

EPRI Generator Research

Recent, In-Progress, and Future Planned

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Sr. Technical Executive
EPRI

IRIS Rotating Machinery Conference (Virtual)
June 15, 2022



To Start Off – Please respond via chat

- Multiple Choice Question
- Generator Stator Windings have been cooled by:
 - A. Air
 - B. Hydrogen
 - C. Water
 - D. Oil
 - E. Helium
 - F. A and B
 - G. A, B and C
 - H. A, B, C and D
 - I. All of the Above

Agenda

- Quick Overview of EPRI - 50 Years
- Past Generator Related Research
- P65 to Program 220: Generators and Auxiliary Systems
- Recent Generator Related Research: 2018 to 2022
- Future Generator Related Research: 2023 & Beyond

50 Year Anniversary in 2022

- Founded in 1972, the Electric Power Research Institute (EPRI) is considered by many to be the world's leading independent, non-profit energy research and development organization.
- Started after numerous challenges hit the industry
 - Great Northeastern Blackout of 1965
 - Electricity demand spikes through the 1960s
 - Fuel and energy shortages
- U.S. Congress, state governments, and public and private utilities came together and recognized the need for an independent collaborative research and development (R&D) organization to address significant energy challenges.
- Dr. Chauncey Starr, EPRI's founding CEO, answered formed an EPRI team in collaboration with U.S. industry members.
- Dr. Arshad Mansoor is now the CEO of EPRI. He will be the keynote speaker at the upcoming CIGRE conference in Paris in August.



Chauncey Starr
1912 - 2007



The Physics Years (1936 - 1943)
Birth of the Nuclear Age (1944 - 1965)
UCLA & Risk Analysis (1966 - 1971)
The EPRI Years (1972 - 2007)

What We are Known For

COLLABORATION

EPRI's collaborative platform:

- Leverages your research dollars
- Connects you to a global network of peers
- Accelerates deployment of technology
- Mitigates the risk and uncertainty of going it alone

CREDIBILITY

EPRI's independent research offers:

- Objective solutions
- A proven track record
- Scientifically based research you can trust

EPRI members make up 90% of the electricity generated & delivered in the US, with more than 450 member companies in nearly 40 countries.

EXPERTISE

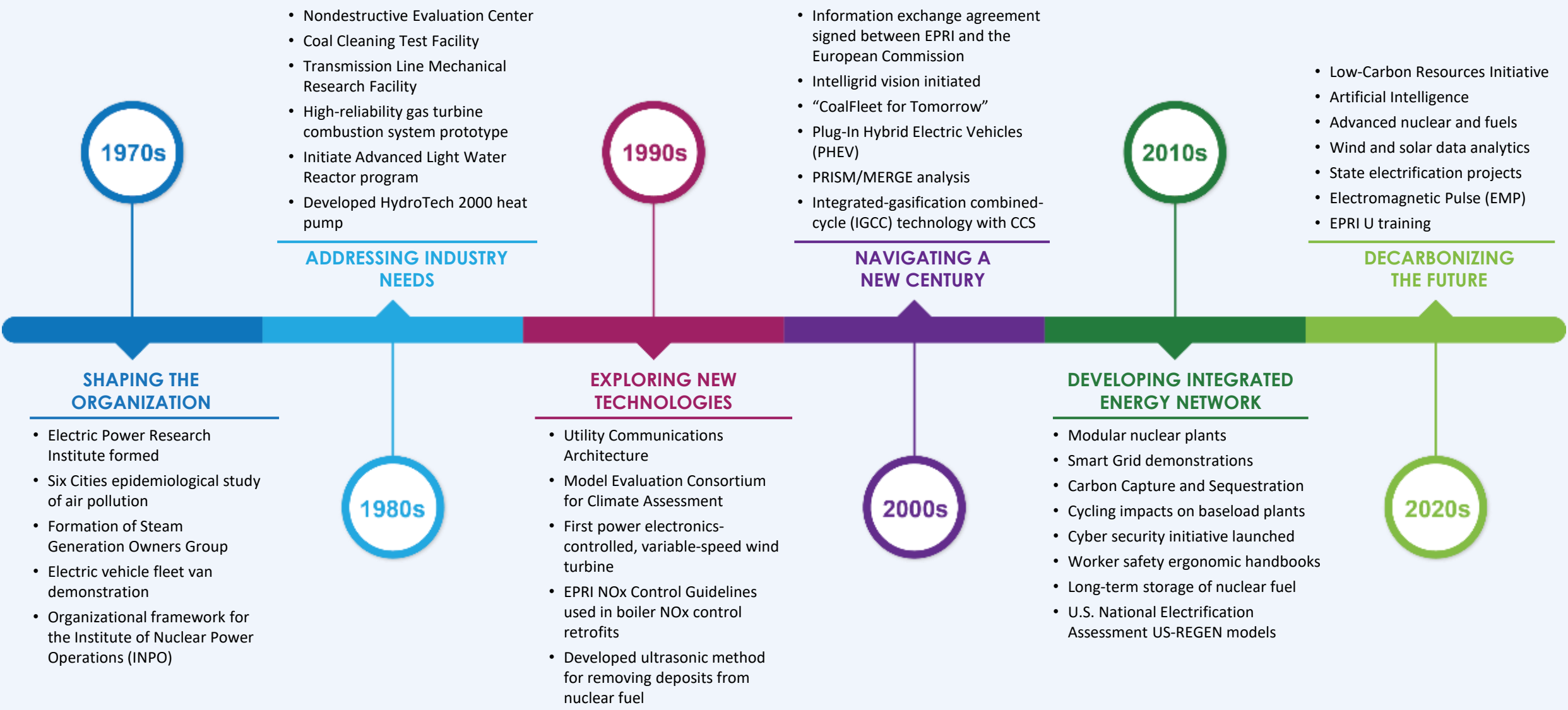
For more than 50 years, EPRI has been applying R&D to help solve real challenges.

With EPRI, you can:

- Access an industry repository of collective experiences, technical expertise, and training resources
- Extend your staff and make your teams more robust and more confident
- Benchmark, learn and share best practices
- Save time and money troubleshooting problems EPRI and its stakeholders have seen before



EPRI's Technology Milestones Over the Decades



1970s

- Nondestructive Evaluation Center
- Coal Cleaning Test Facility
- Transmission Line Mechanical Research Facility
- High-reliability gas turbine combustion system prototype
- Initiate Advanced Light Water Reactor program
- Developed HydroTech 2000 heat pump

ADDRESSING INDUSTRY NEEDS

SHAPING THE ORGANIZATION

- Electric Power Research Institute formed
- Six Cities epidemiological study of air pollution
- Formation of Steam Generation Owners Group
- Electric vehicle fleet van demonstration
- Organizational framework for the Institute of Nuclear Power Operations (INPO)

1980s

1990s

- Information exchange agreement signed between EPRI and the European Commission
- Intelligrid vision initiated
- "CoalFleet for Tomorrow"
- Plug-In Hybrid Electric Vehicles (PHEV)
- PRISM/MERGE analysis
- Integrated-gasification combined-cycle (IGCC) technology with CCS

NAVIGATING A NEW CENTURY

EXPLORING NEW TECHNOLOGIES

- Utility Communications Architecture
- Model Evaluation Consortium for Climate Assessment
- First power electronics-controlled, variable-speed wind turbine
- EPRI NOx Control Guidelines used in boiler NOx control retrofits
- Developed ultrasonic method for removing deposits from nuclear fuel

2000s

2010s

- Low-Carbon Resources Initiative
- Artificial Intelligence
- Advanced nuclear and fuels
- Wind and solar data analytics
- State electrification projects
- Electromagnetic Pulse (EMP)
- EPRI U training

DEVELOPING INTEGRATED ENERGY NETWORK

- Modular nuclear plants
- Smart Grid demonstrations
- Carbon Capture and Sequestration
- Cycling impacts on baseload plants
- Cyber security initiative launched
- Worker safety ergonomic handbooks
- Long-term storage of nuclear fuel
- U.S. National Electrification Assessment US-REGEN models

2020s

DECARBONIZING THE FUTURE

EPRI Research – Many Areas

TECHNOLOGY INNOVATION

Driving thought leadership, advanced R&D, and technology scouting and incubation to sustain a full pipeline of solutions



Nuclear Power



Energy Supply and Low-Carbon Resources



Electrification and Sustainable Energy Strategy



Transmission and Distribution Infrastructure



Integrated Grid and Energy Services

STRATEGIC RESEARCH



Low-Carbon Resources



End-Use/
Economy-Wide Carbon Reduction



Electric System Reliability/Resilience



Electric System Flexibility



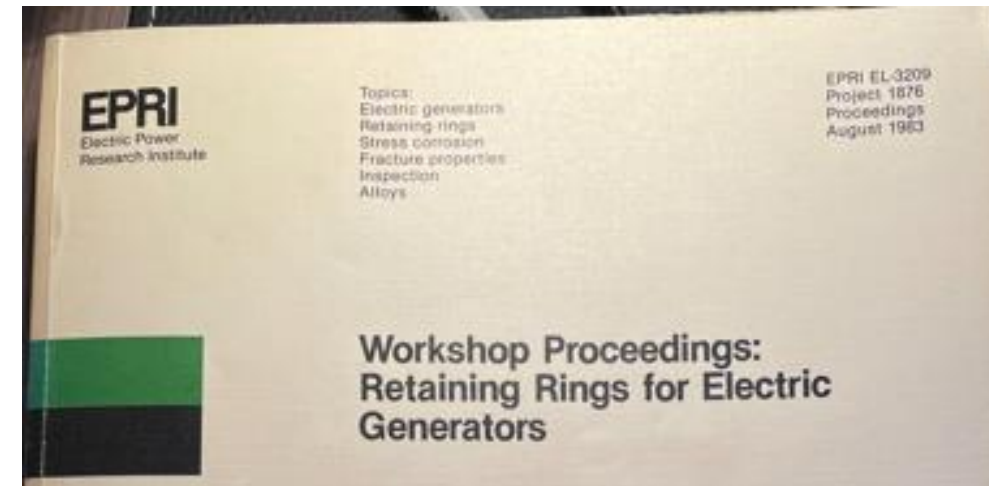
Market Transformation/
Policy/Regulatory Education

P65: Combined Steam Turbine & Generator

“The Early Years”

Retaining Ring Corrosion/Damage

- 18Mn5Cr retaining rings found susceptible to SCC (Stress Corrosion Cracking)
- Two major OEM's with vary different policies – “replace with cause” vs. blanket replacement
- EPRI provided a common meeting ground for OEM position presentations, feedback by owners and users, and industry guidelines and recommendations ([EL-3209, 1983](#))
- Generator Retaining Ring Moisture Protection Guide ([TR-102949](#)) 1993
- Evaluation of Nonmagnetic Generator Retaining Rings ([TR-104209](#)) 1994
- Risk-Informed Inspection of 18Mn 18C Generator Retaining Rings [3002003589](#) (2014)
- Review of Damage to Generator Retaining Rings [3002006238](#) (2015)



In the old EPRI days, we used to have workshops on one component. This one on RR's was in 1993.

Clip-to-Strand Water Cooled Leaks

- EPRI work in low temperature corrosion showed that phosphorus in the brazing material interacts with pure water to form acid that attacks the copper strands
- EPRI helped to advance independent analyses, repair solutions and inspection options
- Guidelines for the Procurement of On-Site Clip Replacement and Repairs of Water-Cooled Generators (TR-107680) 1996
- Stator Bar Wetness Detector (TR 108733) 1997
- Electrochemical Corrosion Potential (ECP) of Hollow Copper Strands in Water Cooled Generators, V1 Craig, V2 Tarong (1014813) 2007
- 3002000420: Turbine Generator Auxiliary System Maintenance Guide



Coil strand package with clip removed

Generator Rotor Dovetail Cracking

- Initially, 6 large rotors found with cracks/indications. Cracks in rotor dovetails at wedge butt joint location where there was also hardened material due to negative sequence current arc damage
- EPRI TGUG presentation identified that the dovetail cracking problem has occurred before on Parsons machines and helped to further define the scope of the problem
- Focused on flexible rotors with a length/rotor diameter ratio greater than 5.0 and negative sequence damage
- EPRI helped to advance independent analyses, repair solutions and particularly inspection options with retaining rings still in place
- Generator Rotor Slot Dovetail Fretting Fatigue Cracks ([1009262](#))
- TGUG Presentations



Dye Penetrant of rotor dovetail shows crack

Excessive Stator End-winding Vibration

- Broad industry issue affecting units of all manufacturers
- Coil copper strand cracking, phase lead cracking
- No clear alarm levels or action limits
- EPRI funded Generator Stator Endwinding Vibration Guide: Tutorial ([1021774](#))
- Multiple Webcasts (EPRI P65 web page): 2012-2014
- Many TGUG Presentations including a Bump Testing Panel Discussion
- Pushing towards defined “safe limits” of operation continuing with 2017 project
- Bump Test Guide published by EPRI



Failure of stator coil end turn

EPRI resources – Previous P65 Research

- Advances in Generator Monitoring, M&D Centers, & Testing
 - GEMS, MICAA, PD, Hydro-Track, AC Hipot vs. DC Hipot Testing, Many more
- Generator Rotor Arcing: Theory and Simulation **3002008541** (2016)
- Maintenance Guidelines for Generators Used in Simple and Combined Cycle Plants (**3002003590**) and Webcast June 17, 2015
- Generators in Combustion Turbine (CT) Applications: Failure Mechanisms (**3002000441**)
- Generator Fan/Blower Design, Inspection, and Maintenance: Best Practices **1025335** (2012) and Webcast: June 12, 2013

All Reports can be accessed at www.epri.com with an EPRI logon ID. Search is available without ID and many reports are publicly available!



Program 220: Generators & Auxiliary Systems **Now, its own program!**

EPRI Program 220 Generator & Auxiliary Systems



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Key EPRI Staff to Support Member Needs for Program 220

TGUG Continues – 2X/Year since 2000

- January 2022 – Hybrid, 59 Utilities, 32 Live Registrants, 120-210 Virtual Attendance
- August 2022 – Onsite only, Kansas City, MO, August 15-19
- Will Continue 2X per year, January 2023 in Savannah, Onsite only, Summer Meetings Hybrid in Charlotte

The First TGUG Meeting

June 22, 2000 Meeting in Saratoga Springs NY



- Gideon Putnam Hotel
- Combined with two-day STG Maintenance and Inspection Seminar

- 31 EPRI member attendees
- 18 companies represented
- 5 OEM attendees (representing GE, Siemens, Alstom)

- Randy Bunt (Southern Company) 1st TGUG Chairman
- First-time OEM presentations
- First-time member roundtable
- Decision made to combine TGUG with Workshops starting 2001
- TGUG Charter introduced

Monday	Tuesday	Wednesday	Thursday	Friday
New Member Tutorial		OEM Sessions <ul style="list-style-type: none"> • Siemens • GE • Mitsubishi • Toshiba 	User Group Sessions <ul style="list-style-type: none"> • User Roundtable • Operating Experience • Leadership Topics 	Subject Matter Expert Deep Dive
Generator & Turbine Parallel Sessions	Generator & Turbine Parallel Sessions			
Generator & Turbine Parallel Working Groups	Generator & Turbine Parallel Working Groups			
Supplier Technology Forum	Supplier Technology Forum	Early Career Network		

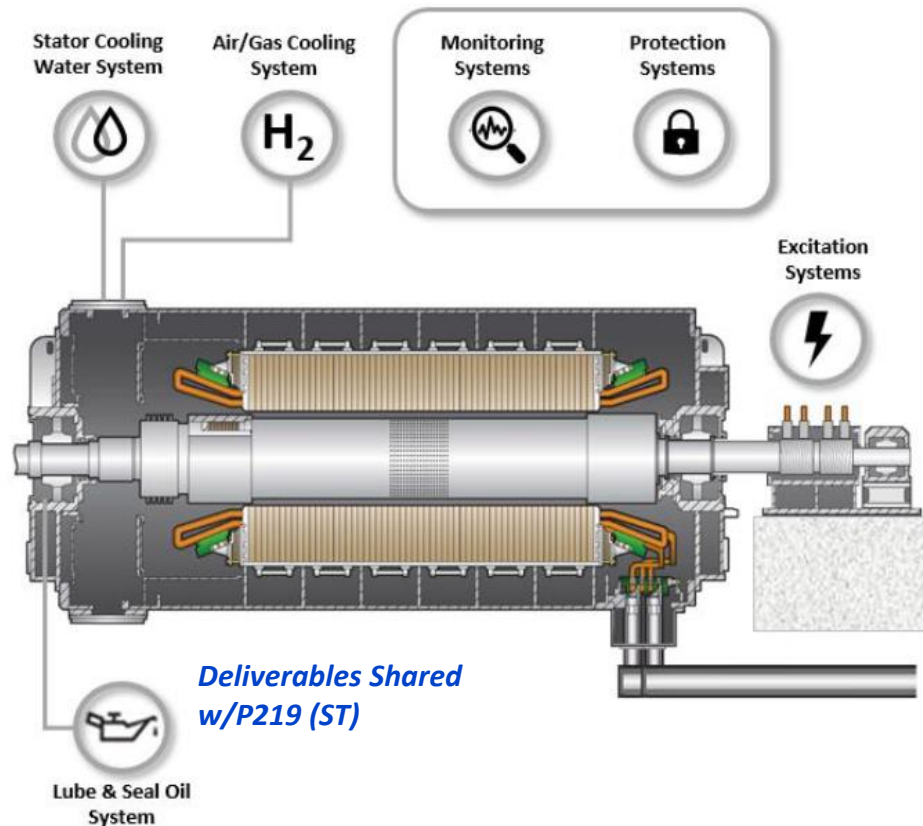
2022 Webcasts Below

(6 to 8 per year – Over 70 Past Audio Recordings & PP's Available)

Topic	EPRI Lead	Date (10:00am EDT U.S. unless noted)
Program 220 Webcast on Planned 2022 Generator Research	Prescott	March 10
Brushless Exciter Maintenance Guide Overview	Moore	April 7
Circuit Breaker Selection Fundamentals Workshop	Schaeffer	April 21
Generator Electrical Testing Field Guide Summary	Moore	May 12
Program 220 Webcast on Proposed 2023 Generator Research	Prescott	June 9
Iso Phase Bus Overheating & Monitoring	Schaeffer	July 7
Hydro Generator Research Topics: Best practices for Rewinds & Health Assessment Tool	Moore	October 13
Best Practices for SCW (Stator Cooling Water) Chemical Cleaning	Moore	November 10

Research is at the Core of What EPRI Does:

P220: Generator and Auxiliary System Component Coverage



Fossil, Hydro & Nuclear Assets

196 Published Program Deliverables

- Generator & Auxiliary Systems
 - Component Health & Reliability Risks
 - Maintenance, Assessment, and Repair
 - Inspection & Monitoring Approaches

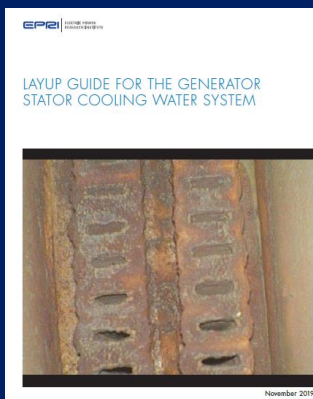
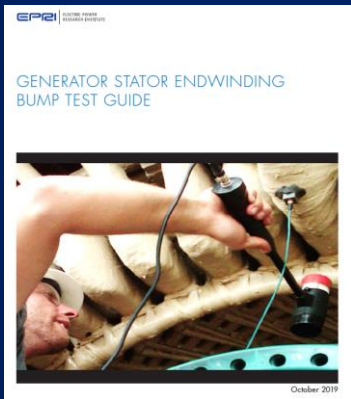
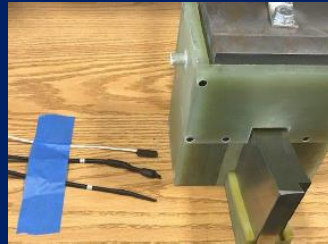
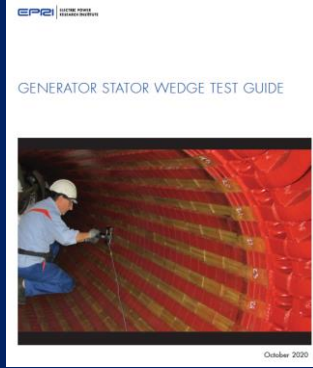
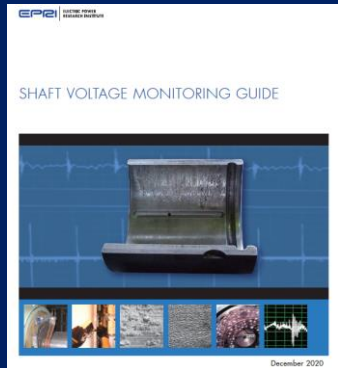
Expanding Research ...

- Hydrogenerator
- Excitation & Voltage Regulation
- Generator Protection & Relays
- Power Delivery Line Components, CT/PT/IPB



Recent Generator Research Completed 2018, 2019, 2020

EPRI Program 220: Generators & Auxiliary Systems



Research Completed in 2018, 2019 and 2020

- Stator Winding Bump Test Guide
- Generator Stator Wedge Test Guide
- Shaft Voltage Monitoring Guide
- Generator FMEA & Sensor Gap Analysis
- Outage Intervals for Generators in Flexible Operation
- PMBD Module for Air-Cooled Generators
- Operator Training Modules for Decisions on Generators with Abnormal Operation
- Generator Brazing Guidelines
- Generator Robotic Inspect & Test Guidelines
- Layup Guide for the Stator Cooling Water System
- Generator Rotor Arcing

**Research listed is not inclusive of program research activities*

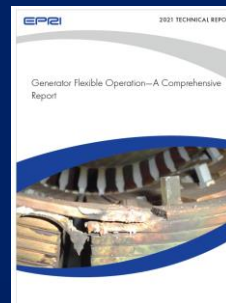
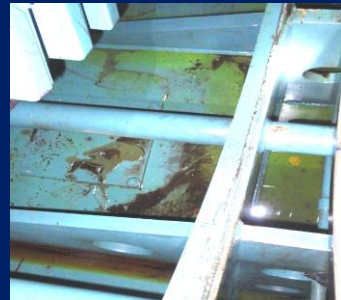
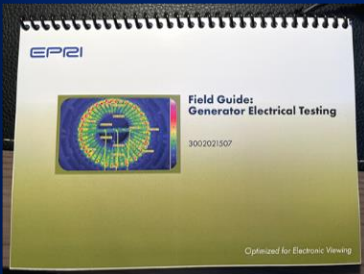


Recent Generator Research Completed 2021 & 2022

EPRI Program 220: Generators & Auxiliary Systems

Research 2021 & 2022

- Field Guide: Generator Electrical Testing
- Generator Exciter System Maintenance Guide
- Best Practices to Avoid Problems During Stator Rewinds
- Generator Health Assessment Tool (GHAT) v1.2
- Hydrogenerator Health Assessment Tool (HGHAT)
- Stator Water Cooling System Chemistry: Sourcebook
- Nuclear Generator Flexible Operation
- Generator Flexible Operation- A Comprehensive Report
- Best Practices to Avoid Problems During Hydro Rewinds
- Field Guide: EMI Sniffer
- Seal Oil Maintenance Guide
- Best Practices For Chemical Cleaning Water-Cooled Bars



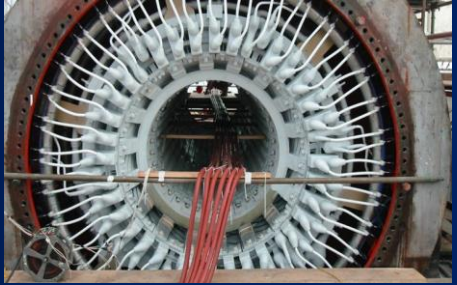
Unit	Last Evaluated	Unit Weighted Risk Summary	Stator Winding	Stator Wedge System	Stator Core	High Voltage Bushings/Terminals	Rotor Winding	Rotor Firing	Retaining Rings	Rotor Slot Wedges	Rotor Fans/Blowers	Rotor Journals	Generator Cooling System	Exciter/Automatic Voltage Regulator	Risk Tolerance Index
UNIT A	8/19/2021	45%	49%	40%	22%	14%	65%	0%	72%	33%	0%	0%	0%	5.2%	Average
UNIT B	8/19/2021	52%	49%	40%	22%	14%	65%	0%	72%	33%	0%	0%	0%	5.2%	Average

*Research listed is not inclusive of program research activities



Research on Generators in Progress Now

EPRI Program 220: Generators & Auxiliary Systems



Stator Ground Protection 59G, 27TN, 59D, 64S



Research to be Completed by Year End 2022 (in progress)

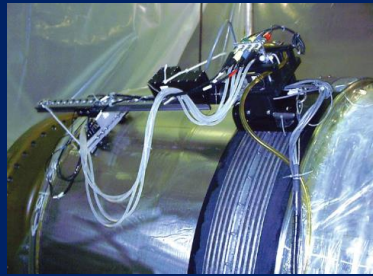
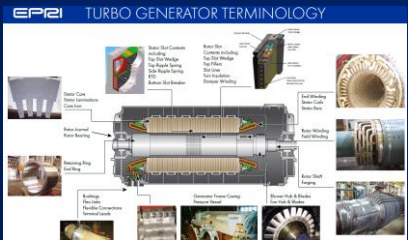
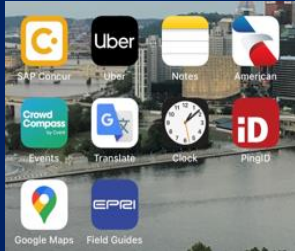
- *Lube Oil System Sensor Gap Analysis and Workbook*
- *Stator Core Inspection, Test, Repair & Replacement Guide*
- *Rotor Online & Offline Ground Detection*
- *Generator Hydrogen Use Best Practices*
- *Stator Ground Fault Detection & Protection*
- *Instrument Transformer Guide*

**Research listed is not inclusive of program research activities*



Proposed Research for 2023 & Beyond

EPRI Program 220: Generators & Auxiliary Systems



Research Proposed for 2023 & Beyond

- *Generator AVR Maintenance Guide*
- *Drone Inspections for Turbo Generators*
- *Field Guide: Generator NDE*
- *Phone App for Electrical Test Guide*
- *Field Guide: Generator Collector & Brushrigging*
- *GVPI Generators: Inspection, Repair & Replacement*
- *SF6 Experimental Research: Impact on Generators*
- *Flex Lead & Main Lead Inspection, Test & Repair*
- *Health Assessment Case Studies*
- *Generator Design & Construction Tutorial*

EPRI Hydro Generator Fast Track Health Assessment

Utility:

Unit	Last Evaluated	Unit Weighted Risk Summary	Stator Winding	Stator Wedge System	Stator Core and Frame	High Voltage Bushings/Terminals	Field Pole Winding and Pole-Connectors	Rotor Shaft, Spider and Rim	Field Pole Body, Dovetail and Endcap	Amortisseur Winding	Rotor Fans	Rotor Journals	Generator Cooling System	Collector Assembly (Rings / Brushrigging), Exciter	Risk Tolerance Index
Unit 1	5/23/2022	49%	31%	50%	4%	37%	100%	13%	39%	5%	4%	5%	53%	18%	Average

*Research listed is not inclusive of program research activities

Supplemental Projects

- 25% of Generation Membership Allocated for Self-Directed Project Participation
- METT (Manager of EPRI Technology Transfer) Responsible for Allocating Funding
- Join a Collaborative Project, or Define a Single Member Need



Popular Areas of Interest...

Root Cause Analysis	Sensor Analysis	Equipment Health Assessment
Operational Change Risk Assessment	Asset Integrity Benchmarking	Topical & Risk Training
PMBD Configuration Optimization	Supplier Quality Audit	Specification Development

Ongoing...

- Generator Health Assessment
- Back of Core Arc Detection and Monitoring
- Application of Generator Robotic Inspection

What does EPRI engagement provide?

- **Knowledge & tools help members meet significant industry challenges:**
 - Anticipate/adapt to change – variability in operations and grid transformation
 - Accelerate new approaches, technologies and mitigate risks of adoption
 - Technology scouting and quick insights
 - Leverage industry best practices – regulatory requirements and cost reductions
 - Manage aging assets and infrastructure – industry databases
 - Manage transitioning workforce

- **Participation allows members provide input on direction of research and access to program outputs & experts:**
 - Technical reports, reference guides
 - Software tools
 - Laboratories and forensic analysis
 - Training/workshops/knowledge transfer sessions
 - Technical resources for staff (an extension of the members team)
 - Participation in demonstration projects with other members

EPRI can be an Extension of Your Team

EPRI's Mission Statement

Advancing *safe, reliable, affordable,* and *environmentally responsible energy* for society through global collaboration, thought leadership, and science & technology innovation





Together, we are shaping the future of energy

Founded in 1972, the Electric Power Research Institute (EPRI) is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe.

Explore EPRI's research across the Nuclear, Generation, and Power Delivery and Utilization sectors ranging from decarbonization to grid modernization to low carbon resources.

[READ MORE](#)



Building on Our Legacy

In honor of our 50th anniversary, EPRI is



EPRI Leading Global Initiative to Address Power System Climate...



Electrification 2022 International Conference and Expo

If you have any research ideas, thoughts or comments on the presentation, or have interest in how EPRI can help you, please email Bill Moore at bgmoore@epri.com or call me at 980.229.6308.

- **Generators?**

- Stator Cores?
- Stator Winding?
- Rotors/Windings?
- Retaining Rings?
- Fans

- **Excitation/AVR?**

- Brushless?
- Static?

- **Auxiliaries?**

- IPB?
- SCWS?
- H2 Gas?
- Seal Oil?



EPRI 50th

ANNIVERSARY

Together...Shaping the Future of Energy®