTX condition indices, failure rates derived from EPRI's Industry-wide Database and replacement forecasts assist ATC's transformer asset management program reviews and performance comparisons against industry benchmarks.

**Circuit breakers:** "Gas fill" analysis results support future asset decision making.



#### National Grid UK

##### Alarm Data Analysis Informs Underground Transmission Asset Management

Applied data science techniques to analyze underground transmission system data (alarms, demographic information, work orders, GIS locations), produce a map where alarms are displayed (type, duration, location) and then applied the map to help better understand oil leak rates, gauge failure rates etc.

Results help understand how alarming events are related to the physical asset. Metrics can be incorporated in NG UK's underground transmission risk model. Once this analysis is fully implemented, it could help National Grid UK with replacement and maintenance discussions with their regulator.



#### Salt River Project

##### Circuit Breaker Replacement Ranking

Applied EPRI Circuit Breaker Ranking method to prioritize SF<sub>6</sub> breakers (69 kV and higher) to identify replacement candidates.

Results were used to identify problematic breaker models, develop replacement strategies, control costs and maintain reliability.

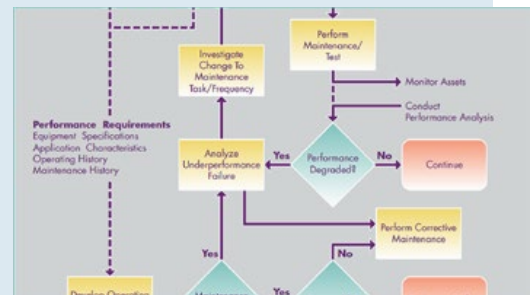


#### Consolidated Edison

##### Applying EPRI's Asset Management Guidelines

Developed transmission substation asset management program based on EPRI's Asset Management Guideline.

Resulting implementation based on EPRI guidelines have enabled a systematic, consistent and repeatable process that drives common understanding and links company's metrics and asset performance.



## Supplementals

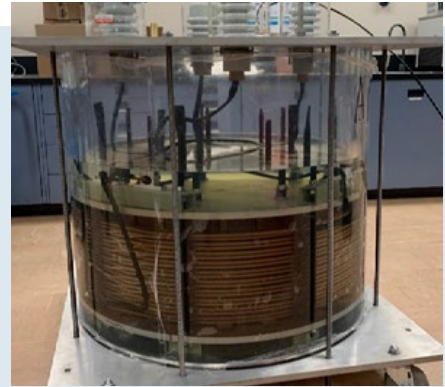
### Status

#### Power Transformer Through Fault Risk Assessment

Tim Raymond, [traymond@epri.com](mailto:traymond@epri.com)

Using fault magnitude, duration, frequency, transformer design, application etc. to develop rules to assess transformers' susceptibility to through faults. Also working to validate the rules and implement them in PTX.

Research to date has resulted in development of a theoretical through fault susceptibility assessment model. Laboratory tests are underway to assess model adequacy.



#### Substation Equipment Spares Strategy Evaluation Model Development

Sean Jiang, [sjiang@epri.com](mailto:sjiang@epri.com)

Develop analytics that may help utilities in better understanding the benefit of having one or more spares on hand. Ongoing focus is on transformers.

Research to date has developed and applied a prototype at eight utilities. New algorithms and reporting features are being added. Extending the approach to include other assets such as CCVT's, circuit breakers and bushings.



#### Advanced Analytics for Overhead (OH) and Underground (UG) Systems

Bhavin Desai, [bdesai@epri.com](mailto:bdesai@epri.com)

Using advanced analytics such as Natural Language Processing or Machine Learning to analyze large data sets to yield insights for improving inspection, assessment and removal decisions.

This utility-specific project intends to help members with detailed analysis of their company's data. Wood pole, steel structure, conductor and shield wire data from two utilities has been analyzed.

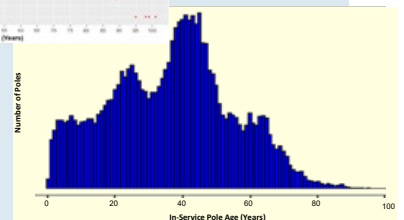
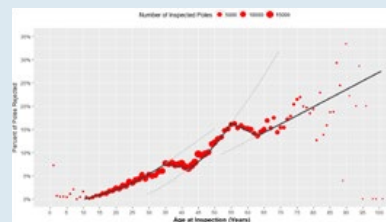


#### Applying Transmission Asset Management Analytics – Tools And Methods

Bhavin Desai, [bdesai@epri.com](mailto:bdesai@epri.com)

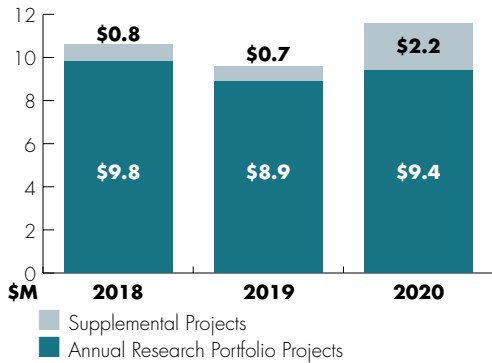
Applying software tools and analytical techniques developed as part of annual research projects with the goal of getting members more acquainted.

Research is helping members apply deliverables such as PTX, breaker ranking etc. As new tools and methodologies are developed, this project intends to help members with application and technology transfer.

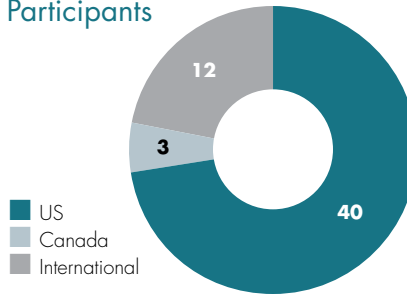


## 2020 Accomplishments & Look Ahead to 2021

### Funding - \$11.6 million



### Participation 55 Participants



**Gary Sibilant**  
Overhead Transmission Program Manager  
gsibilant@epri.com

### Project Number, Name & Manager

### 2020 Accomplishments

### 2021 Plan

P35.001  
**Inspection and Assessment**  
Tim Shaw, tshaw@epri.com

A new chapter on the use of drones for transmission line inspection was added to the Inspection and Assessment Guidebook. Three new field guides (Corona Rings, Infrared Inspection and Foundation Inspection) have been added to the field guide mobile app.

The Inspection and Assessment Guidebook is going online. A new training module in OTLOT on using drones for inspection is in development. A series on inspection and assessment virtual training classes is planned.

P35.002  
**Conductor, Shield Wire and Hardware Corrosion Management**  
Neal Murray, nmurray@epri.com

The geometry factor for 17 conductor types have been completed for service life modeling using the atmospheric corrosivity maps. Conductor movement has been identified as the cause of the most severe type of conductor corrosion.

Correlate vibration sensor data and weather data to categorize severity levels of fretting corrosion and development of field repair methods. Develop an understanding of the corrosion initiation mechanism in AAAC and Alumoweld conductors.

P35.003  
**Structure and Sub-Grade Corrosion Management**  
Neal Murray, nmurray@epri.com

Reference guides have been published on Wood Pole Management and Concrete Management. The resolution of the soil corrosivity maps have been increased and metrics have been developed for stray and circulating current corrosion.

Field validation and refinement of stray current corrosion metrics and an evaluation of the effects of AC circulating currents coupled with DC stray currents. Evaluation of engineered backfills will be added to the concrete management reference guide.

P35.004  
**Compression Connector Management**  
Gary Sibilant, gsibilant@epri.com

Continued the evaluation of aged samples provided by member utilities. Finished accelerated aging of single-stage and two-stage compression connectors. Developed guidance on specifying third-party x-ray services and establishing a population assessment and maintenance program.

Perform post-accelerated aging mechanical tests on single-stage and two-stage compression connectors. Develop field guide for x-ray inspection. Research common unmanned vehicle connector inspection methods. Continue evaluations of aged samples provided by member utilities.

P35.005  
**Composite Structure Management**  
Martin Hughes, mhughes@epri.com

Increased knowledge of composite material mechanical performance when operating under temperature extremes, and after exposure to wildfire conditions. Tested lightning and switching impulse flashover distances for typical 230 kV composite structures.

Performance evaluation of composite structure attachment hardware. Development of composite structures application guide. Increase knowledge of HV impulse performance, and effect of puncture testing on wet pole composite material.

P35.006  
**Lightning Performance of Grounding of Transmission Lines**  
Camille Le Mauff, clemauff@epri.com

Tested surge arrester leads mechanically and proposed a solution to improve service life. Updated TLW-Gen2 to calculate the circulating current and Joule losses in shield wires. Updated the Lightning and Grounding reference guide and applets.

Benchmark the Rizk attraction model for tall structures with lightning location data. Develop a grounding measurement training video. Update the Lightning and Grounding reference guide.

P35.007  
**Line Design Tools and Practices for Construction and Maintenance**  
Pierre Marais, jmarais@epri.com

The first version of Op10 was released, which determines optimal line tension. New software completed includes the first release of stand alone Red Book applications. A new Guide for the Application and Selection of Aerial Warning Devices was produced, which included results from wind tunnel tests.

A major revision of Chapter 5 (Switching surges) of the Red Book Guide is planned. The new guide for the Optimal Selection of Pole foundations will be updated. New material is also planned for the Guide for Coordination of Overhead Line Designs for Construction and Maintenance.

P35.008  
**Line Hardening and Emerging Designs**  
Pierre Marais, jmarais@epri.com

A new initiative was launched to research Dynamic Impact Loading, which will culminate in the development of software to automatically calculate this design input. A joint workshop was held to explore lessons learnt from emergency restoration on transmission lines.

The first tests on the Dynamic Impact test line will be conducted in the newly built test facility in Lenox, MA. New material will be added to both the Guide for Emergency Restoration, as well as the Guide on Practical Overhead Line Hardening Techniques.





**Project** Number,  
Name & Manager

**2020 Accomplishments**

**2021 Plan**

P35.010  
**Live Working:  
Research, Techniques,  
and Procedures**  
Gary Sibilant, [gsibilant@epri.com](mailto:gsibilant@epri.com)

Completed the application guide for Live Working on Non-Ceramic Insulators. Updated the Live Working reference book (sections 6, 8 and 11). Updated the MAD software to include IEEE and IEC calculations. Compiled an initial report detailing 60 Hz insulating tool flashover events.

Start tests to investigate the 60 Hz insulating tool flashover events. Migrate MAD software graphics engine to increase software functionality. Begin research into the use of Temporary Protective Grounds (TPG).

P35.011  
**Polymer and  
Composite Overhead  
Transmission Insulators**  
Tim Shaw, [tshaw@epri.com](mailto:tshaw@epri.com)

Released a new software tool for finding the best location of ADSS cable on a transmission structure. Repaired and restarted several insulator aging tests. Enhanced the E-field modeling software and population assessment software with new features.

Advance development of tests to evaluate insulator resistance to handling related damage. Add three new revised chapters to the Insulator Reference Book. Begin steep front impulse testing of polymer insulators.

P35.012  
**Porcelain/Glass Insulator  
Integrity Assessment**  
Tim Shaw, [tshaw@epri.com](mailto:tshaw@epri.com)

Completed a series of steep front impulse testing on new and aged insulators. Completed a series of salt fog flashover tests on glass insulators coated with RTV silicone. Completed preliminary assessment of insulator performance with non-environmental contaminants.

Summarize the lessons learned from a series of porcelain insulator failure studies. Analyze how a post insulator's design (e.g. diameter) affects its strength and use. Evaluate test results examining insulator strength after cement loss.

P35.013  
**Overhead Line  
Ratings and  
Increased Power Flow**  
Paula Traynor, [ptraynor@epri.com](mailto:ptraynor@epri.com)

Completed use of weather service forecasts for transmission line ratings and updated increased power flow guidebook economics chapter. Field assessment of rating technologies continued.

Phase II field assessment of ratings technologies will be published and Phase III will start. A key report on use of predictive ratings for ambient adjusted ratings will be published and absorptivity testing of conductors will start.

P35.014  
**High Temperature  
Operations of  
Overhead Lines**  
Gary Sibilant, [gsibilant@epri.com](mailto:gsibilant@epri.com)

Added a "Conductor Resistance Calculator" to the HTC Matrix. Completed a report on stress-strain testing of conductors at room and elevated temperatures. A chapter on high temperature switch testing was added to the Guide.

Determine the tensile strength of ACSR conductors and connectors operating at 150° C versus standard room temperature tensile strength. Completion of the high temperature marker ball evaluation. Updating the High Temperature Operation Guide.

P35.015  
**Qualification, Selection  
& Maintenance of  
Advanced Conductors**  
Gary Sibilant, [gsibilant@epri.com](mailto:gsibilant@epri.com)

Completed the second round of comparative ACSS and ACSR vibration tests. Updated the Guide with information on new HTLS conductors and added a chapter on relevant standards. Finalized the report on a carbon core qualification test.

Completion of a report listing all the carbon core conductor qualification tests completed to date. A summary of the vibration tests and the practical impact of self damping is intended to be produced. Further mechanical testing of ACSS at high temperatures.

P35.018  
**Line Switch Management**  
Erika Willis, [ewillis@epri.com](mailto:ewillis@epri.com)

Developed a start for the reference guide for line switch installations. In addition, made significant gains on the process for being able to test quick break whips.

Continue with quick break whip testing by soliciting a laboratory partner to complete testing. Enhance the guide on inspections by focusing on batteries.

P35.019  
**HVDC Lines**  
Gary Sibilant, [gsibilant@epri.com](mailto:gsibilant@epri.com)

Completed testing based on the hardware corona specifications developed, to determine the corona performance of hardware. Updated the live working chapter in the HVDC Line Design Guide with information on live work practices in Brazil.

Evaluation of the performance of a DC voltage detector to be used during line maintenance. Completion of the report on HVDC corona specifications. Update the HVDC Reference Book (Olive Book). Update the HVDC Line Design Guide.

## 2020 Deliverables

### Key Deliverables

#### Inspection and Assessment

**3002018858**

Visual Inspection of Steel Structures

**3002018860**

Construction and Inspection of Compression Connectors for Overhead Transmission Lines

**3002018862**

Visual Inspection of Wood Structure

**3002018863**

Inspection of Transmission Line Foundations

**3002018866**

Inspection of Conductors for Overhead Transmission Lines

**3002018867**

Live Working Rope

**3002018869**

Visual Inspection of Avian Issues on Transmission and Distribution Structures

**3002018870**

Visual Inspection of Porcelain and Glass Disc Insulators

**3002018871**

Overhead Transmission Inspection and Sensing Information Tool (OTIS) Version 2020

**3002018872**

Visual Inspection of Polymer Insulators

**3002018873**

Daytime Discharge Inspection of Transmission and Distribution Overhead Lines and Substations

**3002018874**

Overhead Transmission Inspection, Assessment, and Asset Management Reference Guide - 2020 (Yellow Book)

**3002018876**

Yellow Book Browser Application (YBB) 2020

**3002018877**

Overhead Transmission Line Inspection – Online Training (OTLOT) Version 2020

**3002018878**

Field Guide: Infrared Thermography for Overhead Transmission Lines - Insulators, Compression Connectors, Overhead Ground Wire, Surge Arresters

**3002018879**

Transmission Line Aerial Marking & Lighting

**3002018880**

Evaluation of New and Emerging Technology: State of the Art of Satellite Inspection Technology for Transmission Lines

This report highlights the current capabilities of modern satellites in the context of transmission line inspection practices.

**3002018881**

Utility Inspection and Assessment Practices

#### Conductor, Shield Wire and Hardware Corrosion Management

**3002018882**

Forensic Analysis of Conductors

This report contains guidance for engineers to harvest samples, package the samples and complete a forensic analysis to understand the initiation mechanism leading to a failure.

**3002018885**

C-Corr Performance and Operations Evaluation

**3002018886**

Fleet Management for ACSR & ACSS Conductors: Optimizing Conductor Inspection Program

**3002018887**

Atmospheric Corrosion Sensors Overview: Vision of Use

#### Structure and Sub-Grade Corrosion Management

**3002017907**

Corrosion Monitoring of Transmission Assets

**3002018889**

Coating Selection and Application Guidelines for Transmission Fleet Management

**3002018890**

Fleet Management for Structural Corrosion

**3002018897**

Concrete Management Guidelines: Transmission Line Structures and Foundations

**3002018899**

Guidelines for EPRI Corrosion Test Protocols: Inspection, Assessment, Mitigation and Forensics

**3002020113**

Wood Pole Management Guidebook

This report contains guidance on relevant codes, designs, degradation modes, preservatives, inspection practices and restoration methods.

#### Compression Connector Management

**3002018901**

Guidelines for Compression Connector Inspection: Population Assessment

This deliverable describes compression connector inspection methodologies, best practices and guidance on developing a population assessment program.

**3002018904**

Long Term Thermal Aging of Compression Connectors at 100C: 2020 Update

**3002018907**

Evaluation of Aged Compression Connectors: 2020 Update

**3002018909**

Radiographic Inspection of Compression Connectors: Inspection Specifications

**3002020057**

Remediation Techniques for Degraded Connectors

#### Composite Structure Management

**3002018914**

Effect of Temperature on Strength and Deflection of Composite Pole Materials

**3002018915**

Insulation Coordination of Composite Structures: 230kV H-Frame

**3002018916**

Effects of Fire Damage on Composite Pole Materials  
This report describes the stresses imposed on composite utility structures by exposure to wildfires, and includes small scale test results.

**3002018917**

Inspection and Maintenance of Composite Poles

#### Lightning Performance and Grounding of Transmission Lines

**3002018919**

Overhead Transmission Line Lightning and Grounding Reference Book 2020 (Gray Book)

**3002018920**

Surge Arresters - Mechanical & Aging Testing  
This report describes the aging of transmission line surge arresters subjected to mechanical stresses and proposes a long-lasting solution to replace the weak copper lead.

**3002018921**

Lightning Impulse Strength of Transmission Lines: Impulse Testing of a 230 kV H-Frame

**3002018925**

Impact of Circulating Currents on Corrosion

**3002018927**

Directional Testers for Measuring the Ground Resistance of Transmission Structures

**3002018930**

Transmission Line Workstation Generation 2 (TLW-Gen2): Lightning Performance and Grounding Modules v8.0

**3002020119**

Summary Report for Evaluations of Alternate Grounding Materials

#### Line Design Tools and Practices for Construction and Maintenance

**3002018981**

Optimal Line Tension Calculator (Op10) -v1.0  
This calculator determines optimal installed line tension after considering all areas impacted by this important variable.

**3002018956**

EPRI AC Transmission Line Reference Book: 200 kV and Above, 2020 Edition

**3002018972**

TLW-Gen2: Design Modules

**3002019001**

Guide for Coordination of Overhead Line Designs for Construction and Maintenance

**3002019059**

Guide for the Application and Selection of Aerial Warning Devices

**3002019060**

Optimal Pole Foundation Selection

## 2020 Deliverables *continued...*

### Key Deliverables

#### Line Hardening and Emergency Restoration

##### 3002019063

Practical Determination of Dynamic Load Impact Factors  
This research aims to quantify the actual impact loads experienced at conductor support points across a large range of span configurations.

##### 3002018101

Cascading Failure Risk Assessment Tool (CASE Tool) Version 3.01

##### 3002019061

Practical Overhead Line Hardening Techniques: 2020 Edition

##### 3002019062

Lessons Learnt from Emergency Transmission Line Restoration

#### Live Working: Research, Techniques and Procedures

##### 3002019066

Understanding Insulating Tool Flashovers at Normal AC Voltages (Progress Report)

##### 3002019068

EPRI Live Working Reference Book (Tan Book) – 2020

##### 3002019067

PRE-SW: Minimum Approach Distance Calculator (MAD Calculator), v3.0: Proof of Concept

##### 3002019069

Non-Ceramic Insulator (NCI) Live Working Application Guide

This report provides guidance on the minimum length of healthy (undamaged) NCI required to meet industry safety standards when performing live work on and around energized NCIs.

#### Polymer and Composite Overhead Transmission Insulators

##### 3002019072

Insulator Calculation Engine (ICE) v8.0

##### 3002019073

EPRI Insulator Reference Book: The Violet Book

##### 3002019075

Polymer Insulator Population Assessment (PIPA) v9.0

##### 3002019078

Aging Chamber Report Tool (ACRT) v13.0

##### 3002019079

Summary of lessons learned on Failure Analysis of Polymer Insulators

##### 3002019081

ADSS Application Software

This software tool allows engineers to quickly evaluate the electrical stresses on ADSS cable near transmission wires and optimize its location.

##### 3002019460

Steep Front Testing: How to Assess New Insulators

##### 3002019461

Contamination on Insulators: How it Affects Insulator Performance

#### Porcelain/Glass Insulator Integrity Assessment

##### 3002019082

Steep Front Testing: Useful Tool for Population Assessment

##### 3002019083

Contamination Performance of RTV Coated Insulators  
This report describes the successful initiation of EPRI's salt fog chamber and results of testing RTV coated glass insulators. The results show how RTV coatings compare with bare insulators.

#### Overhead Line Ratings and Increased Power Flow

##### 3002019085

Transmission Rating Workstation (TRW)

##### 3002019086

EPRI Increased Power Flow Guidebook – 2020 (Platinum Book): Increasing Power Flow in Lines, Cables, and Substations

##### 3002019088

Conductor Emissivity and Absorptivity Database: Summary of Testing 2006 – 2020

##### 3002019090

Summary of Recent Increased Transmission Line Utilization Projects: 115 kV and Above

##### 3002019087

Using Weather Service Data For Ratings And Forecasts

This report addresses weather data measurements and modeling and their use in transmission line ratings and forecasts.

#### High Temperature Operation of Overhead Lines

##### 3002019092

High Temperature Conductor Matrix (HTC Matrix) v10.0: Resistance Calculator.

The software was updated with a new calculator which helps the user determine the conductor resistance at various operating temperatures.

##### 3002019093

Guide for Operating Overhead Lines at High Temperatures: Transmission Line Switch Testing

##### 3002019094

High Temperature Effects on Aluminum Conductor Steel Reinforced (ACSR) Obstruction Marking Balls: Testing Update

##### 3002019095

Elevated-Temperature ACSR Drake Stress-Strain Testing: Predicting Sags and Tensions

#### Qualification, Selection & Maintenance of Advanced Conductors

##### 3002019096

Guide for Selection and Application of High-Temperature Conductors

This report provides, information of the relevant HTLS conductor standards, examples of utility applications of HTLS conductors and documents new HTLS conductors available.

##### 3002019097

Carbon Fiber Core Conductor Qualification Testing: Final Test Results

##### 3002019098

Conductor Self Damping Tests: Mallard Type Conductor: ACSR Versus ACSS

##### 3002019099

Effect of High Temperature Operation on HTLS Conductor and Connector Mechanical Strength

#### Line Switch Management

##### 3002019101

Test Procedure for Quick Break Whip Devices: 2020 Update

This report develops the process and techniques to test quick break whips. This research helps to understand and develop a test plan.

##### 3002019102

Practical Maintenance Guide for Installation of a Transmission Line Switch

#### HVDC Lines

##### 3002019107

Transmission Line Workstation Generation 2 (TLW-Gen2): HVDC Electrical Effects Module v7.0

##### 3002019108

HVDC Overhead Line Design Guide: Live Working

This guide was updated with specific information on the live line working techniques used in Brazil.

##### 3002019110

EPRI High Voltage Direct Current (HVDC) Transmission Reference Book (The Olive Book) – 2020 Edition



## Examples of Member Application of Results

### Value Obtained

#### PSE&G

##### Porcelain Insulator Population Assessment

Three flashover events occurred on a 500 kV line that prompted an assessment of the insulator population. EPRI performed a six-step process to evaluate the insulators that included laboratory testing and visual inspection.

EPRI provided PSE&G with a summary report on the test results and population analysis. The analysis identified the probability of an insulator breaking at less than its rated strength. Considering the recent flashovers, the age of the insulators, and the test results, PSE&G is developing a population replacement plan. In addition, EPRI guided PSE&G in the placement of bird deterrents to reduce the bird related issues that were contributing to the flashovers.

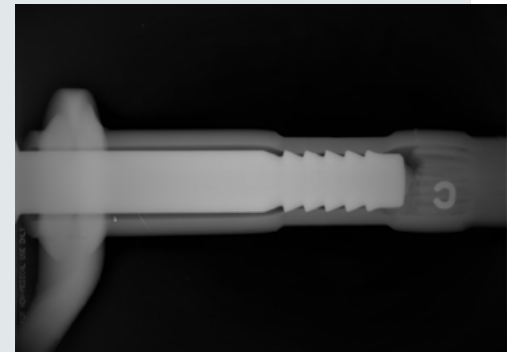


#### LADWP

##### Compression Connector X-ray Inspection Specifications

LADWP required a specification to acquire third-party services to x-ray their overhead compression connectors. They needed technical advice on what to include in their specification.

LADWP and EPRI worked together to develop specific Radiographic Inspections guidelines to be used for third party contractors. The specifications developed may help LADWP improve the inspections, and help line crews and contractors make better assessments of the connectors.

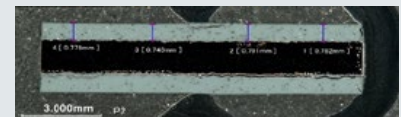


#### Dominion Energy

##### Coating System Evaluation

Dominion required insight into the performance of various candidate coating systems used for structure corrosion prevention and mitigation.

EPRI was able to assist Dominion by performing tests on several candidate coatings. EPRI test results on how they performed could help reduce O&M costs and increased system reliability.

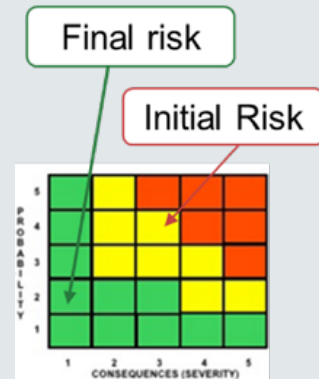


#### Bonneville Power Administration

##### Line Rating Risk Assessment

BPA needed to assess and reduce risks to lines associated with differences in climate type across the system and during different seasons.

Historical climate data was assessed and recommendations were provided that may reduce the risk of exceeding design limits by over 30% without reducing power flow during summer peak demand.



## Supplementals

### Status

#### Testing of Porcelain/Glass Suspension Insulators to Assess an Aging Population

Timothy Shaw, [tshaw@epri.com](mailto:tshaw@epri.com)

This project provides a large, homogeneous sample set to understand the current, in-service conditions of aged insulators, helping to identify degradation modes, and better understand insulator life expectancy.

To date, 100 insulators have been tested and the results show that the population was nearing the end of life. A new project member has come on board with an additional 100 insulators to be tested.



#### Beyond Visual Line of Sight UAS Operations

Dexter Lewis, [dlewis@epri.com](mailto:dlewis@epri.com)

The goal of this project is to answer the questions around how utilities would use UAS if they could operate them beyond visual line of sight (BVLOS).

Transmission operators could benefit by BVLOS UAS operations which regulatory constraints do not allow. EPRI is researching how these operations can be performed safely. The goal is to develop a transmission inspection safety case that can be applied for each utility participant.

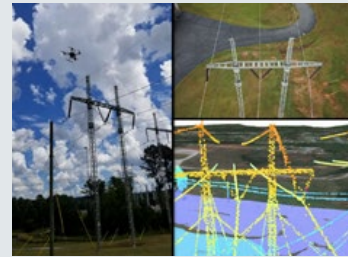


#### Unmanned Aircraft System Automation Technologies for Transmission Inspection: Phase 2

Dexter Lewis, [dlewis@epri.com](mailto:dlewis@epri.com)

This project investigates the feasibility of fully automating a comprehensive transmission line inspection.

Previous EPRI R&D has shown that drone automation can translate to faster transmission inspection. However, there is little to no tolerance for false negatives in an automated inspection solution. This new project will investigate the inspection quality from different automation approaches.



#### HTLS-Conductor Connector Systems

Gary Sibillant, [gsibillant@epri.com](mailto:gsibillant@epri.com)

This project evaluates the long-term conductor and connector system performance of new High Temperature Low Sag (HTLS) conductors through accelerated thermal-mechanical testing.

Testing has been completed on the C7 conductor and connector samples. A draft report has been prepared. Preparation for testing of ACSS conductor and connectors has begun, and samples have been installed in the test frame.



#### Safety by Design

Kevin Berent, [kberent@epri.com](mailto:kberent@epri.com)

This multi-year project seeks to provide documents and tools for implementing Safety by Design concepts on transmission lines and transmission and distribution (T&D) substations. It intends to determine, document, and share technically sound and useful Safety by Design practices.

The first year of the project saw the completion of a Literature Review (3002019604), a Quick Insight paper (3002020183), and numerous projects calls covering a variety of topics. A virtual workshop, additional reports, and continued collaborative project calls are expected in 2021.



Supplementals *continued...*

**Status**

**ACSR Conductor-Connector Systems**

Gary Sibilant, [gsibilant@epri.com](mailto:gsibilant@epri.com)

This project aims to evaluate the high temperature performance of ACSR compression fittings and to determine ways of mitigating the effects of high temperature operation on connectors.

Testing to determine how effective shunt devices are has been postponed to 2021. Testing of new compression connector designs from two manufacturers has been completed along with a draft report.



**Structure and Foundation Corrosion Fleet Management**

Neal Murray, [nmurray@epri.com](mailto:nmurray@epri.com)

The objective of this project is to optimize structure designs, improve construction practices and improve maintenance practices.

Environmental modeling, condition assessments and laboratory analysis of over 100 structures from New York State and Texas have been completed. Initial studies of another 180 locations have been completed – data analysis and soil modeling will commence once the surveys have been completed.



**Weathering Steel Inspection, Assessment, and Mitigation**

Neal Murray, [nmurray@epri.com](mailto:nmurray@epri.com)

Weathering steel structures are designed for minimal maintenance, but when installed in a poor environment, severe corrosion occurs.

Four field surveys have been completed. For each survey, the causes for accelerated corrosion have been identified, methods to qualify the weathering steel conversion to Goethite have been determined and corrosion control methods have been developed.

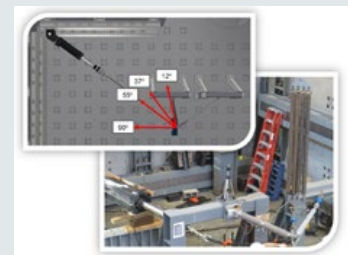


**Understanding Maximum Load Capabilities of Polymer Braced Post Insulators**

Pierre Marais, [jmarais@epri.com](mailto:jmarais@epri.com)

The objective of this project is to determine the load capacity of braced post insulator systems.

All tests have been completed. Beta software to predict post insulator capacity was completed in April 2020. Work on a braced post calculator will commence in 2021.



**Artificial Intelligence for Transmission Images**

Dexter Lewis, [dlewis@epri.com](mailto:dlewis@epri.com)

This project will test several AI models on an existing EPRI AI training and test image set on healthy vs. defective insulators.

This project has recently been initiated. AI may be able to automate the image review task from new or traditional visual inspection approaches, and lower the total cost of transmission inspections.





## Supplementals *continued...*

### Status

#### UAS Compression Connector Inspection Technologies

Gary Sibilant, [gsibilant@epri.com](mailto:gsibilant@epri.com)

This project intends to evaluate UAS connector inspection technologies and compare the inspection results obtained versus traditional methods.

This project was initiated in late 2020. The project plan has been developed and EPRI has been in contact with multiple providers of UAS inspection services.



#### Field Trial of ACCC Carbon-Fiber Core and ACSS Ultra-High Strength Conductors

Gary Sibilant, [gsibilant@epri.com](mailto:gsibilant@epri.com)

The project evaluates the performance of specific HTLS conductors under heavy mechanical and electrical loading.

The conductors have been installed on site. New sensors and base stations have been acquired and are to be installed on the lines in 2021.



#### Corrosion Detection Tool for ACSR Conductors: Field Demonstration

Neal Murray, [nmurray@epri.com](mailto:nmurray@epri.com)

This project aims to develop and evaluate a noncontact, conductor inspection tool.

The corrosion detection tool (C-Corr) has had hardware and software upgrades to provide better data resolution. A field survey was completed in 2020 a second survey is planned for 2021.

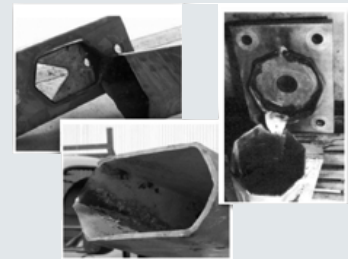


#### Mitigating Vibration on Steel Pole Davit-arms, Phase 1

Pierre Marais, [jmarais@epri.com](mailto:jmarais@epri.com)

Effectively mitigate against resonant vibration in loaded and unloaded arms.

Risk evaluation software was completed in 2020. Preliminary wind tunnel testing is planned for 2021.



#### Advanced Overhead Line Design

Pierre Marais, [jmarais@epri.com](mailto:jmarais@epri.com)

The project objective is to develop a state-of-the-art approach to overhead line design. It seeks to incorporate the most valuable technologies and solutions into overhead lines of tomorrow.

Significant progress on this project was made in 2020, with three chapters completed, including: What is an Advanced Line Design?, Creating and Quantifying Value in Overhead Lines, and Design for Increased Transfer Capacity.



Supplementals *continued...*

## Status

### HVDC Live Working Tests

Gary Sibilant, [gsibilant@epri.com](mailto:gsibilant@epri.com)

This project aims to develop a scientific basis for determining the Minimum Approach Distances (MAD) for HVDC Live Line Work.

Results of two sets of tests have been analyzed. A report containing information of both sets of tests is currently being compiled. Based on the analysis further testing may be undertaken.



### Effects of Cellular Antenna Attachments on Transmission Line Structures

Neal Murray, [nmurray@epri.com](mailto:nmurray@epri.com)

Transmission line structures with cellular attachments represent risk to increased galvanic corrosion and circulating current corrosion. This project quantifies the effects and prescribes corrective actions.

Seven utility surveys have been completed. Findings have shown that the cellular antenna attachments are increasing the corrosion rates on transmission structures. Corrosion control methods have been developed to mitigate the damage.



### Effects of Corrosion on Transmission Line Structures due to Pipelines and Railroads within the Rights of Way

Neal Murray, [nmurray@epri.com](mailto:nmurray@epri.com)

Stray and circulating currents have been known to cause severe corrosion on utility structures. This project provides guidance in how to identify, quantify and mitigate the cause of the corrosion.

GIS based maps have been compiled with T-line circuits, pipelines, railroads and highways to identify locations with stray currents. Metrics have been developed to identify locations, categorize them by severity and assign corrosion control methods.



### Evaluation of High Emissivity Coated Conductors

Gary Sibilant, [gsibilant@epri.com](mailto:gsibilant@epri.com)

This project intends to identify the long-term thermal performance of high-emissivity coated conductors and determine the effect on compression connector performance.

This project was initiated in late 2020. A project plan has been developed and EPRI has been in contact with a manufacturer of high-emissivity coated conductors.



## Supplementals *continued...*

### Status

#### ACSS Conductor Material Properties Evaluation

Gary Sibilant, [gsibilant@epri.com](mailto:gsibilant@epri.com)

The work done in this project aims to determine the material properties of ACSS conductors by performing mechanical, electrical resistance, and chemical measurements, performing mechanical and electrical resistance measurements, and comparing results against manufacturer specifications and ASTM standards.

Mechanical and thermal aging tests have been completed on four conductors. This data has been analyzed and a report has been completed. Additional mechanical strength tests were completed in late 2020 and will be included in the draft report for 2021.



#### Design and Installation of Vibrated Steel Caissons

Pierre Marais, [jmarais@epri.com](mailto:jmarais@epri.com)

The objectives of this project are to achieve greater accuracy and optimization for vibratory pile capacity analysis and to avoid refusal and damage during installation.

Phase 1 of the project has been completed. Significant interest in this project has allowed for an expansion to include full-scale testing in 2021.

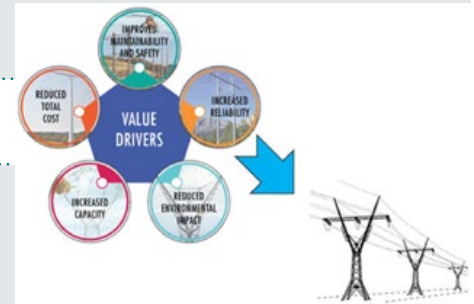


#### Advanced Transmission Structure Concept Design

Pierre Marais, [jmarais@epri.com](mailto:jmarais@epri.com)

The project aims to develop a concept for Advanced Overhead Line Structures based on member requirements, using a collaborative approach and leveraging the latest design techniques and technology.

Project work will start in 2021.

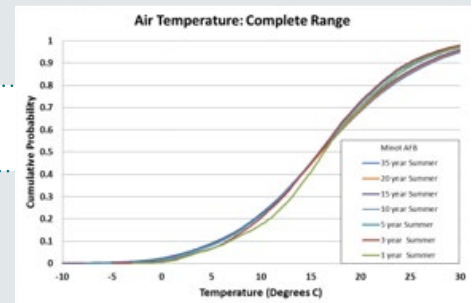


#### Overhead Transmission Ratings: Risk Analysis of Weather Based Ratings

Paula Traynor, [ptraynor@epri.com](mailto:ptraynor@epri.com)

The objective of this project is to provide ratings risk factor of assumptions considering historical data and perform a sensitivity analysis to indicate weather parameter adjustments.

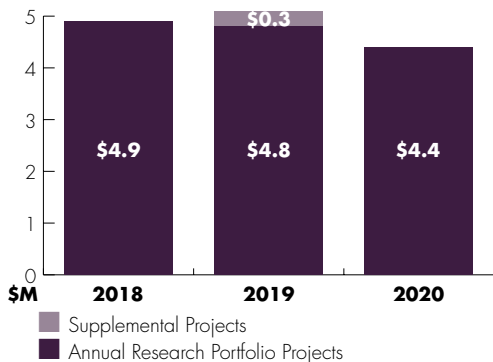
Two analysis projects to improve the transmission ratings using approximately 30 years of weather data are in progress.





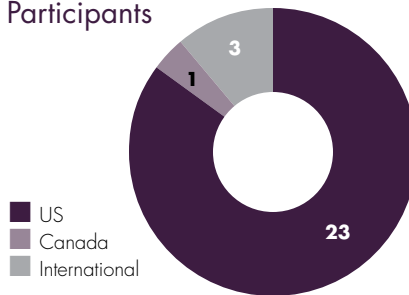
## 2020 Accomplishments & Look Ahead to 2021

### Funding - \$4.4 million



### Participation

27 Participants



**Tom Zhao**

Underground Transmission Program Manager  
tzhao@epri.com

### Project Number, Name & Manager

### 2020 Accomplishments

### 2021 Plan

P36.001  
**Design, Construction, Ratings, and Operation and Maintenance Underground Transmission Systems**  
Tom Zhao, tzhao@epri.com

Completed the primer for underground cable installation in tunnels. Completed investigation on pipe-type to extruded cable conversion, focusing on options using HVDC cables. Developed a concept and completed a prototype on robotic inspection techniques for underground vault inspection. Added a module to UT Workstation for dc cable ampacity calculations. Completed forensic analyses on cables, joints and terminations provided by member utilities.

Continue working on investigations of pipe-type to extruded cable conversion, focusing on verifications of EPRI cable design concepts. Complete analysis of termination after multi-stress aging tests and start new tests using newly-built test rigs in outdoor environments. Complete verifications of EPRI robotic inspection techniques for underground vaults. Enhance the dc cable ampacity module in UT Workstation. Update Construction and Installation Manual.

P36.002  
**Extruded Dielectric Cable Systems**  
Tom Zhao, tzhao@epri.com

Completed thermo-mechanical bending tests (two phases, final phase in 2021) on 230 kV cable with copper corrugated sheath. Reported finite element analyses on three cables. Completed mechanical bending aging tests on cables of copper and aluminum conductors and demonstrated the approach. Completed building a 138 kV test rig with two terminations, a joint, and a cable section for a long-term study at an outdoor station.

Complete thermo-mechanical bending tests (final phase) on the 230 kV cable with copper corrugated sheath and report results. Prepare mechanical parameter tests on a 345 kV laminate sheath cable. Perform mechanical bending aging tests on cables of different designs. Operate the outdoor 138 kV test rig with two terminations, a joint, and a cable section. Perform partial discharge tests on terminations by using acoustic emission sensors.

P36.003  
**Laminar Dielectric Cable Systems**  
Tom Zhao, tzhao@epri.com

Published a report of a multi-year study on paper cable failure root causes. Updated report on buried steel pipe corrosion. Completed development of the guideline report on cable insulation paper and fluid testing. Updated dissolved gas analysis guide by adding more case studies. Updated pipe-type vintage guide.

Continue study on buried steel pipe corrosion. Update guideline documents on cable insulation paper and fluid testing and dissolved gas analysis guide by adding more case studies. Report results on failure root cause studies. Continue updating pipe-type cable vintage guide.

P36.006  
**Principles and Practices for Underground Transmission**  
David Kummer, dkummer@epri.com

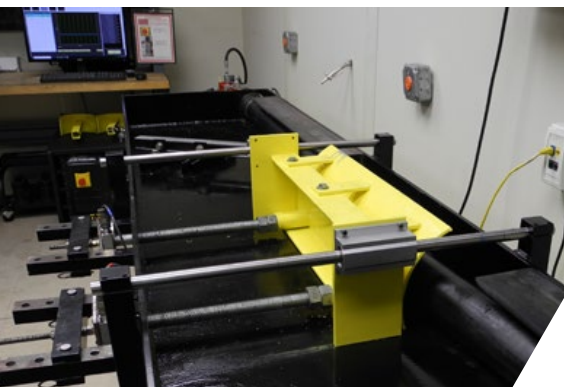
Completed update of all chapters of the Green Book after several years of effort. Published the final report on underground transmission protection. Provided educational sessions in hydraulic station upgrade, sheath bonding systems, and feasibility study guide for HVDC cable applications.

Continue updating Underground Transmission Systems Reference Book and Increased Power Flow Guidebook. Publish the final updated report on life-cycle costing of underground transmission systems. Continue providing educational sessions.

P36.008  
**HVDC Land & Submarine Cable Systems**  
Ram Adapa, radapa@epri.com

Reported results of a multi-year study in fault location techniques for long dc cable. Issued UTW-DC Version 1.0 for HVDC cable rating calculations based on procedures developed in previous year. Updated HVDC Olive Book.

Report results on development of a guide on HVAC and HVDC array and export power cables for offshore wind farms. Enhance HVDC cable rating calculation procedures and UTW-DC software tool. Continue updating HVDC Olive Book.



## 2020 Deliverables

### Key Deliverables

#### Design, Construction, Ratings, and Operation and Maintenance of Underground Transmission System

##### 3002019112

Accelerated Aging Tests of Transmission Cable Terminations with Composite Insulation: 2020 Update

##### 3002019113

Underground Transmission Workstation (UTW) v7.6

##### 3002019116

Retrofitting Pipe-Type Cable Pipes with HVDC Cables

##### 3002019117

Primer for Installation of High-Voltage Cable in Tunnels

This report describes types of tunnels, tunnel construction techniques, installation of transmission-class cables, technical considerations, safety measures and risks, and case studies of noteworthy power cable tunnel installations worldwide.

##### 3002019118

Underground Transmission Vault Inspection Using Robotic Techniques: 2020 Update

##### 3002019119

Industrywide Performance and Failure Database for Underground Transmission Cables and Accessories – 2020 Update

#### Extruded Dielectric Cable Systems

##### 3002019121

Finite Element Analysis for EPRI Thermo-Mechanical Tests of Aluminum Corrugated Copper Corrugated and Lead Sheath Cables

This report provides results of finite element analysis performed on three cables tested or to be tested at the EPRI Charlotte Laboratory.

##### 3002019122

Electrical Insulation Testing of Extruded Cable Sheath Bonding Components: 2020 Update

##### 3002019123

Asset Vintage Guide for Extruded Dielectric Cables, Terminations, and Joints – 2020 Update

##### 3002019124

Guide for the Application of Distributed Fiber Optic Temperature Sensing to Underground Power Cables – 2020 Update

##### 3002019125

Mechanical Bending Aging Tests of Transmission Extruded Dielectric Cables – 2020 Update

#### Laminar Dielectric Cable Systems

##### 3002019126

Mitigation Inspection and Monitoring of Corrosion on Buried Steel Pipes of Pipe-Type Cable Transmission Systems: 2020 Update

##### 3002019127

Test Station Development for Condition Monitoring of Buried Steel Pipes in Pipe-Type Cable Systems: 2020 Update

##### 3002019128

EPRI Guide for Testing Insulating Paper and Fluid of Laminar Dielectric Transmission Cables – 2020 Update

##### 3002019129

Dissolved Gas Analysis Guide for High-Voltage Cables and Transformers: 2020 Update

##### 3002019130

Evaluation and Documentation of Vintage Pipe-type Cable Performance and Experience – 2020 Update

##### 3002019131

Determining Root Causes of Pipe-Type Cable Failures—Impact of Fluid Freezes on Energized High-Pressure Fluid-Filled Pipe-Type Cable Insulation  
This report describes a small-scale test approach and test results for an investigation of dielectric properties of fluid/paper insulation as a function of temperature at various fluid pressure levels.

#### Technology Transfer for Underground Transmission

##### 3002019132

Underground Transmission Workshop Proceedings: Cable Fault Location and Pressurizing Plant Upgrades

##### 3002019133

EPRI Underground Transmission Systems Reference Book (The Green Book) – 2020 Edition

##### 3002019086

Increased Power Flow Guide Book (The Platinum Book) – 2020 Edition

##### 3002019134

Underground Transmission System Protection – 2020 Update

This report describes theories and options for cable system fault protection, including special considerations for hybrid overhead and underground lines.

#### HVDC Land and Submarine Cable Systems

##### 3002019110

EPRI High Voltage Direct Current (HVDC) Transmission Reference Book (The Olive Book): 2020 Edition

##### 3002019135

Underground Transmission Workstation – DC Ampacity (UTW-DC) V1.0

##### 3002019137

Off-Line Fault Location Systems for Long HVDC Cables

This report introduces the concept of time-frequency domain reflectometry as a method for locating cable faults. The cable fault detection algorithm was demonstrated at a submarine cable test site and on a 113-km HVDC submarine cable.





## Examples of Member Application of Results

### Value Obtained

#### Exelon

##### Forensic Analysis of XLPE Cable Joint

Evaluated 115 kV extruded-dielectric cable joint removed from service. Provided recommendations on various aspects from installation to inspection and maintenance.

Better understand cable joint failure mechanisms. Improve service life of transmission cable components by applying improved installation, inspection and maintenance practices.

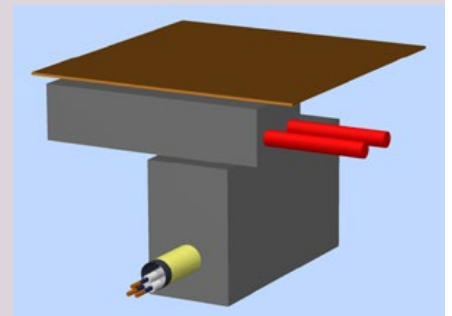


#### Public Service Electric & Gas

##### Rating Calculations of 230kV Underground Line with Distribution Circuits Crossing

Evaluated de-rating effect on a 230 kV pipe-type cable circuit due to underground distribution circuits crossing. Applied EPRI-developed Underground Transmission Workstation software (UTW) with the unique feature for this study. Provided results with various line configurations to guide circuit operations.

Better understand de-rating effects due to circuits crossing. Improve underground transmission system operations by applying evaluation results. Provide recommendations to improve circuit performance.



#### New York Power Authority

##### Options for Reconducting or Replacing Pipe-type Cable Circuit

Evaluate options to provide higher reliability without dielectric liquid in cable circuit. Evaluation takes advantage of EPRI innovations in cable design and installation.

Investigate and demonstrate methods to convert existing high-pressure fluid-filled transmission cable to extruded-dielectric cable. Methods may reduce replacement, operation and maintenance costs, and minimize fluid leaks.



#### Salt River Project

##### Forensic Analysis of XLPE Cable Terminations

Evaluated 69 kV extruded-dielectric cable terminations removed from service. Provided analysis results on failure mechanisms and recommendations.

Better understand failure mechanisms of cable terminations of a specific type. Improve service life of transmission cable components using improved specification, selection, installation, inspection and maintenance practices.





## Supplementals

### Status

#### Condition Assessment of Underground Transmission Laminar Dielectric Cables

Tom Zhao, [tzhao@epri.com](mailto:tzhao@epri.com)

Improve understanding of cable aging mechanisms and end-of-life criteria. Develop a common approach to assess condition of underground transmission laminar dielectric cables. Demonstrate approaches on cable circuits in service.

Complete field circuit inspections at utility sites. Develop operation and maintenance manuals. Complete field aboveground corrosion surveys. Provide results for all phases of investigations.



#### Root Causes of Pipe-Type Cable Failures

Tom Zhao, [tzhao@epri.com](mailto:tzhao@epri.com)

Understand and characterize failure mechanisms of pipe-type cables. Evaluate influence of cable system service and design factors on identified failure modes.

Project covers investigation and documentation of known failure and performance issues, evaluation of cable and joint sections removed from service, and various laboratory tests.



#### Evaluation of Cable Joint from Service

Tom Zhao, [tzhao@epri.com](mailto:tzhao@epri.com)

Validate design and installation. Analyze results in mechanisms of subject failures, based on electric stresses, ac breakdown strength, thermal aging and overheating, and effect of any abnormality in installation.

Dissected joint unit to re-engineering and obtain assembly dimensions. Observed for any workmanship, installation, or material issues. Compared dimension measurements with installation instructions. Performed electric field calculations. Compared calculated electric stress levels with measured values on paper samples. Project is complete.

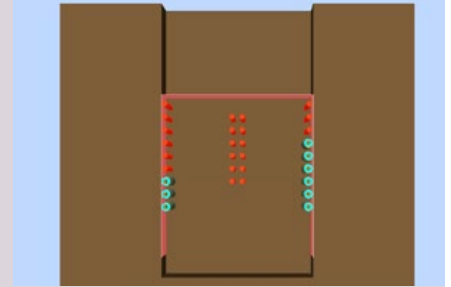


#### Workshop on Magnetic Field Management of Underground Transmission Cable Systems

Tom Zhao, [tzhao@epri.com](mailto:tzhao@epri.com)

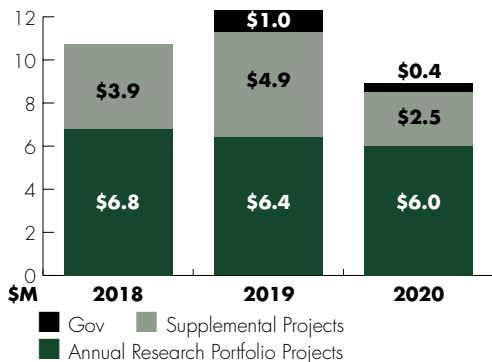
Apply EPRI results in underground transmission magnetic management study to cable system design, operation and maintenance to improve efficiency and reduce costs.

Workshop covers magnetic field shielding mechanisms, advantages and disadvantages of magnetic field management methods, and applications to address specific challenges. Project is complete.



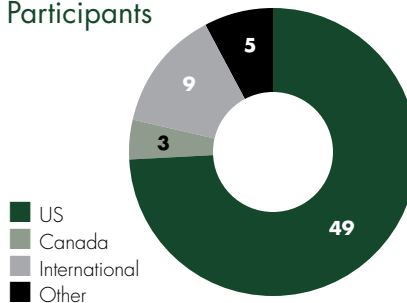
## 2020 Accomplishments & Look Ahead to 2021

### Funding - \$8.9 million



### Participation

66 Participants



**Luke Van der Zel**  
Substations Area Leader  
lvanderz@epri.com

Project Number,  
Name & Manager

### 2020 Accomplishments

### 2021 Plan

P37.101  
**Transformer Life Management**  
Luke van der Zel, lvanderz@epri.com

Laboratory evaluations of a wide range of on-line DGA and on-line bushing monitors. Field deployments to-date of six novel dehydration membranes. Enhancement of the EPRI Transformer Guidebook. Development of an on-line gas chromatograph for detailed field research of new markers.

Research in 2021 will focus on the performance of alternative transformer fluids, evaluation of a wide range of monitoring technologies in EPRI's 138 kV substation - plus field research on new transformer dehydration technologies.

P37.102  
**Circuit Breaker Life Management**  
Bhavin Desai, bdesai@epri.com

SF<sub>6</sub> leak sealing technique development continues to advance through full scale laboratory tests and utility field trials. Enhancement of EPRI Circuit Breaker Guidebook. Development of test plan to evaluate online circuit breaker monitors.

Research in 2021 will focus on advancing SF<sub>6</sub> leak sealing, evaluation of online circuit breaker monitors and developing interactive guides to assist field personnel in troubleshooting circuit breakers.

P37.103  
**Protection and Control**  
Yuchen Lu, ylu@epri.com

Developed configuration management guidelines for relay settings and firmware change control. Developed a guide for transitioning from time-based to condition-based protection system maintenance programs. Provided tech transfer and hosted virtual workshops for advancing new P&C designs by embracing the IEC 61850 digital substation technologies.

Research on automating relay settings management process by evaluating configuration management tools and demonstrating viable solutions. Develop new approaches for enabling condition-based protection system maintenance. Advance new P&C designs by providing technology transfer and pilot experience sharing.

P37.104  
**Substation Ground Grid Corrosion Management**  
Neal Murray, nmurray@epri.com

A method to evaluate ground grid connectors was developed to understand the failure mode, and three models were aged to failure. The process for design and installation of a cathodic protection system was developed and tested in Lenox.

Additional ground grid connectors will be evaluated and correlated to the soil corrosivity maps for service life forecasting. Isolation surge protectors will be evaluated on substation shield wires to allow AC to pass but block stray currents.

P37.105  
**Substation Batteries, CCVTs, Arresters, Disconnect Switches, and Ratings**  
Johnny Bolano, jbolano@epri.com

Developed content for the selection of substation arresters by application and environment. Conducted laboratory test to better understand the failure modes and degradation of substation arresters. Updated Information Tool for Transmission Line and Substation Sensor Systems.

Research in 2021 will evaluate online substation battery monitors on new and field-aged batteries.

P37.108  
**Gas Insulated Substations and Lines**  
Luke van der Zel, lvanderz@epri.com

SF<sub>6</sub> replacements is the first of the two important tasks in the project. EPRI is performing HV tests and tracking and reporting on SF<sub>6</sub> replacement deployments worldwide. The second topic is GIS/GIL diagnostics using the newly commissioned GIS laboratory in Charlotte, NC to generate valuable insights.

High Voltage testing of SF<sub>6</sub> replacements will continue at differing pressures and mixtures. Lessons learned from SF<sub>6</sub> deployments in the field will be reported. The EPRI GIS laboratory in Charlotte will have defects intentionally introduced to evaluate a wide range of diagnostic techniques.

P37.113  
**Bushing Monitoring & Diagnostics**  
Poorvi Patel, ppatel@epri.com

Three polymer bushings in the 138 kV yard have been energized for almost two years with various voltages, over voltages, currents and extreme weather conditions. The bushings have been monitored with off-line testing and on-line bushing monitoring system. To better assist utilities on specifying polymer bushings, a polymer bushing guide has been initiated.

In 2021 the polymer bushings in the 138 kV yard will continue to be subjected to harsh electrical and environment conditions. The bushings will also be subjected to impulse testing. To understand the most common failure modes of polymer bushings, a study will be performed. Accelerated bushing testing to replicate the common failure modes will be designed.

P37.115  
**Performance of External Insulation in Contaminated Environments**  
Erika Willis, ewillis@epri.com

For 2020, there was a large focus on the salt fog chamber and getting testing up and running with validation of the test results. Testing was successfully completed and compared to standard results.

As the project progresses into 2021, the push will be to streamline the salt fog testing with precision. In addition, the practical maintenance guide will continue to be reviewed and enhanced for easier use in the field.

P37.116  
**HVDC and FACTS Technologies**  
Rambabu Adapa, radapa@epri.com

A new converter concept - Single Arm Modular Multilevel Converter was developed and demonstrated in a lab. HVDC Reference Book was updated with latest information on Overhead Trans Lines. Development of a Novel VSC concept with Fault Current Limiting capability was initiated. Technical and Economic comparison of FACTS controllers was also initiated.

Technical and Economic comparison of SSSC (Static Synchronous Series Compensator) vs TCSC as well as SVC vs STATCOM vs Synchronous Condenser are planned. Planning is underway to demonstrate the Novel VSC concept with fault current limiting capability. HVDC Reference Book will be updated with latest information on VSCs and HVDC cables.

P37.117  
**Using Voltage & Current Measurements for Monitoring Asset Conditions**  
Poorvi Patel, ppatel@epri.com

Research on technologies using voltages and currents from VT, CCVT and CT to assess the condition of transformers and circuit breakers has been performed.

Install Voltage and Current technology to the feeding transformers in the 138 kV yard to evaluate the accuracy as well as advantages and disadvantages of the technology. One of the technologies available commercially may be installed in 138 kV yard in 2021.

## 2020 Deliverables

### Key Deliverables

#### Transformer Life Management

##### 3002018706

P37-101 Transformer Webinar:  
Alternative fluids for transformers – The Basics

##### 3002019138

TRW (Transmission Ratings Workstation) V5.0

##### 3002019140

Assessment of On-Line EPRI Dry-Out Technologies that Allow for Continuous Dehydration with Minimal Maintenance: Results of Field Trials

##### 3002019141

Robotic Inspection Technologies for Transformers: Laboratory and Field Assessments

##### 3002019146

EPRI Power Transformer Guidebook:  
The Copper Book 2020 update

##### 3002019147

Assessment of On-Line Monitoring:  
On-Line DGA and Bushing Laboratory  
Data to Support Functional Specifications  
The report provides valuable insights from the EPRI  
138kV research laboratory on monitor performance  
and maintenance costs.

##### 3002019148

Improving Transformer Diagnostics Through  
New Marker Compounds: Development of  
Real-Time Monitoring of New Markers

#### Using Voltage and Current Measurements for Monitoring Asset Conditions

##### 3002019246

Using Existing Voltages and Currents in Substations  
for Equipment Diagnosis  
The first report in this newly launched project provides a  
helpful state-of-the-science review and lays out the EPRI  
R&D plan for 2021.

#### Circuit Breaker Life Management

##### 3002019152

Novel SF<sub>6</sub> Leak Sealing Techniques: Results from  
Full Scale Laboratory Tests  
This report provides key information on performances of  
leak sealing techniques applied at EPRI Labs as well as  
pilots in the field at utility substations.

##### 3002019153

Effectiveness Assessment of Circuit Breaker  
Diagnostic Tests: Characterization of Dynamic  
Contact Resistance Measurement

##### 3002019155

Circuit Breaker Guidebook: 2020 Update

##### 3002019156

Circuit Breaker Mechanism Maintenance Guides

#### Protection & Control

##### 3002019158

Life Cycle Management of Relay Settings:  
Configuration Management Guidelines  
and Effective Practices  
Through collaboration with a wide range of utilities, this  
report shares industry best practices and helps utilities  
manage relay settings.

##### 3002019159

Life Cycle Management of Relay Settings:  
Tools Assessment

##### 3002019161

Application Guide of Relay Firmware  
Change Management

##### 3002019162

Application Guidelines for  
Protection System Maintenance

#### Substation Ground Grid Corrosion Management

##### 3002019213

Guidelines for Substation Ground Grid Corrosion  
Management: Soil Library Development and  
Connector Degradation

##### 3002019215

Inspection and Assessment for Substation Ground  
Grids: Evaluation of Grounding System Testing,  
Monitoring and Materials  
Through real-world testing in EPRI's 138 kV research  
substation this report guides members on the  
performance of a range of grounding system tests

##### 3002019217

Ground Grid Protection Methods: An Overview of  
Mitigation Options

#### Gas Insulated Substations and Lines

##### 3002019226

GIS (Gas Insulated Switchgear) GIL (Gas Insulated  
Line) Condition Monitoring: SF<sub>6</sub> (Sulfur Hexafluoride)  
Replacements and GIS/GIL Condition Monitoring  
This step-by-step flowchart-driven guide assists members  
in the selection and application of GIS/GIL condition  
monitoring

##### 3002019227

SF<sub>6</sub> Alternatives: EPRI Laboratory Testing Plus  
Updates on Worldwide Field Deployments

#### Bushing Monitoring & Diagnostics

##### 3002019228

Guidelines on Specification and Maintenance  
of Polymer Bushings  
Polymer bushings are gaining popularity but have  
unique requirements for specification and maintenances.  
This report presents these important insights.

##### 3002019229

Performance of Dry Bushings Under Extreme  
Environmental Conditions: 2020 Update

#### Substation Batteries, CCVTs, Arresters, Disconnect Switches, and Ratings

##### 3002019221

Station Class Metal Oxide Surge Arrester:  
Guidelines for Selection, Application,  
and Monitoring  
This report guides the reader through the important  
changes in the standards and provides helpful  
assistance in selection

##### 3002019223

Substation Surge Arresters: Performing a Laboratory  
Diagnostic Test

##### 3002019224

Substation Condition Monitoring and Implementation  
Technologies

##### 3002019682

Substation Inspection and Sensing Information

#### Performance of External Insulation in Contaminated Environments

##### 3002019238

Field Guide for Site Severity Assessment  
(Mobile Application)

##### 3002019239

Testing of Remedial Measures for Contaminated  
Insulators: Development of Test Methodology  
and Commissioning Testing

##### 3002019240

Contamination Performance of Insulators:  
Practical Maintenance Guide  
EPRI's Salt Fog contamination laboratory has  
helped produce valuable insights that are  
presented in this report.

#### HVDC and FACTS Technologies

##### 3002019242

HVDC and FACTS Tech Watch

##### 3002019243

A Single-Arm Modular Multilevel Converter:  
Design, Simulation, and Experimental Validations

##### 3002019110

EPRI High Voltage Direct Current (HVDC)  
Transmission Reference Book (The Olive Book):  
2020 Edition  
The updated guidebook provides a useful  
centralized resource for utilities interested in  
specifying or maintaining HVDC systems



## Examples of Member Application of Results

### Value Obtained

#### Southern Company Application of IR results

Research two IR technologies and algorithms effectiveness on underground splices and switches.

Based on the results of the research Southern Company was able to define what IR technology they would deploy to monitor underground assets.



#### ComEd Installation of a Ground Grid Corrosion Sensor

Installation of a sensor suite to monitor activity of the ground grid and the changes in the environmental factors in the soil and atmosphere.

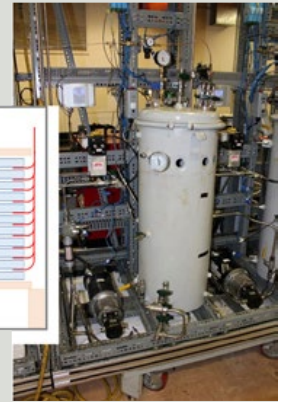
ComEd may use the soil corrosivity algorithm to model the corrosion activity on the substation ground grid and forecast real time changes in the system.



#### National Grid Increased Transformer Ratings Using Novel Fluids

Evaluation of new fluids to explore the potential for upgrading of transformers.

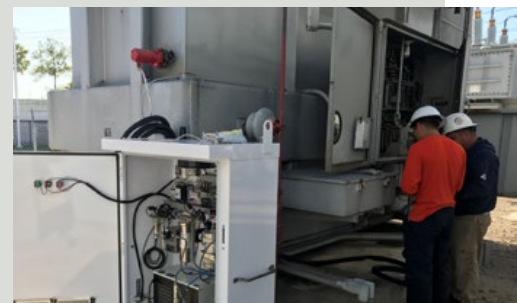
Through the application of a new test setup using a model transformer with extensive thermocouples, a new fluid (NYNAS BIO Nytro 300X) was effectively evaluated. The results set the basis for further valuable upgrading tests with new fluids such as nanofluids.



#### CenterPoint Energy Novel Transformer Dehydration using Membranes

Application of EPRI novel transformer dehydration technology using membranes.

Through a field demonstration, a novel transformer dehydration technology was evaluated for keeping the power transformer dry over its lifetime. This has resulted in O&M savings through no cartridge replacements and no need for recurring on-site dry-outs using conventional methods.



Supplementals

Status

**Substation Ground Grid Corrosion**

Neal Murray, [nmurray@epri.com](mailto:nmurray@epri.com)

This project seeks to understand grid degradation, to locate suspect areas of corrosion and to provide environmental data supporting asset management decisions.

A ground grid corrosion sensor array has been installed at the Braidwood substation. The system has been commissioned and is gathering environmental and ground grid potential data to trend the aging and performance of the ground grid.

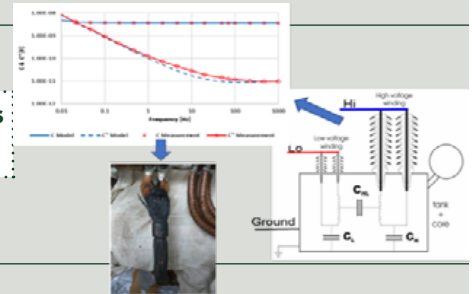


**Evaluation of Dielectric Frequency Response (DFR) Analysis on Transformers and Bushings**

Poorvi Patel, [ppatel@epri.com](mailto:ppatel@epri.com)

This research will evaluate dielectric frequency response technology on transformers and bushings.

The project kick-off is planned for January 2021.



**Robots for Substation Asset Inspections**

Poorvi Patel, [ppatel@epri.com](mailto:ppatel@epri.com)

Research of commercially available robotic platform suitable for substation inspection. Deploy new sensing payloads on the robotic platform and demonstrate the technologies in EPRI's Lenox 138 kV research substation.

Different robotic solutions are currently being evaluated. Next steps will be to decide on technologies to use.



**Evaluation of Infrared Monitoring Analytics-Substation assets**

Poorvi Patel, [ppatel@epri.com](mailto:ppatel@epri.com)

Evaluation of commercially available IR analytical solution for transformer and substation asset monitoring in the 138 kV Yard.

Two IR cameras have been installed and set-up in the 138 kV yard. The software and communication to the server is being established. Testing will initiate in 2021. Simulated faults will be introduced on bushings and arrestors.



**Substation Seismic Studies Group**

Ram Adapa, [radapa@epri.com](mailto:radapa@epri.com)

Addressing deficiencies in IEEE 693 seismic standard by conducting tests and modeling substation equipment for different intensities of earthquakes. This will help qualify substation products to have higher probability of surviving earthquakes.

Shake table tests on bushings, transformers and dampers were done. Finite element models were developed. Recommendations for changes in IEEE 693 standard were provided. Tests on more equipment is planned in the future.



## Supplementals *continued...*

### Status

#### Alternative Fluids Research

Luke van der Zel, [lvanderz@epri.com](mailto:lvanderz@epri.com)

The project is researching a wide range of new fluids for transformers to examine the potentials for reduced fires, extended life, reduced environmental impact and increased transformer ratings.

Aging tests with natural and synthetic esters were recently completed and now benchmarking with mineral oil is underway. There are many new tasks underway on DGA interpretation, on-line DGA monitors and transformer uprating.

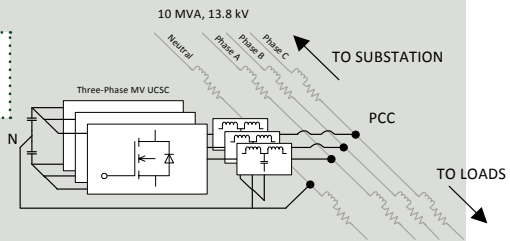


#### Unbalanced Current Static Compensator

Ram Adapa, [radapa@epri.com](mailto:radapa@epri.com)

Development of UCSC to balance currents in all three phases in T&D systems and eliminating neutral currents.

A medium voltage (13.8 kV) UCSC prototype was developed using SiC MOSFETs and was tested in a lab environment. Utility demos are planned in the future.



#### Life Extension Guidelines Application for HVDC Converter Stations

Ram Adapa, [radapa@epri.com](mailto:radapa@epri.com)

Application of life extension guidelines for utility converter stations, and provide recommendations for repair or replacement.

EPRI developed life extension guidelines by surveying many utilities. These guidelines are applied to member converter stations and provided recommendations. Planning to work with other utilities in the future.



#### Switching Safety and Reliability

Paula Traynor, [ptraynor@epri.com](mailto:ptraynor@epri.com)

Annual project dedicated to ensuring the safety of workers, and the reliability of electric power systems during switching activities. Conducts research on methodologies, human performance issues and advances in technology related to operational switching.

The annual workshop and conference were held, additional videos have been released and key switching issues were addressed in the monthly webcasts. There are now 41 videos on electrical safety, substation safety, three-part communication as well as motor operator operation.



#### EPRI|U for Transmission

Kevin Berent, [kberent@epri.com](mailto:kberent@epri.com)

This new, annual project focuses on creating and delivering high quality, technically-based training on various transmission topics (i.e.: assets, assets management, operations, planning, EMF, etc.) For assets, it includes material for Programs 35, 36, and 37.

This was the project's first year, and it was very well received. By the end of the year, the project funders had access to over 30 videos, 3 webinar series, and 7 computer-based training modules, including the brand-new "Transmission 101" training. Additional new training material will be delivered in 2021.





## Supplementals *continued...*

### Status

#### Technology Assessment and Demonstration of Process Bus and Non-Conventional Instrument Transformer

Yuchen Lu, [ylu@epri.com](mailto:ylu@epri.com)

Research on how to digitalize the interface between switchyard equipment and relaying systems in substation control house through fiber optics and digital communication technologies.

The project is conducting independent lab testing to assess interoperability of merging units and relaying equipment, performance and reliability of new protection designs, new substation infrastructure. Functional requirements will be developed.



#### Implementation and Maintenance Guide for P&C Systems in IEC 61850 Substations

Yuchen Lu, [ylu@epri.com](mailto:ylu@epri.com)

Develop application guide to new protection and control designs by embracing IEC 61850 digital substation technologies.

The project is developing viable solutions to overcome the technical barriers in field deployment of IEC 61850 substations. The utilization of monitoring capabilities is being explored to improve reliability and reduce time based maintenance needs and a guide will be developed.



#### Research to Protect Power Facilities from Unmanned Aircraft Systems and Improve Resiliency - Phase 2

Kevin Berent, [kberent@epri.com](mailto:kberent@epri.com)

Counter-UAS technologies often are not developed with electric utilities in mind and may be incompatible with the unique electrical environment at utility sites. Research is needed to identify and assess the performance of existing counter-UAS technologies, and develop functional specifications for technologies deployed in an electric utility environment.

Collaborative summer research was conducted virtually with the U.S. Air Force Academy. One vendor evaluation was completed at the Lenox lab in November, and technical briefings started in December. Additional technology evaluations and project calls are planned for 2021.



#### Physical Security

Kevin Berent, [kberent@epri.com](mailto:kberent@epri.com)

This annual project seeks to enhance physical security and resiliency by reducing the potential impact of disruptions and/or damage to critical infrastructure from various threats. The R&D is conducted from one unified, annual supplemental project with a scope that includes topics applicable to overhead (Program 35), underground (Program 36), and/or substations (Program 37).

Many topics were covered throughout the year. Two highlights include: ballistic testing on two types of overhead conductors to understand more about damage from attacks, and the potential use of facial recognition technology was shared in a technical report.



#### Research and Testing of Alternatives to Sulfur Hexafluoride (SF<sub>6</sub>)

Luke van der Zel, [lvanderz@epri.com](mailto:lvanderz@epri.com)

EPRI is answering significant questions regarding the dielectric performance, safe and effective handling, operation, maintenance, and disposal of SF<sub>6</sub> alternatives. The questions are being answered through testing of SF<sub>6</sub> Alternatives in high voltage laboratories.

EPRI is working to understand and share the available SF<sub>6</sub> replacement technologies and tracking worldwide deployments. Laboratory tests are underway to better understand health and safety aspects and the operations and maintenance replacement technologies.



## 2020 Accomplishments & Look Ahead to 2021

### Status

#### Robotic Painting of Transmission Structures

Neal Murray – [nmurray@epri.com](mailto:nmurray@epri.com)

Tower painting programs represent significant cost to the utilities due to labor and logistics. This project is designed to develop a robotic painting system which may reduce cost and increase service life of the structure.

Grippers (to attach to structure) were designed and assembled in 2020, and will be tested in 2021.

#### Live Work Real-time Tracking System

Gary Sibilant – [gsibilant@epri.com](mailto:gsibilant@epri.com)

Developing a real-time worker tracking system to use during live work to improve safety. Creating the capability to track and display a worker's position on the line and MAD via an AR device.

Investigation and evaluation into the potential use of complementary technologies was completed. Evaluating methods for image capture and 3D modeling. Test application being built to match real world worksite objects to coordinates in virtual 3D model.

#### Material Absorptivity Test Instrument

Paula Traynor – [ptraynor@epri.com](mailto:ptraynor@epri.com)

The goal is to develop a method of testing the absorptivity of coated conductors, an HTLS conductor, new condition utility samples, and utility samples removed from service.

Currently testing two different prototype systems to determine which one would be most suitable for our application.

#### Transformer Collaboration at Manchester

Luke Van der Zel – [lvanderz@epri.com](mailto:lvanderz@epri.com)

The collaboration with research at the University of Manchester provides significant leverage to EPRI, and the transformer expertise extends EPRI's perspective on a number of key research topics.

The research has produced helpful results on the aging of various alternative fluids. Additional helpful results have been produced in the area of bubble formation. The work will help reduce transformer flashovers during periods of overload.

#### Transmission Asset RF Monitors (Lines and Substations)

Andrew Phillips – [aphillip@epri.com](mailto:aphillip@epri.com)

This project is developing the next generation RF Monitors Suite to evaluate the condition of Transmission Line and Substation Assets. RF Monitors under development and improvement include: Conductor Vibration and Galloping, Partial Discharge: Acoustic Emission (AE) and Radio Frequency Interference (RFI), and Shield Wire Lightning /Fault Monitors.

New algorithms were developed for the Conductor Galloping RF monitor extending the frequency range and increasing accuracy, the AE and RFI Partial Discharge (PD) Monitors improving detection and reducing false positives, the Shield Wire Lightning Monitor by defining measurement parameters. In addition a new communication protocol, LORA, is being developed in order to extend the range of RF reception of the RF Monitors.

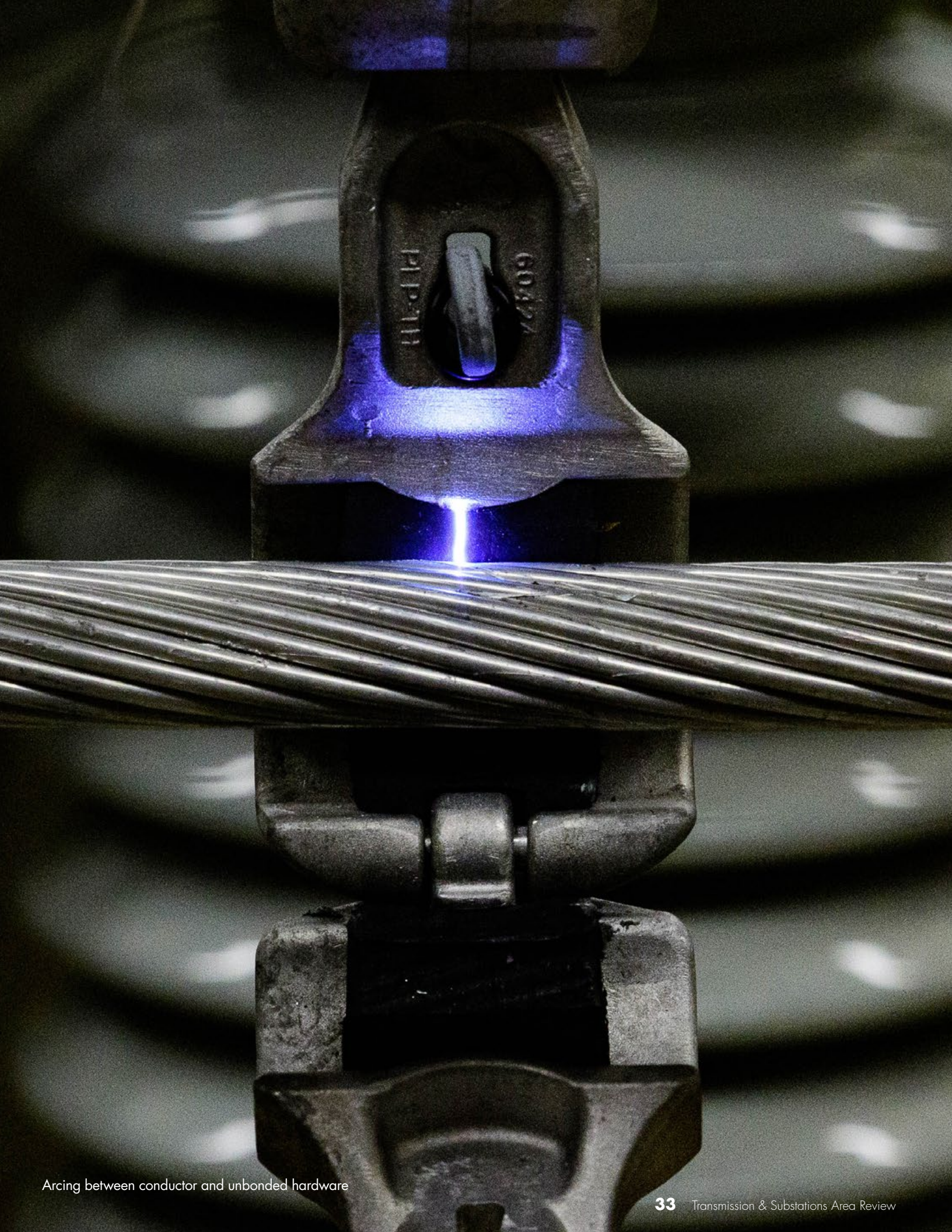
#### Diagnostics Using Advanced Imaging

David Kummer, [dkummer@epri.com](mailto:dkummer@epri.com)

The ability to locate abnormalities of transmission cables is extremely critical to prevent failures of such equipment. This project studies potential of 3D X-ray imaging systems for detection of abnormalities in insulation systems of transmission cables and joints that are mostly contained in a metallic casing or sheath.

The research builds upon the previous development of a limited angle computerized tomography system that can be deployed inside underground transmission vaults. Enhancements were made to aid in the calibration and image optimization for defect detection on the 3D scan.





Arcing between conductor and unbonded hardware



## EPRI's Transmission Area Tech Transfer Activities January - December 2020



### Transmission and Substation Technology Transfer Award Winners 2020

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 2019 - 2020 time period. Awards were selected in the Fall of 2020.

#### 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, and
- Leadership, innovation, and initiative demonstrated.

Name of Technology Applied	Companies	Winners	Area
<b>Risk Based Assessment of Climate Conditions for Improved Seasonal, Regional and Dynamic Transmission Line Ratings</b>	Bonneville Power Administration CenterPoint Energy Great River Energy Powerlink Queensland Transgrid	Natasha Gentry Tyler Ashburn Brett Bowers Cristal Jimenez Adam Ali Jim McGuire Rick Jeanson Glenn Stapleton David Sharp Hoang Tong	Overhead Transmission
<b>State-of-the-art Line Monitoring Devices Providing Situational Awareness on Galloping, Blowout and Vibration</b>	Dominion Energy, Inc.	Brandon Patterson Mike Lamb	Overhead Transmission
<b>Algorithms for Utility Infrared Inspection and Monitoring in Substations</b>	New York Power Authority	Atena Darvishi Ramadan Elmoudi Alan Ettlinger Gregory Pedrick	Substations



## Field Guides

Pictorial based documents intended to be used in the field to aid inspection and assessment as well as implement tasks. Contain thousands of images of field aged equipment collected by EPRI SMEs.

Corona Rings for Polymer Insulators	3002019725	12/31/20	(electronic; optimized for electronic viewing)
Visual Inspection of Steel Structures	3002018858	08/06/20	(electronic; optimized for electronic viewing)
Visual Inspection of Polymer Insulators	3002018872	12/31/20	(electronic; optimized for electronic viewing)
Infrared Thermography for Substations	3002014396	08/31/18	(electronic; optimized for electronic viewing)
Visual Inspection of Steel Structure Foundations	3002005629	12/15/15	(electronic; optimized for electronic viewing)
Visual Inspection of Porcelain and Glass Disc Insulators	3002018870	12/31/20	(electronic; optimized for electronic viewing)
Did That Transformer Really Fail?	1024553	12/31/11	(electronic; optimized for electronic viewing)
Inspection of Transmission Line Grounding Systems	3002018857	12/31/20	(electronic; optimized for electronic viewing)
Lubrication of High-Voltage Circuit Breakers (HVCBs)	3002014395	08/31/19	(electronic; optimized for electronic viewing)
Visual Inspection of Avian Issues on Transmission and Distribution Structures	3002018869	12/31/20	(electronic; optimized for electronic viewing)
Visual Inspection of Wood Structures	3002018862	12/31/20	(electronic; optimized for electronic viewing)
Daytime Discharge Inspection of Transmission and Distribution Overhead Lines and Substations Guide with Video	3002018873	12/31/20	(electronic; optimized for electronic viewing)
Smart Ground Meter	1024555	12/31/11	(electronic; optimized for electronic viewing)
Smart Ground Meter	1020400	11/05/09	(electronic & hardcopy)
Field Guide for Switching Personnel: EPRI Switching Safety and Reliability	3002020022	12/31/20	(electronic; optimized for electronic viewing)
Construction and Inspection of Compression Connectors for Overhead Transmission Lines	3002018860	12/31/20	(electronic; optimized for electronic viewing)
Live Working Rope	3002018867	12/31/20	(electronic; optimized for electronic viewing)
Transmission Line Aerial Marking & Lightning	3002018879	12/31/20	(electronic; optimized for electronic viewing)
Compressors for High-Voltage Circuit Breakers	3002010228	12/31/17	(electronic; optimized for electronic viewing)
Inspection of Transmission Line Foundations	3002019679	12/31/20	(electronic; optimized for electronic viewing)
Inspection of Conductors for Overhead Transmission Lines	3002018866	12/31/20	(electronic; optimized for electronic viewing)
Tier 1, Above and Below Grade Corrosion Assessment of Weathering Steel Transmission Structures	1023499	12/31/11	(hardcopy & electronic; optimized for electronic viewing)
Infrared Thermography for Overhead Transmission Lines, Overhead Distribution Lines, and Substations	3002028878	12/31/20	(electronic; optimized for electronic viewing)
Inspection, Maintenance, and Troubleshooting of Sacrificial Anode Cathodic Protection Systems for Transmission Line Structures	3002007677	10/07/16	(electronic; optimized for electronic viewing)
Substation Physical Security (2019 Update)	3002015698	11/27/19	(electronic; optimized for electronic viewing)



## Computer Based Training

Description	PID #	Date Published
Computer Based Training for Structure Grounding Measurement	3002007686	11/21/16
Crossarm Inspection and Evaluation Web-based Training v1.0	3002000981	11/22/13
Live Work Computer-Based Training (LW-CBT)	3002012652	12/06/18
SF6 Computer Based Training (Update)	3002015691	10/21/20
Overhead Transmission Line Inspection – Online Training (OTLOT) Version 2020	3002018877	12/31/20
Transmission 101	3002019849	12/31/20



## Mobile Apps



### Overhead Transmission / Substations

#### Transmission, Distribution, and Substations (TD&S) Guide

This app provides access to research activities, available reports, EPRI contacts, and subject matter leaders along with a complete listing of meetings and other events scheduled within the Advisory and Task Force structure.

### Overhead Transmission

#### Daytime Discharge Inspection of Transmission and Distribution Overhead Lines and Substations

This application is devoted to the subject of daytime discharge inspection. Although technology for viewing corona and arcing discharges during the day has been available for a number of years, it can be rather difficult to interpret the images produced by this technology. This systematically organized document was prepared to help overcome some of these difficulties. It is intended for practical use by workers in the field.

#### Visual Inspection of Steel Structure Foundations

This application is a catalog of photographs illustrating various conditions and factors that commonly affect transmission line steel structure foundations, along with their likely causes, a Maintenance Priority Rating, and suggested actions to be taken by utility personnel. Sections include types of foundations, foundation reveals, steel degradation, and concrete degradation.

This Field Guide is designed to aid utility field crews in assessing observed conditions on steel structure foundations, identifying specific problems, and deciding on a course of action. It will also facilitate a discussion of the findings and results among utility crews, engineers, managers, and EPRI researchers.

#### Live Working Rope

This application, intended as a practical reference for use by workers in the field, is a culmination of several years of EPRI research in the area of ropes, with special emphasis on ropes used in contact with or in proximity to energized conductors. The guide is designed to help improve safety and efficiency in live working environments.

#### Visual Inspection of Avian Issues on Transmission and Distribution Structures

Electric transmission lines and wild birds must co-exist. Power lines traverse birds' flight routes, birds commonly roost on lines and poles, and birds make their nests—the largest of which weigh thousands of pounds—on transmission structures. Some avian activities can have deleterious effects on outdoor structures and transmission—for example, nests have been known to collapse and span critical clearances during storms, resulting in outages. Accordingly, it is important for utilities to regularly inspect for bird-related problems. An array of legal, safety, and health issues must also be considered.

#### Visual Inspection of Porcelain and Glass Disc Insulators

This field guide is devoted to the subject of porcelain and glass disc insulators. It provides a general, field-deployable resource designed to support inspection and assessment of transmission components. The guide is conveniently organized and deals with each technology separately. Full-color photographs support visual evaluation of the range of conditions likely to be encountered in the field, including corrosion, cracking, contamination, and dielectric shell damage. A maintenance priority rating system is incorporated to aid decision making.

#### Polymer Insulator Inspection

The Polymer Insulator Inspection Mobile Guide is a photo rich resource to help users identify the typical degradation observed on in service transmission line polymer insulators and furthermore provides a textual description of the degradation, how the degradation develops, and what the possible consequences of the degradation can be if ignored. As a mobile guide, this resource can be conveniently distributed to inspection personnel and readily available in the field.

#### Visual Inspection of Steel Structure

The mobile application identifies areas on a structure that are subject to degradation due to environmental exposure or mechanical damage. This list of structures encompasses direct bury lattice, concrete foundations, tubular structures and guy anchors. In addition to identifying damage, the mobile app provides the guidance to quantify the degradation, understand the initiation mechanism and allocate the proper corrective action based upon severity. Lastly, the mobile app provides an understanding of the level of risk associated with the consequence of doing nothing.

#### Inspection of Transmission Line Grounding System

This field guide is designed to aid utility work crews in assessing the condition of grounding systems, identifying specific problems, and deciding on a course of action.

#### Construction and Inspection of Compression Connectors for Overhead Transmission Lines

This mobile application field guide provides a general, field-deployable resource for utility professionals who are engaged in the construction and installation of compression connectors, as well as those who are involved with in-service inspection and assessment of this line component. It describes typical applications, compression connector basics, construction methods, common assembly errors, and inspection methods. In addition, it provides a list of relevant technical and training resources.

### Substations

#### Lubrication of High-Voltage Circuit Breakers

High-voltage circuit breakers (HVCBs) perform essential protection and control functions on power transmission networks. Circuit breaker mechanisms have multiple components that must operate in concert in order for the breaker to perform properly. If one component does not operate correctly, the circuit breaker may mis-operate or fail. A circuit breaker mis-operation may cause equipment damage and outages—both expensive consequences. Proper lubrication can help to ensure that HVCBs operate reliably, and help prevent premature failures and slow operation.

#### Infrared Thermography for Substations

The subject of this app is infrared (IR) thermography for inspection of substation equipment, and it is intended for both thermographers and engineers.

#### Site Severity Assessment (ESDD NSDD v2.0)

This mobile application enables users to calculate the equivalent salt deposit density (ESDD) and non-soluble deposit density (NSDD), calculate and record the values, and therefore removes the need to carry laptops or heavy computer systems in the field for this task. It should aid and train field personnel on how to assess the contamination severity at a site when using dust deposit gauges to understand the environment.





## Reference (Color) Books

These reference books contain all the relevant information developed by both EPRI and other industry resources. They are considered the industry benchmark and are regularly updated.

Description	PID #	Date	Info
BLACK BOOK Switching Safety and Reliability Reference Book – Fifth Edition	3002020021	12/31/20	(electronic)
BLUE BOOK Transmission Line Reference – 115 – 400kV Compact Line Design	3002012638	11/28/18	(electronic)
BRONZE BOOK Underground Distribution Systems Reference Book	3002018091	03/11/20	(electronic)
COPPER BOOK EPRI Power Transformer Guidebook Development	3002019146	12/31/20	(electronic)
EMERALD BOOK Power Quality Reference Book – 2020 Edition	3002019378	12/18/20	(electronic)
GOLD BOOK Power Electronics-Based Transmission Controllers Reference Book	1020401	12/23/09	(electronic)
GRAY BOOK Overhead Transmission Line Lightning & Grounding Reference Book - 2020	3002018919	12/18/20	(electronic with applets)
GREEN BOOK Underground Transmission Systems Reference Book – 2006 Edition	1014840	03/29/07	(electronic & hard copy)
GREEN BOOK Underground Transmission Systems Reference Book – 2020 Edition	3002019133	11/16/20	(electronic)
LIGHT BLUE BOOK EPRI Power System Dynamics Tutorial – 2020 Edition	3002018947	11/23/20	(electronic)
MAROON BOOK Fault Current Management Guidebook	1024227	12/31/12	(electronic)
OLIVE BOOK High Voltage Direct Current (HVDC) Transmission Reference Book – 2020 Edition	3002019110	12/30/20	(electronic)
ORANGE BOOK EPRI Transmission Line Reference – Conductor Motion – 2019 Edition	3002015610	12/26/19	(electronic)
PLATINUM BOOK EPRI Increased Power Flow Reference Book – 2020 Edition	3002019086	12/31/20	(electronic)
RED BOOK AC Transmission Line Reference Book – 200kV and above, 2020 Edition	3002018956	12/23/20	(electronic)
RED BOOK KIT EPRI Transmission Line Reference Book - 200kV and Above – 2005 Edition	1011972	12/15/05	(hard copy + applets)
TAN BOOK EPRI Live Working Reference Book – 2020 Edition	3002019068	12/31/20	(electronic)
VOILET BOOK EPRI Insulators Reference Book – 2020 Edition	3002019073	12/31/20	(electronic)
YELLOW BOOK Overhead Transmission Inspection, Assessment, and Asset Management Reference Guide - 2020	3002018874	12/31/20	(electronic)



## Software

Software to support member engineers address complex issues and computer-based training to transfer results.

Description	PID #	Date
115 / 138 kV Insulator Aging Test	3002011040	04/21/17
AC to DC Line Conversion - DC Convert Software	1020651	10/26/10
AC vs DC Wizard 2.0 – Software for Comparing AC and DC Options	3002000854	12/16/13
ADSS Application Software v 1.0	3002019081	12/31/20
Cascading Failure Risk Assessment Tool (CASE TOOL), v 3.01	3002019065	12/31/20
Circuit Breaker Lubrication Selection Tool (CBLS) v. 5.0	3002015675	12/31/19
Circuit Breaker Maintenance And Replacement Ranking Software (CBMRR) Version 7.0	3002019258	12/31/20
Electronic Information Tool for Transmission Line and Substation Sensor Systems (SCMID) v 6.0	3002010199	12/12/17
Foundation Analysis & Design (FAD) v. 5.1.19	3002005097	03/02/15
High-Temperature Conductor (HTC) Matrix Resistance Calculator v. 10.0	3002019092	12/31/20
Industrywide Transmission & Substations Failure And Performance Database (idb.epri.com)	3002015545	12/31/19
Insulator Calculation Engine (ICE) v. 8.0	3002019072	12/31/20
Increased Power Flow Wizard (IPFWiz) v 2.2	1021704	11/23/11
Interactive 138kV/230kV Aging Chamber Report Tool (ACRT) v. 11.0	3002012658	11/07/18
Live Work Computer Based Training (LW-CBT)	3002011295	10/24/17
Minimum Approach Distance Calculator (MAD Calculator), v. 2.6	3002012650	11/19/18
Normalized Span Method Design Tools for XLPE Power Cables in Pipe, Duct and Manhole Systems (NSPAN) v. 1.0	1012963	12/04/09
Optimal Line Tension and Conductor Strength (Op10) v.10	3002018981	12/31/20
Overhead Transmission Inspection and Sensing Information Tool (OTIS), v 9.0	3002019067	09/24/20
Power Transformer Expert System DLL (PTXDLL) v7.0	3002019257	12/31/20
Power Transformer Expert Systems Software Version 7.0	3002019256	12/31/20
Transmission Line Workstation – Gen 2 (TLW-Gen2) v. 8.0: AC Design Module	3002018972	12/31/20
Transmission Line Workstation – Gen 2 (TLW-Gen2) v. 8.0: HVDC Electrical Effects	3002019107	12/31/20
Transmission Line Workstation – Gen 2 (TLW-Gen2) v. 8.0: Lightning & Grounding	3002018930	12/31/20
Transmission Rating Workstation TRW v5.5	3002019085	12/31/20
Transmission Rating Workstation TRW v. 4.5 Overhead Transmission Line Module	3002019085	12/04/20
Transmission Rating Workstation TRW v. 4.5 Transformer Module	3002012606	11/09/18
Underground Transmission Workstation (UTW) v. 7.6	3002019113	12/31/20
Underground Transmission Workstation—DC Ampacity (UTW-DC) v. 1.3	3002019135	12/22/20
Yellow Book Browser Application (YBB) 2020	3002018876	12/31/20
Zed+Meter v. 3.2	3002007950	12/31/16

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