

## Substations - Program 37

### Program Overview

#### Program Description

This program helps substation owners enhance safety, reliability, equipment life, and performance, as well as maximize the return on asset investments despite limited resources. It offers a portfolio of tools and technologies such as decision support analytics and transformer monitoring. The program also includes resources such as failure databases and aging models to improve transformer and circuit breaker life management and training materials for systems operators. Program results help operations and maintenance engineers extend equipment life, optimize maintenance costs, reduce outages, and reduce switching errors.

#### Research Value

This research and development (R&D) program has been grouped into two broad classes: equipment reliability and industry issues. Collectively, the goal is to develop tools, techniques, and methodologies that help improve the maintenance, specification and procurement practices, inspection, assessment, and risk-based asset management at a utility. The information provided through the collection of projects in this program will provide members with information that can help with the following:

- Extend equipment life with maintenance guidelines
- Reduce maintenance costs via condition-based maintenance
- Reduce losses via improved sulfur hexafluoride (SF<sub>6</sub>) management
- Increase awareness of high-impact low-frequency (HILF) events and be better prepared for these events
- Implement predictive maintenance practices for reduced outages
- Reduce failures of critical assets
- Reduce switching errors, increase worker safety, and prevent outages

#### Approach

Electric Power Research Institute (EPRI) substation research will yield a variety of beneficial data, knowledge, and training materials to program members. This information will be delivered in a number of forms and is expected to include the following:

- Component aging models
- Equipment diagnostic and risk-assessment tools and software
- Maintenance best-practices guidelines
- Reference books, guidelines, videos and interactive "game-based" training materials, and field guides
- Industry-wide failure databases
- Collaborative environments for sharing near misses and best practices

#### Accomplishments

In the past, the Substations program has delivered valuable information that has helped its members and the industry. Some examples include the following:

- **Transformer Industry-wide Database: Equipment Performance and Failure Database Analysis - Status Update (1023047):** The EPRI Transformer Industry-Wide Database (IDB) is a collaborative effort to pool significant transformer operating and failure data in order to assemble a statistically valid population of many types of power transformers. Analysis of these data will provide information about transformer historical performance and models for projecting future performance that may guide both asset managers and maintenance managers in their decision making. This report presents some examples of the types of analyses possible using IDB data.

- **SF<sub>6</sub> Complete Library, Version 2.0:** The SF<sub>6</sub> Computer-Based Training Modules, Version 2.0, are a set of four CDs for computer-based training on SF<sub>6</sub> safety, handling, and analysis that include the impact of SF<sub>6</sub> on the environment.
- **Industry-wide Substation Equipment Performance and Failure Database—Data, Model and Results—Electronic Media:** The electronic media provides the following information using a Microsoft PowerPoint Presentation:
  - Analytical techniques used for analyzing industry-wide data
  - Results library using data on 11,679 in-service transformers and 1185 failure records. Two types of analysis are included:
    - Analysis to better understand component and sub-system performance characteristics (e.g., tap-changers, bushings, winding failures)
    - Analysis to better understand transformer failure rates by family, make, model, application, and age
  - Data model to assist utilities in data gathering.
- **Guidelines for the Life Extension of Substation Equipment:** This material was first developed in the 1990s. It was felt that the standing collection of guidelines lacked the specific guidance and procedures to form a comprehensive maintenance and life extension program. This gap was bridged through technical content review which took place between 2005–2010. The resulting report provides the rationale and technical basis to form a comprehensive maintenance, condition assessment, and life extension program for transformers, circuit breakers, and other substation equipment.
- **Annual Switching Safety and Reliability Conference:** The conference is an opportunity for managers, supervisors, and operations personnel to exchange information about switching policies and procedures that contribute to improved safety and reliability practices. The conference addresses issues ranging from detailed switching procedures and associated software (through programs for training, audits, and incident investigation) to management strategies and policies for developing error-immune procedures and for dealing with errors and responsible individuals.

### Current Year Activities

In the coming year, the Substations program expects to accomplish these objectives:

- Industry-wide databases for substation equipment with new analysis results
- New versions of *Substation Life Extension Guidelines* with field guides and learning modules
- Transformer and circuit breaker aging models
- Transformer reference book (the Copper Book)
- Inspection and assessment strategies for Balance of Substation
- Circuit breaker life management and lubrication
- Development of fault current limiters to the 69 kV level
- Circuit breaker diagnostics using relay data
- Fault current management and substation grounding best practices
- Switching safety and reliability conference and practice sharing
- Management of legacy relays and integration of the next generation

### Estimated 2013 Program Funding

\$6.9M

### Program Manager

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## Summary of Projects

Project Number	Project Title	Description
P37.101	Transformer Life Management	Effective transformer life management via novel condition-monitoring techniques and new algorithms for turning that condition-monitoring data into actions.
P37.102	Circuit Breaker Life Management	This project performs research to help utilities better understand the implication of time- and stress-driven degradation in circuit breaker components and subsystems. This project develops tools, methodologies, and information to enable cost-effective methods for instituting condition-based maintenance or selecting the most appropriate material, work practices and tasks. It will include high-voltage and medium-voltage (13.8 kilovolt [kV] to 69 kV) breakers.
P37.103	Protection and Control	The R&D effort aims to reduce the complexity, human errors and costs associated with protection system maintenance and Protection and Control (P&C) asset management; increase the reliability and performance of P&C systems; develop guides to facilitate the deployment of next-generation P&C technologies; and address pressing P&C issues.
P37.104	Substation Ground Grid Research	This project conducts research and develops guidelines and tools for designing and evaluating the performance of substation grounding grids and for corrosion mitigation approaches.
P37.105	Other Substation Equipment: Arresters, External Insulation & Equipment Ratings	Inspection, assessment, maintenance strategies, and equipment ratings tools and methodologies will be developed for the balance of the substation in this project (i.e., all components not specifically handled in other projects).
P37.106	High Impact Low Frequency Events; With Focus on Electromagnetic Pulse (EMP)	This project will track the HILF-related threats to the electric power system. For each type of event in the HILF category, the state of the science will be provided in the threat itself, the vulnerability of the electric system to the threat, and the latest operational and hardware mitigation approaches. Regulatory changes and emerging compliance rules will be captured and communicated as well.

There are two associated supplemental projects:

1. Sunburst supports the installation and measurement of geomagnetically induced currents (GIC) monitors on participants substations. The information is combined with other host sites in the project to show in real time how storms progress across the system. These results are fed back into modeling and prediction tools, such as NASA Solar Shield, and like the models being developed in the Geomagnetic Disturbance (GMD) Supplemental project to help validate and refine the models. The information gathered in the Sunburst project improves our understanding of solar storms and their coupling with the electric grid. This is fed into the ARP project to support the risk management of HILF events.

Project Number	Project Title	Description
		2. Geomagnetic Disturbance focuses on education, vulnerability assessment, and mitigation of solar storms. Models will be developed to assess the response of the grid to given input scenarios, including severe storms that led to the collapse of the Hydro Quebec system in the early hours of March 13, 1989. The project will assess the efficacy of mitigation strategies and hardware, and develop new operational approaches and blocking devices. The results of the GMD supplemental project will be fed back into the membership research project to help companies effectively manage the risk of solar storms on their system.
P37.108	SF6 Management	This project helps members address SF <sub>6</sub> issues through improved safety, reduced SF <sub>6</sub> emissions, and enhanced knowledge capture and training.
P37.110	Switching Safety and Reliability	This project aims to develop controls and procedures that prevent errors in power switching (both in the control room and in the field), enhance worker and public safety, and improve power delivery reliability.
P37.111	Risk Based Substation Equipment Asset Management	Condition information combined with analytics based on fundamental understanding of the equipment (built, designed, operated, and maintained) are brought together to provide decision support for improved performance and risk management. Ongoing R&D efforts are focused on developing condition assessment and risk mitigation algorithms to understand existing performance for transformers and circuit breakers.
P37.112	Industry-wide Equipment Performance Database	This project provides participating utilities with aggregated data and information resources, not currently available to individual utilities to assist in developing repair/refurbish/replace strategies for aging substation equipment fleets. The project collects equipment performance and failure data in a common format from many sources to establish a database that enables statistically valid analysis to better determine equipment failure rates, identify "bad actors" early, and help identify best maintenance and specification practices.
P37.113	Next Generation Condition Monitoring and Diagnosis	This project researches and documents new technologies and implementation methodologies for condition monitoring and diagnosis of substation equipment. It also aims at increasing the understanding of the physical properties associated with failure mechanisms of individual equipment.

## P37.101 Transformer Life Management (072010)

### Key Research Question

The results from this project provide significant value to members by anticipating and preventing failures in transformers, extending transformer life, and capturing and transferring vast amounts of key knowledge. There is an increasing need for electricity companies to maximize the use of assets while maintaining system reliability. In this environment, management of the aging population of power transformers has become the most critical issue facing today's substation managers and engineers. Central to transformer management are effective transformer diagnostics, condition assessment, knowledge retention and transfer, aging assessment, and life extension. This project addresses these key issues through focused themes, and a multi-year plan of tasks to support those themes.

## Approach

Each year, results are delivered through tasks performed to address six broad themes. These include the following:

- **Novel sensors:** Under this theme, EPRI conducts research on new sensors for assessing transformer condition. The research develops specialized sensor hardware to provide insights into transformer health that are not obtainable using traditional techniques—or provide a step increase in change decrease in overall costs. Research also helps members understand new emerging sensors in the marketplace—both in the utility industry and in other industries where sensor advances could be easily translated to transformers.
- **Training and knowledge transfer:** *The Copper Book, a comprehensive transformer reference book that focuses on all aspects of transformer operation, maintenance, procurement, and life-cycle management is being developed. It is written from the perspective of a utility engineer and comprehensively addresses each phase of activity from specifications through to end-of-life. The Copper Book serves as a valuable training aid and guides engineers through case studies of common calculations necessary for transformer specification and management.*
- **Effective strategies for interpreting sensor data:** EPRI has developed a versatile Research Transformer that can be configured to simulate defects from the field. Research is being conducted on these controlled defects using a range of sensing technologies. The results are providing guidance on which sensing techniques to use first, which triggers to use to advance to different techniques, and how to grade the transformer in terms of risk posed by the defect. Members can get value directly by examining past transformer failures and simulating those exact failure modes in the Research Transformer— thus answering the question on what sensor strategies may help prevent future failures.
- **Improved accuracy in transformer remaining life assessment:** Improved estimates of a transformer's remaining life offer significant financial and reliability benefits. EPRI is researching the dynamic behavior of new chemical markers in the oil that hold the potential for significant improvements in the accuracy of transformer life estimates—possibly even without knowledge of the history of the transformer or the oil.
- **Transformer life extension:** New research has demonstrated the possibility for continuous online filtration of oxygen and moisture with new membrane technologies that offer the potential for low-cost, minimal maintenance. This would open the door for life-long filtration and corresponding life extension to the transformer.
- **Transformer forensics—linking diagnostics and maintenance with true internal condition:** EPRI research is examining retired or failed transformers and relating the evidence to both transformer operations and diagnostics data. The resulting forensics library provides members with new insights into likely end-of-life scenarios for the increasing population of aging transformers.

## Impact

- Guidance on selection, application, and interpretation of condition-monitoring techniques, through simulations of defects within a Research Transformer
- Novel sensor development, focused on laser-based optical techniques that are low-cost and highly robust
- Effective knowledge transfer through the Copper Book, a comprehensive collection of transformer knowledge designed specifically for utility owners and operators
- Improved estimates of the remaining life in transformers, providing improved insights into likely end-of-life scenarios for the increasing population of aging transformers
- Extended transformer life through application of novel filtration materials and techniques
- Improved decision-making on replacement, diagnosis, or refurbishment of transformers through the growing forensics database

## How to Apply Results

Substation engineers, designers, and operations and maintenance personnel can use this project's results to obtain greater knowledge about the condition of a transformer, enabling them to make decisions on the disposition of transformers without additional consultation, testing, and analysis. Results take the form of hardware, software, and guidebooks. The hardware prototypes will be tested in utility substations—allowing for easy future adoption. Algorithms are commonly commercialized into vendor hardware—allowing for easy adoption. The Copper Book will be a comprehensive reference book that can be used by utility personnel responsible for all aspects of transformer operation, maintenance, procurement, and life-cycle management. It will be used as a training aid and as a repository for all pertinent information on transformer ownership.

## 2013 Products

Product Title & Description	Planned Completion Date	Product Type
<b>Novel sensors - Robust and low-cost laser-based sensing technologies for DGA (Dissolved Gas Analysis):</b> In 2013 the first prototype sensor will be ready for a field trial both in a substation and in the EPRI Research Transformer. In parallel, improvements will continue in the laboratory.	12/31/13	Technical Update
<b>EPRI Copper Book Development – Final Appendices:</b> The Cooper Book will be completed through the addition of two valuable appendices. The first is an Appendix that walks the reader through how to solve the most important equations in the Copper Book using a hypothetical transformer nameplate. The second is an Appendix on Current Industry Research. The complete compilation of all chapters and appendices is issued as an electronic kit under this deliverable.	12/31/13	Technical Update
<b>Effective strategies for interpreting sensor data:</b> Through simulations in the EPRI Research Transformer of real defects that lead to failures in the field, valuable guidance will be developed on which sensing technologies are effective for the various defect types. Often multiple sensing technologies are appropriate, and the research results will help identify which techniques to use first and at what point to consider extending the investigation with further technologies.	12/31/13	Technical Update
<b>Improved accuracy in transformer remaining life assessment:</b> The research to date has identified promising new approaches to assessing remaining life. The approaches have worked well in the laboratory, and in 2013 we will move into a substation setting and validate the results in the field. The results will help utilities manage this important fleet of assets.	12/31/13	Technical Update
<b>Transformer life extension - Membrane technologies for lifelong oil filtration:</b> Under this project, cost-effective and low-maintenance membrane technologies have shown strong potential for life extension of transformers. In 2013 the laboratory results will be validated using a field prototype in a substation and on the EPRI Research Transformer. The results will help guide the members on how and where to effectively apply this new development.	12/31/13	Technical Update
<b>Transformer Forensics Library:</b> The forensics library allows utilities a unique perspective on a wide range of transformer inspections and the condition monitoring data that preceded the tear-down. The results are of significant value to decision-making on how to prevent failures or extend life of a fleet of transformers.	12/31/13	Technical Update

## Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<b>Novel sensors:</b> Extension of gas detection limits for robust and low-cost laser-based sensing technologies for DGA (Dissolved Gas Analysis)	12/31/14	Technical Update
<b>Effective strategies for interpreting sensor data:</b> Extended range of defects simulated in the EPRI Research Transformer	12/31/14	Technical Update
<b>EPRI Copper Book Training:</b> Workshop Training based on the completed EPRI Copper Book	12/31/14	Workshop, Training, or Conference
<b>Improved accuracy in transformer remaining life assessment:</b> Wrap-up of field trials and development of an application guide for the use of new markers for improved transformer life assessment	12/31/14	Technical Report

## P37.102 Circuit Breaker Life Management (072011)

### Key Research Question

The life-cycle performance of power circuit breakers is, to a large degree, determined by the performance of constituent materials and components. Some component deterioration (for example, linkages and interrupter) is not time dependent, while the rate of deterioration of lubricants and seals is. Together, the performance of these elements drives the requirements for maintenance and refurbishment. Despite the importance of these issues, utilities have little quantifiable data or a complete understanding of breaker material and subsystem performance to enable cost-effective methods for instituting condition-based maintenance or selecting the most appropriate work practices and tasks. This research will develop the tools, methodologies, and information to address these gaps for high-voltage circuit breakers and extend this application to medium-voltage (13.8 kilovolts [kV] to 69-kV) breakers.

### Approach

To address these needs, in 2013 this project will undertake the following:

#### Circuit Breaker Lubrication:

- Conclude laboratory testing of field-aged grease samples, better understand material composition, and degradation characteristics
- Conclude short-term and long-term laboratory tests on commonly used greases (mineral oil, synthetic or fluoro-silicones) to better understand performance (aging and degradation characteristics, effect of ambient environment, compatibility issues)
- Conclude analysis of field-aged bearings (roller, needle, and ball) from key locations in the circuit breaker operating mechanism (for example, trip latch bearing)
- Initiate development of engineering application guide for circuit breaker lubrication selection and compatibility
- Update existing pocket field guides (high-voltage circuit breaker [HVCB] Lubrication and HVCB Pumps and compressors) with new material

#### Circuit breaker life extension:

- Based on direction established using the roadmap developed in 2012, review the overall content and organization of the guide.
- Initiate the task to rewrite the guide in its entirety. It is anticipated that in 2013 material such as fundamental description, operating and design application principles, maintenance, monitoring, and replacement will be reviewed and specific chapter(s) developed based on utility guidance.

**Component degradation on circuit breaker operation:** The objective is to provide utilities guidance on the most informative and cost-effective procedures to provide information for effective condition-based maintenance. Characterize possible consequences of degraded components on circuit breaker operation (for example, slow trip, abnormal mechanism wear, lubrication, compressor/pump failures) through the following tasks:

- Catalogue failure reports and any other information available from circuit breaker failure events and/or utility root cause analysis
- Documenting industry practices in circuit breaker routine maintenance, diagnostic testing, and overhaul
- Initiating development of component and subsystem failure database
- Catalogue utility experiences of using digital relays for circuit breaker diagnostics: logic, setting changes, and application.

**Innovative algorithms for circuit breaker dielectric condition assessment:** In 2013, initiate a multi-year effort to research, develop, and apply rule-based expert system algorithms that can help to provide information for condition-based maintenance of oil-filled and sulfur hexafluoride (SF<sub>6</sub>) circuit breakers. 2013 task will include concept development. Future year work may include methodology enhancement, prototyping, and additional experience gathering. Associated supplemental projects may be initiated to assist with field demonstrations and testing.

**Effectiveness Assessment of Circuit Breaker Diagnostic Tests:** Initiate a multi-year research initiative to develop and apply assessment metrics to select various high voltage circuit breaker diagnostic techniques. The objective is to provide utilities guidance on the most informative and cost effective procedures to provide information for effective condition based maintenance. The 2013 tasks will include utility use case and experience collection, data analysis, and the development of assessment methodology. Future-year work may include methodology application and solicitation of feedback through field demonstrations and laboratory tests.

#### **Technology Transfer:**

- Develop and deliver an annual circuit breaker life management workshop

Combined knowledge gained about circuit breaker component and sub-system performance from the above tasks enables utilities to develop the following:

- A quantitative understanding of aging and deterioration rates
- Expected life of circuit breaker component materials and subsystems
- Enhanced cost-effective methods for implementing a condition-based maintenance approach

#### **Impact**

As circuit breaker maintenance intervals are extended, the risk of exceeding the useful life of individual components and subsystems increases. Increased knowledge of lubrication and component performance is expected to result in increased circuit breaker availability and reduced maintenance costs. Members will gain the following benefits:

- More effectively utilize maintenance resources
- Avoid capital investment for replacement breakers via more effective maintenance of existing assets
- Increase reliability through improved circuit breaker operations as a result of enhanced maintenance effectiveness and better condition assessment

#### **How to Apply Results**

Project funders can use project results to implement more effective and efficient circuit breaker maintenance programs and improve their selection, specification, procurement, and application practices.

## 2013 Products

Product Title & Description	Planned Completion Date	Product Type
<p><b>Circuit breaker lubrication compatibility &amp; selection – laboratory assessments:</b> This product builds on research done in 2012 and adds new information to summarize the results of ongoing research:</p> <ul style="list-style-type: none"> <li>Continued laboratory testing of field aged-grease samples to better understand material composition and degradation characteristics</li> <li>Continued long-term laboratory tests on commonly used greases (mineral oil, synthetic, or fluoro-silicones) to better understand performance (aging and degradation characteristics, effect of ambient environment, compatibility issues)</li> <li>The 2013 report will provide a final report on methodology, underlying approach, and test results.</li> </ul>	12/31/13	Technical Update
<p><b>Circuit breaker lubrication compatibility &amp; selection - engineering application guide:</b> Since 2006, EPRI has undertaken a significant effort to better understand the challenges of circuit breaker lubrication. To that end, laboratory investigations and field application have produced results that provide the rationale and methodology to assist with circuit breaker lubrication selection and compatibility. Through a two-year effort, this product will document in detail the rationale, methodology, underlying approach, and test results with the ultimate objective of serving as an engineering application guide to help utilities improve their circuit breaker lubrication practices. This work will complement other EPRI efforts associated with circuit breaker knowledge capture, training, field guide development, and maintenance.</p>	12/31/13	Technical Update
<p><b>New Versions of Pictorial Field Guides – Power Circuit Breaker component degradation assessment:</b> New versions of pictorial field guides will use results from ongoing studies to characterize the aging of circuit breaker components and provide application-specific guidance in a pocket guide format for utility field staff. Existing versions of two field guides—<i>HVCB Lubrication Guide</i> and <i>HVCB Pumps, Compressors and Control Valves</i>—will be updated with new material.</p>	12/31/13	Technical Update
<p><b>Life Extension Guideline for Circuit Breakers:</b> This reference guide is specifically designed to help substation owners operate and maintain circuit breakers. This guide helps members initiate a new maintenance, condition assessment, or life extension program, or refine an existing one. Based on direction established using the roadmap developed in 2012, the overall content and organization of the guide was reviewed. Revision of the guide in its entirety will begin in 2013. It is anticipated that material such as fundamental description, operating and design application principles, maintenance, monitoring, and replacement will be reviewed and specific chapter(s) will be developed based on utility guidance.</p>	12/31/13	Technical Update
<p><b>Effectiveness Assessment of circuit breaker diagnostic tests:</b> This product will be part of a multi-year research initiative to develop and apply assessment metrics to select various high-voltage circuit breaker diagnostic techniques. The objective is to provide utilities guidance on the most informative and cost-effective procedures to provide information for effective condition-based maintenance. 2013 tasks will include utility use case and experience collection, data analysis, and the development of an assessment methodology. Future year work may include methodology application and soliciting feedback through field demonstrations and laboratory tests.</p>	12/31/13	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<p><b>Effect of component degradation on circuit breaker operation :</b> This product builds on previous research and adds new information through a multi-year effort to summarize the results into characterizing the possible consequences of degraded components on circuit breaker operation (for example, slow trip, abnormal mechanism wear, lubrication, compressor/pump failures) through the following means:</p> <ul style="list-style-type: none"> <li>Catalogue failure reports and any other information available from circuit breaker failure events and/or utility root cause analysis</li> <li>Documenting industry practices in circuit breaker routine maintenance, diagnostic testing, and overhaul</li> <li>Initiating development of a component and sub-system failure database</li> <li>Catalogue utility experiences of using digital relays for circuit breaker diagnostics</li> </ul>	12/31/13	Technical Update
<p><b>HVCB Life Management Workshop:</b> This annual workshop will include tutorials on the material contained in the project's products, presentations on utility experiences, and examples of the application of the project's results.</p>	12/31/13	Workshop, Training, or Conference

**Future Year Products**

Product Title & Description	Planned Completion Date	Product Type
<p><b>Innovative Algorithms - Circuit Breaker Dielectric Condition Assessment:</b> This product will be part of a multi-year research initiative to research, develop, and apply innovative rule-based expert system algorithms that can assist in providing information for effective condition-based maintenance of oil-filled and SF<sub>6</sub> circuit breakers. 2013 task will include concept development. Future year work may include methodology enhancement, prototyping, and additional experience gathering. Associated supplemental projects may be initiated to assist with field demonstrations and testing.</p>	12/31/14	Technical Update
<p><b>Circuit breaker lubrication compatibility &amp; selection - engineering application guide:</b> Since 2006, EPRI has undertaken a significant effort to better understand the challenges of circuit breaker lubrication. To that end, laboratory investigations and field application have produced results that provide the rationale and methodology to assist with circuit breaker lubrication selection and compatibility. Through a two-year effort, this product will document in detail the rationale, methodology, underlying approach, and test results, with the ultimate objective of serving as an engineering application guide to help utilities improve their circuit breaker lubrication practices. This work will complement other EPRI efforts associated with circuit breaker knowledge capture, training, field guide development, and maintenance.</p>	12/31/14	Technical Update
<p><b>Effectiveness Assessment of circuit breaker diagnostic tests:</b> This product will be part of a multi-year research initiative to develop and apply assessment metrics to select various high-voltage circuit breaker diagnostic techniques. The objective is to provide utilities guidance on the most informative and cost-effective procedures to provide information for effective condition-based maintenance. Future year builds on work done in 2013 and may include methodology application and soliciting feedback through field demonstrations and laboratory tests.</p>	12/31/14	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<p><b>Life Extension Guidelines for circuit breakers:</b> This reference guide is specifically designed to help the substation owners operate and maintain circuit breakers. This guide helps members initiate a new maintenance, condition assessment, or life extension program, or refine an existing one. Based on direction established using the roadmap developed in 2012, the overall content and organization of the guide was reviewed. Revision of the guide in its entirety will begin in 2012. It is anticipated that material such as fundamental description, operating and design application principles, maintenance, monitoring, and replacement will be reviewed and specific chapter(s) will be developed based on utility guidance. Future year tasks will develop material for additional chapters according to the outline and based on utility guidance.</p>	<p>12/31/14</p>	<p>Technical Update</p>

**P37.103 Protection and Control (072012)**

**Key Research Question**

The utility protection and control (P&C) infrastructure, driven by the fast-evolving technologies from electronics, communication, and information technology, has experienced revolutionary changes throughout the past three decades. Meanwhile, utilities are facing the challenges in many areas:

- Increasing complexity of modern P&C technology and asset management
- Tighter regulation on protection system maintenance and reliability
- Growing needs for knowledge retention and new skill-set development
- Shorter life cycle of microprocessor-based relaying assets
- Needs for standard-based next generation P&C technologies

The project will develop effective methodologies and tools, collect industry experiences and create application guides to help members overcome the challenges.

**Approach**

The project will use multi-year approaches to address five broad themes. Each year, research tasks will be conducted to achieve the targeted milestones and planned deliverables.

**1. Optimal maintenance for modern P&C systems:** The reliability and performance of protection systems largely depends on the well-established maintenance programs. The traditional time-based maintenance (TBM) is high-cost, low-efficiency, and prone to human errors. On the other hand, modern P&C technologies provide utilities with various opportunities and desirable non-intrusive methodologies to develop next-generation protection system maintenance programs. Three approaches will be explored:

- Condition based maintenance (CBM)
- Event-analysis based maintenance (EBM)
- Performance based maintenance (PBM)

By selectively combining CBM, EBM, and PBM to create an optimized maintenance program, it can help utilities achieve the goals of reducing unnecessary maintenance activities, minimizing human errors, lowering maintenance costs, and increasing overall P&C system reliability.

**2. Configuration and setting management for P&C systems:** Errors in configuration or setting can directly lead to protection system failure, therefore tightly managed processes and quality controls are necessary to help utilities maintain the high reliability of protection systems and meet increasing regulatory requirements. The challenges in setting and configuration management are due to many factors, which include ever-growing

complexity and flexibility of the configurable parameters in digital relays, proprietary data format created by various vendors, and lack of effective tools for managing and keeping track of the configuration or setting throughout its entire life cycle. To meet the challenge, three approaches will be explored:

- Collect utility experiences and generate good practices
- Perform technology assessment of management tools and commercial products
- Track progress of developing common data format on protection settings

**3. Life-Cycle Management of Protection, Control and Associated Data Acquisition Infrastructure:** Utilities are facing the increasing challenge in life-cycle management of a highly diverse and fast-evolving P&C infrastructure. Most installed electro-mechanical relays or first-generation microprocessor relays are aging and close to their designed life cycle. Meanwhile, newly installed digital relays and data acquisition systems have an anticipated shorter life span than the primary equipment being protected. Sound life-cycle management strategies and approaches are necessary for utilities to ensure smooth transitions and facilitate equipment replacement or upgrade in the foreseeable future. The project will perform utility needs assessment, conduct forward and strategic thinking, collect and document good practices, and address the practical issues such as relay firmware upgrade, software version control, spare parts policy, and knowledge retention for legacy systems.

**4. Development of next generation protection, control and automation systems based on the IEC 61850 standard:** The International Electrotechnical Commission (IEC) 61850 standard and communication technology lays the foundation for developing next-generation protection control and substation automation technology. Adoption of the standard will have a profound impact on today's utility practices. The project aims to help utilities explore the opportunities of new technologies and overcome the challenges in the following areas:

- Design, engineering, and documentation of IEC 61850-based P&C systems
- Testing and maintenance in the new IEC 61850 environment
- Communication network and tools in support of mission-critical P&C applications
- Assistance in education and learning of emerging technologies

The project will take the following approaches:

- Host an annual workshop to facilitate industry-wide collaboration and experience sharing on field implementation of IEC-61850 based protection, control, and substation automation technologies
- Collect, document, and share good practices, lessons-learned, and success stories
- Keep members abreast of the state-of-the art IEC 61850 technologies and latest development of the standard

**5. Mitigation of the AURORA threat through P&C engineering practices – phase III:** The North American Electric Reliability Corporation (NERC) issued the AURORA alert to industry in 2010 and raised the industry-wide concern on the safety of the generator and motor fleet. One mitigation direction for the AURORA threat is to identify and fill the gap through protection engineering practices. This project aims to help utility staff obtain a better understanding of the system vulnerability, and develop P&C methods and tools to assist risk assessment and mitigation. The project will study the protection functions in protective relays and hardware mitigation devices, develop risk assessment criteria and tools, perform case studies, and collect and recommend approaches and practices for risk mitigation.

## Impact

- Increase protection system reliability, lower maintenance costs, reduce human errors
- Help utilities meet regulatory and compliance requirements
- Improve protection data management and asset life-cycle management
- Promote industry-wide learning and sharing of IEC 61850 project experiences
- Obtain a better understanding of the AURORA vulnerability and mitigation methods

**How to Apply Results**

Utilities can selectively apply the approaches, methodologies, guides, and technologies developed in the projects to create their own optimal maintenance programs and asset life management solutions for protection systems; support and guide IEC 61850 projects and field deployment; and assist in the risk mitigation of the AURORA threat.

**2013 Products**

Product Title & Description	Planned Completion Date	Product Type
<p><b>Optimal Maintenance for Protection and Control Systems:</b> The project will continue the needs assessment and technology evaluation to help utilities develop condition-based maintenance (CBM), event analysis-based maintenance (EBM), and performance-based maintenance (PBM). More specifically, the following tasks will be conducted:</p> <ul style="list-style-type: none"> <li>Perform vendor surveys on protective relaying and associated communication systems to investigate the enabling technologies for CBM</li> <li>Conduct case studies of real-world post-event analysis to develop the practical approaches and methodology for EBM</li> <li>Perform needs assessment and identify data requirement for PBM</li> </ul> <p>The product will provide a technical guide, in phased approach, for utilities to develop their own optimized maintenance programs by leveraging the opportunities of CBM, EBM, and PBM.</p>	12/31/13	Technical Update
<p><b>Configuration and Setting Management for Protection and Control Devices and Systems:</b> In 2013, the project will continue to conduct the following tasks:</p> <ul style="list-style-type: none"> <li>Perform case studies by collecting and documenting good experiences and effective processes across member utilities, generate good practices based on case study results</li> <li>Keep track of the industry effort and progress on standardizing protection settings using common data format will be explored</li> <li>Engage vendors to perform technology assessment of configuration management tools</li> </ul> <p>The technical update product will document all the research findings and project progress.</p>	12/31/13	Technical Update
<p><b>EPRI Protection Control and Automation Workshop:</b> This product includes an annual IEC 61850 workshop with specific focus on protection, control, and substation automation technologies; a Technical Update including the workshop proceedings; and the latest IEC 61850 technology development. In addition, the product will document success stories and use cases from the IEC 61850 projects across member utilities. The outcome of the research work can help utility technical staff obtain a good understanding of the state-of-art utility adoption of the standard, as well as practical challenges in deploying the IEC 61850 standard in substations.</p>	12/31/13	Workshop, Training, or Conference
<p><b>Lifecycle Management of Protection, Control and Associated Data Acquisition Infrastructure:</b> The product will perform R&amp;D based on the needs assessment of previous results, continue identifying gaps, and develop a methodology to assist utility protection and control staff and asset managers in developing a strategy for infrastructure management.</p>	12/31/13	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<p><b>Mitigation of the AURORA Threat through Protection Engineering Practices:</b> This product will provide technology assessment on protection functions in HMD (hardware mitigation device) and protective relays; perform case studies using practical model and data provided by member utilities; develop risk assessment criterion that can be applied to screen vulnerable generator units; recommend risk mitigation approaches and available options from the perspective of protection engineering practices.</p>	12/31/13	Technical Update

### Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<p><b>EPRI Protection Control and Automation Workshop:</b> This product will include an annual IEC 61850 workshop with specific focus on protection, control, and substation automation technologies; a Technical Update including the workshop proceedings; and the latest IEC 61850 technology development. In addition, the product will document success stories and use cases from the IEC 61850 projects across member utilities. The outcome of the research work can help utility technical staff obtain a good understanding of the-state-of-art utility adoption of the standard as well as practical challenges in deploying the IEC 61850 standard in substations.</p>	12/31/14	Workshop, Training, or Conference
<p><b>Optimal Maintenance for Protection and Control Systems:</b> The product will provide an update on the progress of developing condition-based maintenance (CBM), event analysis-based maintenance (EBM), and performance-based maintenance (PBM); summarize vendor survey findings to present the state-of-the-art self condition monitoring of protective relaying and associated communication systems; continue documenting and assessing the enabling technologies for each maintenance approach; propose R&amp;D plans for identified technical gaps; and provide a guide (phased approach) for utilities to develop their own optimal maintenance programs by leveraging the opportunities of CBM, EBM, and PBM.</p>	12/31/14	Technical Update
<p><b>Configuration and Setting Management for Protection and Control Devices and Systems:</b> This product will continue to collect use cases with the support of members; continue to provide updates of the industry progress on development of common data format for protection settings; and continue to develop a guide to help utilities manage the settings and configurations for a large P&amp;C asset fleet.</p>	12/31/14	Technical Update
<p><b>Lifecycle Management of Protection, Control and Associated Data Acquisition Infrastructure:</b> The product will perform R&amp;D based on the needs assessment of previous results, continue to identify gaps, and develop a methodology to help utility protection and control staff and asset managers develop a strategy for infrastructure management.</p>	12/31/14	Technical Update
<p><b>Emerging Issues in Protection and Control:</b> The product will address the emerging protection and control issues suggested by task force members.</p>	12/31/14	Technical Update

## P37.104 Substation Ground Grid Research (072013)

### Key Research Question

A substation ground grid is an essential component of the substation. It must do the following:

- Serve as a safety feature for any personnel who may be in the substation during a fault
- Minimize hazards to the public, such as step-and-touch voltages near the substation
- Provide adequate ground for substation equipment—especially control room electronics

The ground grid must be carefully designed to ensure that even the worst occurring faults will not harm the staff or the public and will not damage substation equipment. Today, substation ground grids are receiving more attention because of their advanced age and increasing fault current levels. Facilities that were designed and installed 50 or more years ago were often based on a calculated fault current from the generation sources and interconnections of that time. Although the common practice then was to base the design on a conservative calculation of available fault levels, over the years additional generation and introduction of increased power flow measures (such as high-temperature conductors) have resulted in increased fault current levels. At the same time, there are sites at which enough corrosion of the grid, damage (perhaps not immediately noticeable) due to construction and other factors, and copper theft have occurred over the decades to measurably decrease the effectiveness of the ground grid. Research is required to develop ways to refurbish grids that may have deteriorated over the years.

### Approach

In the early 1980s, EPRI developed software for the design of substation grounding grids. EPRI developed the Smart Ground Multimeter (SGM), a sophisticated electronic instrument for measuring substation ground grid impedance and other parameters without requiring an outage. Final enhancements were completed in 2006. Building on these accomplishments, this project conducts a study of ground grids, substation grounding designs, and substation ground surface conditions, with a focus on enhancing fault current ratings of ground grids, refurbishing deteriorated grids, and minimizing hazards within and outside the substation. This activity includes full-scale tests to verify the studies and their recommendations. Project products include data and guides on the design and construction of new ground grids with increased current ratings, ground grids to which an incremental area is being added, ground grids that must be augmented to increase their fault current rating, and the characteristics of substation ground surface finish (gravel, asphalt, concrete). The research can lead to providing advice on when to consider the possibility of corrosion of the ground grid, what choices can minimize the degradation of corrosion, and how deteriorated grids can be detected, assessed, and refurbished most economically. Results also can be used to enhance industry standards such as Institute of Electrical and Electronics Engineers (IEEE) 80, 81, and 837.

### Impact

- Improve the ease and accuracy of evaluating the adequacy of installed grounding systems.
- Provide effective methods to design and install new grids, bolster grids that have deteriorated, or improve grids that need upgrading because of higher fault current levels
- Quantify the properties of various ground surface materials (gravel, asphalt, concrete)
- Increase public safety and substation worker safety in areas adjacent to the substation via design of high-quality substation ground grids
- Increase the quality of reference ground for substation electronic equipment to minimize misoperations and failures

### How to Apply Results

Members can use ground grid design, maintenance, and refurbishment research results and guides developed in this project for planning new grids and enhancements to existing grids; evaluating the condition and degree of deterioration of existing grids to ensure public and worker safety and proper operation of substation electronic equipment; and developing grid repair decisions based on economics and enhancement of industry standards.

**2013 Products**

Product Title & Description	Planned Completion Date	Product Type
<b>Corrosion rates, effect of soil properties:</b> Based on surveys, connector aging tests, and analyses conducted in previous years, this product will summarize the findings in a final Technical Report and provide general guidelines and recommendations for remedial and mitigation approaches to minimize substation ground grid corrosion.	12/31/13	Technical Update

**Future Year Products**

Product Title & Description	Planned Completion Date	Product Type
<b>Develop cost-effective approaches to augmenting or repairing substation ground grids:</b> Substation ground grids may not meet performance requirements because of increasing fault currents, deterioration over time due to corrosion, damage (perhaps not immediately noticeable) due to construction and other factors, copper theft, and other issues. This product will include essential data and guides for augmenting or repairing grids to increase their fault current rating and grounding effectiveness. As an example, the guidelines may include case studies that provide percentage increase in a grid's capability when the grid is augmented with a specific grid section, or when additional ground rods are installed.	12/13/14	Technical Report
<b>Ground grids for HVDC substations :</b> Many utilities are considering converting ac lines to dc and/or building new dc lines, which will require installation of dc substations. Essential data are lacking regarding grid design for dc substations. This product will help fill this knowledge gap.	12/31/15	Technical Update
<b>New materials (replacement for copper) – grid, pigtails:</b> Copper theft and deterioration (corrosion) of substation ground grids are major concerns to utilities. This product will provide an overview of alternate materials that could be used in place of copper for substation grids, and it also will assess their performance characteristics.	12/31/16	Technical Update
<b>"Blind study" - three audits ("as is," "damaged," "repaired"):</b> Conduct a three-stage "blind" study using the Smart Ground Multimeter: <ul style="list-style-type: none"> <li>Assess the "as-is" condition of an aging (possibly damaged) ground grid</li> <li>Assess the condition of the grid in the same substation after unknown modifications (additional damages) are performed by the utility, without informing the researchers of the details of the modifications</li> <li>Assess the condition of the grid in the same substation after repairs are performed by the utility, without informing the researchers of the details of the repairs</li> </ul>	12/31/16	Technical Report

## **P37.105 Other Substation Equipment: Arresters, External Insulation & Equipment Ratings (065593)**

### **Key Research Question**

Increasing the reliability, safety, and life of substation equipment requires timely and effective maintenance based on accurate inspection and knowledge of equipment condition. Additionally, the demand for electric power over transmission circuits is increasing faster than substation assets can manage. This trend has pushed the capacity of many existing transmission circuits to their design limits. Also, much of the grid has already aged beyond its original design specifications.

To increase the reliability, safety, and life of substation equipment, personnel need to understand the balance of substation equipment, their degradation and failure modes, thermal ratings, and current industry inspection and assessment practices. Availability of new technology, coupled with a loss of institutional knowledge, increases the challenge facing substation owners. Engineering and maintenance staffs need to remain abreast of the latest inspection developments and assessment techniques to be able to select the appropriate course for their particular circumstances. Field personnel need tools and training to ensure that correct and consistent decisions are made.

### **Approach**

Balance of Substation includes all components and assets in the substation other than the components handled specifically in other projects (i.e., apart from transformers, circuit breakers, Gas Insulated Substations, ground grid, protection and control devices). Other components addressed include, but are not limited to: external insulation, disconnect switches (manual and motor operated), current transformers (CTs), voltage transformers (VTs), capacitor banks and ground switches, concrete foundations, station batteries, and insulators in substations.

To meet the research needs, EPRI will continue to do the following:

- Build on previous research and maintain a "living" needs assessment and R&D roadmap to identify and address outstanding issues for each substation asset type.
- Develop a better understanding of associated issues such as design, vintage and type issues, failure mechanisms, and degradation modes. In this task, work will focus on equipment of interest. Based on available funding, the Task Force will prioritize components of interest and, based on priority, sample-gathering guidelines will be provided and a test plan developed.
- Develop software tools and methodologies related to equipment thermal ratings. A Transmission Ratings Workstation (TRW) will be created. The efforts under this project will focus on the ratings modules for other substation equipment (e.g., disconnect switches, buss work)
- With appropriate effort, applicable research in other equipment areas can be adapted and applied to ongoing R&D in other substation equipment. One example is the impact of contamination on insulator performance.

In 2013 this project will undertake the following tasks:

- **Life Extension Guidelines**
  - Based on the direction established using the roadmap developed in 2012, review the guide's overall content and organization.
  - Initiate the task to rewrite the guide in its entirety. It is anticipated that in 2013 material on disconnect switches, current transformers, and arrestors will be reviewed and developed based on utility guidance.

- **Transmission Ratings Workstation (TRW)**
  - This software will incorporate all EPRI equipment ratings-related software modules under one roof.
  - Efforts under this project will focus on the ratings modules for other substation equipment (e.g., disconnect switches, buss work).
  - A beta version of the software will be delivered in 2013.
- **External Insulation**
  - **In-service testing of Surge Arrestors**
    - Better understand underlying failure modes and degradation mechanisms
    - Develop, demonstrate, and document prototype test and measurement technology to effectively assess surge arrestors in the field without removing them from service.
- **Current transformers**
  - Conduct a knowledge review to document different current transformer designs in service at utilities, as well as their applications.
  - Catalogue examples or samples of utility-related problems or parts failures. Using a web-based survey, document industry practices and experiences of root-cause analysis and failure investigations.
  - Through needs assessment, identify tasks that require laboratory testing or tasks that are essential to better understand fundamental failure modes and degradation mechanisms through aging tests. Develop and communicate a plan.
- **Concrete foundations**
  - Assess current utility practices using a web-based survey, analyze results, document gaps, and develop a plan to communicate areas that require further development.

The following topics will be addressed in future years:

- **Substation insulators: Resistive Glaze and RTV Coatings**
  - Document the performance and application of resistive glaze insulators and insulation treated with room-temperature vulcanized (RTV) coatings.
- **Dimensioning guidelines for applying insulators in contaminated environments**
  - Develop guidance for dimensioning external insulation and applying booster sheds and shed extenders in substations located in contaminated environments.

## Impact

- Reduces overall maintenance costs, projects operations and maintenance (O&M) cash flow, minimizes unplanned expenses, and maximizes the benefit and value of planned work
- Improves reliability and availability via reduced reliance on time-based maintenance by using asset health and condition analysis to determine maintenance actions
- Enables more effective use of existing infrastructure and data and efficient use of maintenance personnel to manage operational risk
- Enables a more effective optimization of substation equipment ratings

## How to Apply Results

Using project results, participants can assess equipment condition early and implement risk-informed maintenance and asset management decisions based on industry-wide best practices and the most advanced techniques. Results will facilitate knowledge retention and aid in training personnel.

## 2013 Products

Product Title & Description	Planned Completion Date	Product Type
<b>Life Extension Guidelines for Other Substation Equipment:</b> This reference guide is specifically designed to assist the substation owners with their responsibility to operate and maintain other substation equipment—CT's, VT's, disconnect switches, arrestors, concrete foundations, and insulators. This guide helps members initiate a new maintenance, condition assessment, or life extension program—or refine an existing one. Existing technical content is reviewed annually and updated to reflect advancements. New sections on equipment and technologies will be added as appropriate.	12/31/13	Technical Update
<b>Dimensioning Guidelines for Applying Insulators in Contaminated Environments:</b> This product will provide guidance for dimensioning external insulation and applying booster sheds and shed extenders in substations located in contaminated environments.	12/31/13	Technical Update
<b>In-service Testing of Surge Arrestors:</b> This product will document the prototype tests and measurement technology to effectively assess surge arrestors in the field without removing from service.	12/31/13	Technical Update
<b>Transmission Ratings Workstation (TRW) - Beta Version:</b> The Transmission Ratings Workstation (TRW) will continue to be developed in 2013. This software will incorporate all EPRI equipment ratings-related software modules under one roof. The product will be designed for performing ratings studies, evaluating and optimizing static ratings, performing real-time ratings, determining emergency ratings, and forecasting ratings for transformers, other substation equipment, and entire circuits. The efforts under this project will focus on the ratings modules for other substation equipment (e.g., disconnect switches, buss work).	12/31/13	Software
<b>Increased Power Flow Guidebook – 2013:</b> The <i>Increased Power Flow Guidebook</i> (Platinum Book) will continue to be augmented with more and new material on the state-of-the-science and best-practices for increasing and optimizing power flow through existing circuits. The needs for the guidebook are identified by industry experts and EPRI member advisory groups.	12/31/13	Technical Update

## Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<b>Substation Insulators: Resistive Glaze and RTV Coatings:</b> This product will document the performance and application of resistive glaze insulators and insulation treated with room-temperature vulcanized (RTV) coatings.	12/31/14	Technical Update
<b>Transmission Ratings Workstation (TRW):</b> The Transmission Ratings Workstation (TRW) will continue to be developed in 2014. This software will incorporate all EPRI equipment ratings-related software modules under one roof. The product will be design for performing ratings studies, evaluating and optimizing static ratings, and forecasting ratings for transformers, other substation equipment, and entire circuits. The efforts under this project will focus on the ratings modules for other substation equipment (e.g., disconnect switches, buss work)	12/31/14	Software

Product Title & Description	Planned Completion Date	Product Type
<p><b>Life Extension Guidelines for Other Substation Equipment:</b> This reference guide is specifically designed to help substation owners operate and maintain other substation equipment—CTs, VTs, disconnect switches, arrestors, concrete foundations, and insulators. This guide helps members initiate a new maintenance, condition assessment, or life extension program, or refine an existing one. Existing technical content is reviewed annually and updated to reflect advancements. New sections on equipment and technologies will be added as appropriate.</p>	12/31/14	Technical Update
<p><b>Disconnect Switches: Maintenance, Inspection &amp; Assessment:</b> This technical update will document the fundamental failure modes and degradation mechanisms and use this information to improve maintenance, inspection and assessment strategies. Information provided in this product will continue to build on previous years research.</p>	12/31/14	Technical Update

**P37.106 High Impact Low Frequency Events; With Focus on Electromagnetic Pulse (EMP) (072014)**

**Key Research Question**

The electric infrastructure is clearly one of society's greatest assets. With increased reliance on high-quality electric power for society's comfort, safety, and productivity, reliable delivery is of utmost importance. Electricity providers have a long history of managing the traditional threats to reliability, and the grid is inherently reliable. However, it is important that the industry also be mindful of a class of rare risks that have the potential to cause long-term, catastrophic damage to the system. The events are called High-Risk, Low-Frequency (or HILF) events. Events in this class have rarely happened, and in some cases, have never happened. Example include geomagnetic disturbance, high-altitude detonation of a nuclear device to create electromagnetic interference, and intentional electromagnetic interference.

**Approach**

The objective of proposed research is to develop a holistic risk management approach, with specific focus on determining the appropriate balance of resilience, restoration, and protection. The 2012 research tasks include the following:

- Provide investigation, analysis, and strategic measures to assess the costs, benefits, and performance of various technologies and methods capable of reducing the risk of HILF-related events.
- Incorporate new study results to raise awareness and put the risks into context. In many cases this will take the form of industry white papers that describe the latest information of the risks, the vulnerability to the electric system and key equipment, and the mitigation approaches and hardware.
- Conduct an annual industry workshop to collect and share the latest information on HILF events.

As mitigating options are further considered, it is also important to note that it is impossible to fully protect the system from every threat or threat actor. Sound management of these and all risks to the sector should take a holistic approach, with specific focus on determining the appropriate balance of resilience, restoration, and protection. A successful risk management approach will begin by identifying the threat environment and protection goals for the system, balancing expected outcomes against the costs associated with proposed mitigations. This balance should be carefully considered with input from both electric sector and government authorities. Building on the inherent resilience of the system and enhancing the response of the system as a whole to unconventional stresses should be a cornerstone of these efforts.

**Impact**

Participants in this effort can have increased awareness of HILF events and be better prepared for them, which supports improved reliability. Increased understanding of the risks supports informed decision-making with respect to optimal investment in defense.

**How to Apply Results**

Information will be provided via white papers and webcasts. Members can incorporate the results into their project prioritization and risk management processes.

**2013 Products**

Product Title & Description	Planned Completion Date	Product Type
<p><b>Industry Report On High Impact Low Frequency Events:</b> While some of these HILF events have never occurred and the probability of future occurrence and impact is difficult to measure, government and industry must work together to evaluate and, where necessary, enhance current planning and operating practices to address these risks. Care must be taken in consideration of mitigation approaches to maintain affordable power and to avoid unintended consequences to system reliability. This report is designed to synthesize some of the best collaborative thinking on these risks to date and is intended to be part of an ongoing effort. Using result of multi-year research and development, an annual summary report of findings will focus on a class of rare risks with the potential to cause long-term, catastrophic damage to the bulk power system.</p>	12/31/13	Technical Update
<p><b>Analysis of Electromagnetic Pulse (EMP) and High-Altitude EMP (HEMP):</b> An <b>electromagnetic pulse</b> is a burst of electromagnetic radiation. The abrupt pulse usually results from certain types of high energy explosions, especially a nuclear explosion, or from a suddenly fluctuating magnetic field. The resulting rapidly changing electric fields and magnetic fields may couple with electrical/electronic systems to produce damaging current and voltage surges. EPRI will perform EMTP modeling to determine impacts on equipment. Additionally, mitigation strategies and devices will be modeled and analyzed for their efficacy.</p>	12/31/13	Technical Update

**Future Year Products**

Product Title & Description	Planned Completion Date	Product Type
<p><b>Industry Report on HILF as it Relates to Cyber Security</b></p>	12/31/14	Technical Update
<p><b>Industry Report On Effect of GIC Blocking Devices :</b> Earth-directed solar storms induce a geoelectric field at the Earth’s surface, which drives geomagnetic-induced currents (GICs) wherever there is a path for them to flow. These quasi-dc currents flow in the Earth and on long manmade conducting paths, such as transmission lines, metallic pipelines, telecommunication cables, and railways. GICs can enter and exit the power system at transformer grounds, disrupt the normal operation of power systems, and potentially damage operating equipment. Along with operation strategies to reduce the impacts of GIC, hardware devices are being designed and built to block GIC from transformers and lines. These devices have the potential to completely mitigate the GIC threat, but questions remain: Will the blocked current appear elsewhere in the system? Will the blocking devices affect the sensitive protective relaying scheme in place today? If the device fails in service, how will the system be affected? These questions and more will be addressed in the report.</p>	12/31/14	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<b>High Impact Low Frequency Events - Workshop:</b> An annual industry workshop will be delivered to collect and share the latest information on HILF events.	12/31/14	Workshop, Training, or Conference

### P37.108 SF6 Management (052021)

#### Key Research Question

Sulfur hexafluoride (SF<sub>6</sub>) is a powerful greenhouse gas with a 100-year global warming potential (GWP) of 23,900 (it is 23,900 times more powerful than carbon dioxide). Utilities face increasing pressures in the areas of SF<sub>6</sub> emissions, safety, training, leak detection, destruction, and SF<sub>6</sub> analysis. As pressure to reduce greenhouse gas emissions grows and cost pressures continue to escalate, energy companies need solutions to meet these challenges.

#### Approach

Three broad themes guide this project's research:

- Reducing SF<sub>6</sub> Emissions—through application of new technology
- Improved SF<sub>6</sub> tracking and reporting—to assist with emerging regulatory requirements
- SF<sub>6</sub> training and knowledge transfer

The project approach is to answer important open questions through both laboratory testing and field validations—and then translate the results into solutions that are easy and cost-effective to apply in the substation.

#### Impact

- Reduces costly SF<sub>6</sub> emissions
- Mitigates risks of potential health hazards via safe-handling techniques, tools, and guidelines
- Minimizes environmental emissions of SF<sub>6</sub>
- Enhances SF<sub>6</sub> tracking and reporting to meet emerging regulations
- Enables members to stay abreast of evolving developments worldwide

#### How to Apply Results

The results are designed for easy and rapid application. For example, members will have ready access to the CD-based SF<sub>6</sub> training tools, with the only requirement being a PC and a printer. Technologies for SF<sub>6</sub> emission reduction are demonstrated to members in both the laboratory setting and in the field—allowing for easy adoption.

#### 2013 Products

Product Title & Description	Planned Completion Date	Product Type
<b>Field tests of the prototype novel SF6 capture technologies for emission reduction:</b> Host utility trials of the SF <sub>6</sub> capture concepts for both SF <sub>6</sub> leaks and SF <sub>6</sub> analysis	12/31/13	Hardware

Product Title & Description	Planned Completion Date	Product Type
<b>2013 Update: Computer-based training</b> : Update of computer-based training modules: <ul style="list-style-type: none"> <li>• SF<sub>6</sub> Safety</li> <li>• SF<sub>6</sub> Analysis</li> <li>• SF<sub>6</sub> and the Environment (including updates on SF<sub>6</sub> replacements research)</li> <li>• SF<sub>6</sub> Handling</li> </ul>	12/31/13	Software
<b>2013 Update Best practices for SF<sub>6</sub> tracking and reporting:</b> The best practices for SF <sub>6</sub> tracking and reporting will share both technology solutions and case studies from member utilities. The results will help members respond to the emerging regulations on SF <sub>6</sub> reporting.	12/31/13	Technical Update
<b>2013 Visual Field Guide of common SF<sub>6</sub> leak locations and sealing solutions</b> : The visual field guide will allow members to efficiently track down and seal SF <sub>6</sub> leaks in the field, while predicting emerging issues on aging breakers. The final benefit will be seen in reduced SF <sub>6</sub> emissions and lower maintenance costs.	12/31/13	Technical Update

### Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<b>Field tests of the prototype novel SF<sub>6</sub> capture technologies for emission reduction:</b> Host utility trials of the SF <sub>6</sub> capture concepts for both SF <sub>6</sub> leaks and SF <sub>6</sub> analysis	12/31/14	Hardware
<b>2014 Novel device to lower cost of testing and reporting:</b> Explore efficacy of a low-cost device for weighing cylinders and/or a device to install on a cylinder to take readings. Explore a handheld device to automate taking inventory. Effective means to capture and recycle gas when sampling.	12/31/14	Technical Update
<b>2014 update to the Visual Field Guide of common SF<sub>6</sub> leak locations and sealing solutions</b> : Includes more effective leak detection technology for indoor applications and very low leak rates. Includes exploration of commercially viable means of sealing leaks for temporary and permanent repairs such as the EPRI “Sock”—innovative technology to assist with leak sealing.	12/31/14	Technical Update
<b>2014 Report on SF<sub>6</sub> Replacements</b>	12/31/14	Technical Update

## P37.110 Switching Safety and Reliability (052029)

### Key Research Question

Safety and reliability of the power grid are at the top of every utility's list of concerns. To meet this challenge, personnel who prepare and review switching orders and/or perform switching must be properly trained to prevent switching errors and avoid error-likely situations. Switching errors must be prevented because they can create unexpected power interruptions to customers and hazardous situations for utility personnel and the public. Although some utilities have achieved very low error rates, others can benefit from further improvements.

### Approach

This project conducts research with the goal of reducing switching errors, improving worker safety, reducing unscheduled outages, improving power quality, and enhancing operating efficiency and compliance with regulatory changes. It also sponsors a successful and unique Annual EPRI Switching Safety and Reliability (SSR) Conference to transfer research results to the utility industry. Using experts knowledgeable about the details of switching, the project analyzes data and procedures to highlight areas that might be improved and to identify industry best practices. Specific goals for 2011 include the following:

- Providing an annual update on lessons learned from incidents, including near misses
- Continuing the development of the *SS&R Reference Book*
- Developing recommendations for qualification of switching personnel
- Discovering weak links in switching processes, and defining remedial and preventive strategies
- Sharing lessons learned
- Identifying safe switching work procedures that improve system integrity and worker safety
- Developing multimedia-based training materials
- Monitoring new industry trends and developments and assessing their impact on switching, as well as developing guidelines and training materials to meet the associated challenges

### Impact

- Increase reliability and safety while reducing errors through best practices and guidelines for transmission and distribution switching
- Reduce worker productivity losses via implementation of appropriate switching procedures that include effective safety elements
- Promote sharing of lessons learned among peers
- Identify and develop best practices and new methods via comparisons of current practices
- Enable an open exchange of information on incidents and findings among participants via the annual EPRI Switching Safety and Reliability Conference.

### How to Apply Results

Reports produced by this project serve as industry benchmarks that members can use to gauge their own performance. Studies of industry best practices provide guidance for improvements and development of error-insensitive procedures. They also help to identify weaknesses and vulnerabilities within procedures being used. The project also sponsors the annual EPRI Switching Safety and Reliability Conference, which provides an opportunity for managers, supervisors, and operations personnel to exchange information about switching policies and procedures that contribute to improved safety and reliability. The conference is open to all interested parties.

### 2013 Products

Product Title & Description	Planned Completion Date	Product Type
<p><b>Situation Awareness in the control room:</b> A recent review of control room design, layout, and color schemes (EPRI report 1015990) suggested changes to improve visualization and facilitate greater situation awareness for operators. This product, which is expected to take advantage of collaboration with other EPRI programs (for example, Program 39 Grid Operations), will seek feedback from control room operators regarding the proposed enhancements and will identify ways of introducing the changes that are compatible with operators' needs.</p>	12/31/13	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<p><b>Annual SS&amp;R Newsletter:</b> The annual SS&amp;R Newsletter is traditionally published in the spring of each year and contains a review of highlights of the previous year's SS&amp;R Conference and preliminary information on the current year's SS&amp;R Conference. Hard copies of the Newsletter are mailed to a large number of recipients worldwide, and electronic copies are available for download under unique PID numbers.</p>	12/31/13	Technical Resource
<p><b>Annual SS&amp;R Conference Brochure:</b> The annual SS&amp;R Conference Brochure is traditionally published in the summer of each year and introduces the program of the current year's SS&amp;R Conference. Hard copies of the Brochure are mailed to a large number of recipients worldwide, and electronic copies are available for download under unique PID numbers.</p>	12/31/13	Technical Resource
<p><b>EPRI Power Switching Safety and Reliability Project: Summaries of Published Reports and Conference Presentations 1996–2012:</b> The SS&amp;R Project was initiated in 1996. This report presents brief descriptions of the publications of the EPRI Switching Safety and Reliability (SS&amp;R) Project and of the presentations at the annual EPRI SS&amp;R Conferences from 1996 (the year of the project's inception) until 2012.</p>	12/31/13	Technical Update
<p><b>SS&amp;R Reference Book chapters:</b> The EPRI Switching Safety and Reliability project was initiated in 1996. Since then, it has produced more than 45 research reports, has contributed to reducing switching errors in the industry, and has sponsored the annual SS&amp;R Conference. Recognizing the practical value of the accumulated volume of research results and conference presentations, the project plans to continue consolidation, started in 2012, of the aggregate knowledge under one cover in the form of a SS&amp;R Reference Book, which will also include a collection of training modules on the subject of power switching safety and reliability. The SS&amp;R Reference Book, when completed in the next few years, will join the EPRI's Color Book series of valuable reference materials.</p>	12/31/13	Technical Update

### Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<p><b>Impact of changing grids on switching safety and reliability:</b> Changing grid characteristics—including the use of high-temperature conductors, DTCR, distributed and non-traditional power sources, increasing fault currents, widespread use of sophisticated multifunctional electronic relays, and other developments—introduce new challenges that demand a detailed assessment of such factors on issues such as control room procedures, switching operations, qualification of operators, switchmen and technicians, and training materials. This product will identify the challenges and lay groundwork for future research to develop appropriate responses.</p>	12/31/14	Technical Update
<p><b>DMS (Distribution Management System) - Impact on switching:</b> Implementation of Distribution Management Systems (DMS) is expected to have a significant impact on power switching safety and reliability. This product will identify the challenges and lay groundwork for future research to develop appropriate responses.</p>	12/31/14	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<p><b>Database of incidents and near-misses in switching:</b> This is an ongoing project that collects information and reports on incidents and near misses in power switching. A reporting template developed in 2008 and updated in 2009 is used to gather the essential information. The searchable database will be populated annually with new information.</p> <p>The reporting template is available from the EPRI project manager upon request.</p>	12/31/14	Technical Update
<p><b>EPRI Power Switching Safety and Reliability Project: Summaries of Published Reports and Conference Presentations 1996–2013:</b> The SS&amp;R Project was initiated in 1996. This report presents brief descriptions of the publications of the EPRI Switching Safety and Reliability project and of the presentations at the annual EPRI SS&amp;R Conferences from 1996 (the year of the project's inception) until 2013.</p>	12/31/14	Technical Update
<p><b>Human Operational Errors Involving Control, Relay, and Auxiliary Equipment:</b> Several years ago, an EPRI report (1013596) described the findings of research related to human operational errors involving new smart control, relay, and auxiliary equipment. That report identified error modes and training needs for technicians servicing such equipment. This new product will build on previous work by defining appropriate barriers to prevent errors and by developing training materials.</p>	12/31/15	Technical Report
<p><b>Technology Innovation in Power Switching:</b> In recent years, some degree of automation, innovation and use of computer-based technologies has been introduced into power switching execution; however, no systematic process of identifying new technologies and evaluating them for suitability to switching operations has been developed.</p> <p>This product will develop a roadmap for development of needed technological innovations in power switching and practical implementation into the utility operations.</p>	12/31/15	Technical Report
<p><b>SS&amp;R Reference Book:</b> The EPRI Switching Safety and Reliability project was initiated in 1996. Since then, it has produced more than 45 research reports, has contributed to reducing switching errors in the industry, and has sponsored the annual SS&amp;R Conference. Recognizing the practical value of the accumulated volume of research results and conference presentations, the project plans to continue consolidation of the aggregate knowledge under one cover in the form of an SS&amp;R Reference Book, which also will include a collection of training modules on the subject of power switching safety and reliability. The SS&amp;R Reference Book, when completed, will join the EPRI's Color Book series of valuable reference materials.</p>	12/31/15	Technical Report
<p><b>EPRI Power Switching Safety and Reliability Project: Summaries of Published Reports and Conference Presentations 1996–2014:</b> The SS&amp;R project was initiated in 1996. This report will present brief descriptions of the publications of the EPRI Switching Safety and Reliability project and of the presentations at the annual EPRI SS&amp;R Conferences from 1996 (the year of the project's inception) until 2014.</p>	12/31/15	Technical Update

## P37.111 Risk Based Substation Equipment Asset Management (072016)

### Key Research Question

Best practice asset management decisions for maximizing performance and minimizing equipment life-cycle costs are based upon risks associated with actual equipment condition and historical performance. There are four key steps involved: understanding existing performance, understanding required performance, projecting future performance, and understanding how to bridge gaps. Ongoing R&D efforts are focused on developing condition assessment algorithms to understand existing performance and project future performance for transformers and circuit breakers. Other substation equipment may be added based on utility guidance and task force feedback.

### Approach

This project conducts research with the goal of providing continually improved risk-based decision-support methodologies for substation equipment asset managers. It envisions that the development will lead to an integrated framework for asset risk assessment, mitigation, and performance improvement.

Developments in risk-based fleet management are addressed through the following tasks:

**Substation Equipment Asset Management Guidelines:** Develop the guideline with the objective of integrating EPRI Substation Equipment Asset Management Tools into a standardized process for broader utility applications, better definition for individual asset management processes, and effective dissemination of information to multiple stakeholders in a systematic and repeatable manner. Envisioned is a two-year effort with the 2013 task focusing on developing the outline and preliminary draft for member review and feedback. It is anticipated that final guideline will be published in 2014.

**Generic tools for substation equipment maintenance and asset management that utilities can apply and adapt:** The 2012 work will further develop tools and document methodologies for calculating condition indices for the transformer main body and a framework to assist utilities with high-voltage circuit breaker maintenance ranking. The tools were provided to eligible members for their review and feedback. In 2013, underlying rules and methodology will be finalized based on utility feedback. The first version of the tools will be delivered. Ongoing research will continue to focus on methodology/rule enhancement, documentation, fine tuning, and validation through new case studies. Based on member feedback, new features will be added, and additional modules will be developed.

**Develop a generic framework for incorporating condition indices, operational requirements, and business rules into risk-based assessment and mitigation methodology:**

#### Substation Equipment Maintenance And Asset Management – Utility Experience Sharing

- Document utility use cases and application notes.
- Using web-based survey, document industry maintenance practices.
- Provide a forum to share lessons learned from utility equipment maintenance and operation experiences.

**Risk Mitigation and Maintenance Strategies Workshop:** Transfer technology and provide training.

### Impact

The research will enhance decision making confidence and results. The resulting development provides tools and methodologies that can be used by substation equipment asset managers for improved decision support, including the following:

- An analytical framework for the application of asset management principles to substation equipment
- Reduces overall maintenance costs, forecasts operations and maintenance (O&M) cash flow, minimizes unplanned expenses, and maximizes the benefit and value of planned work

- Improves reliability and availability via reduced reliance on time-based maintenance by using analytics based on asset health and condition analysis to determine maintenance actions
- Enables more effective use of existing infrastructure and data, as well as efficient use of maintenance personnel to manage operational risk

Collectively, the developed suite of algorithms serves as the framework for Analytics for Substation Asset Performance.

**How to Apply Results**

Project participants will work with a group of equipment and maintenance experts to collect data that helps define performance metrics and models for relevant equipment. Funders can then use developed algorithms, key performance indicators (KPIs), and ranking methodologies in coordination with other equipment-focused projects. Funders also can use products to test and validate end-of-life models being pursued in other equipment-focused projects.

**2013 Products**

Product Title & Description	Planned Completion Date	Product Type
<p><b>Substation Equipment Asset Management - utility experience sharing:</b>                      This product will catalogue and assess current industry maintenance and asset management practices and procedures, including lessons learned by utility experts, and identify gaps and issues with existing practices. Ongoing efforts focus on key substation equipment: transformers and circuit breakers. Over time, through task force feedback and needs assessment, other substation equipment areas will be identified and added. Equipment classes surveyed will also be updated with new questions every year. This product will also provide a forum to share lessons learned from utility equipment maintenance and operation experiences. Finally, this product will also document utility experiences and results from their implementations of risk-based substation equipment asset management approaches, including mitigation strategies.</p>	12/31/13	Software
<p><b>Risk based substation equipment fleet management: tools and methods:</b>                      The product will deliver generic tools and methodology that utilities can apply and adapt to their own needs. Ongoing research enhances underlying algorithms, action triggers, and thresholds. The generic tools first released in 2012 will be updated with enhanced algorithms and new versions released in 2013. Simultaneously, the underlying methodology and approach also will be updated. Generic tools also will be updated with new modules. It is anticipated that in 2013 the transformer condition index development also will include the load tap changer in addition to the main body. Likewise, a new version of the circuit breaker maintenance ranking tool will provide improved guidance for assessing a wider variety of mechanisms. Both will incorporate lessons learned from utility deployments.</p>	12/31/13	Software
<p><b>Risk based substation equipment asset management workshop:</b> The workshop transfers results and provides training on their application. Topics include, but are not limited to, risk assessment methodologies, maintenance strategies, fleet management analytics, application examples, and case studies.</p>	12/31/13	Workshop, Training, or Conference

## Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<b>Substation Equipment Asset Management Guidelines</b> : This product will develop a guideline with the objective of integrating EPRI Substation Equipment Asset Management Tools into a standardized process for broader utility applications, better definition for individual asset management processes, and effective dissemination of information to multiple stakeholders in a systematic and repeatable manner. Envisioned is a two-year effort with the 2013 task focusing on developing the outline and preliminary draft for member review and feedback. It is anticipated that the final guideline will be published in 2014.	12/31/14	Technical Report
<b>Risk Based Substation Equipment Asset Management Workshop:</b> The workshop transfers results and provides training on their application. Topics include, but are not limited to, risk assessment methodologies, maintenance strategies, fleet management analytics, application examples, and case studies.	12/31/14	Workshop, Training, or Conference
<b>Risk based substation equipment fleet management: tools and methods:</b> The product will deliver generic tools and a methodology that utilities can apply and adapt to their own needs. Ongoing research enhances underlying algorithms, action triggers, and thresholds. The generic tools first released in 2012 will be updated with enhanced algorithms, new modules and enhancements, and new versions released in 2014. Simultaneously, the underlying methodology and approach also will be updated. Generic tools also will be updated with new modules.	12/31/14	Software
<b>Substation Equipment Asset Management - utility experience sharing:</b> This product will catalogue and assess current industry maintenance and asset management practices and procedures, including lessons learned by utility experts, and identify gaps and issues with existing practices. Ongoing efforts focus on key substation equipment: transformers and circuit breakers. Over time, through task force feedback and needs assessment, other substation equipment areas will be identified and added. Equipment classes surveyed will also be updated with new questions every year. This product will also provide a forum to share lessons learned from utility equipment maintenance and operation experiences. Finally, this product will also document utility experiences and results from their implementations of risk-based substation equipment asset management approaches, including mitigation strategies.	12/31/14	Software

## P37.112 Industry-wide Equipment Performance Database (060471)

### Key Research Question

Power delivery companies can maximize their return on assets, while maintaining reliable system operations, by ensuring that equipment is not replaced before the end of its useful life. However, leveling capital replacement requirements may also be a consideration. Without historical performance data of assets with similar characteristics, these tasks can be difficult. The goals of this project are to design, develop, populate, maintain, and extract information from an Industry Database for power transformers.

This project provides participating utilities with aggregated data and information resources, not currently available to individual utilities to assist in developing repair/refurbish/replace strategies for aging substation equipment fleets. The project collects equipment performance and failure data in a common format from many sources to establish a database that enables statistically valid analysis to better determine equipment failure rates, identify "bad actors" early, and help identify the best maintenance and specification practices. Data models and software applications will be developed and presented to task force advisors for comment and further refinement. Associated supplemental projects may be launched to populate the industry-wide database (IDB) with historical data and develop company-specific applications.

### Approach

This project performs research through the following means:

- Collecting equipment performance and failure data from participating utilities to develop an industry-wide database. This database is designed to accomplish the following:
  - Enable statistically valid analyses to determine equipment failure rates and identify "bad actors" early.
  - Enable the development of other meaningful asset management and equipment performance metrics.
  - Provide members with aggregated data and information resources not currently available to individual companies.
  - Provide members with information that is critical in developing repair/replace/refurbish strategies for aging substation equipment fleets.
- Developing data models for improving utility and industry historical record-keeping and software applications for analysis. These are developed and presented to task force advisors for comment and further refinement.
- Developing guidelines on approaches to analyzing the data and applying results of analysis.

Associated supplemental projects may be launched to populate the Industry-wide Equipment Performance Database with historical data and develop company-specific applications. Through supplemental project participation, members get customized deliverables that analyze their own fleet performance and provide individual utility failure rates and asset management metrics.

The transformer data collection analysis started in 2006, and now contains records on more than 34,500 power transformers. The circuit breaker database is under development. Tap changers and other substation equipment databases will be addressed in future years.

### Impact

- Improve management of existing infrastructure with early risk detection and risk-informed maintenance and asset management decisions based on industry-wide equipment performance and failure data using pooled performance and condition-related data from participating utilities
- Achieve savings by using consistent data sharing and analyses based on industry standards
- Enable identification of "bad actors" early, reducing unplanned outages

### How to Apply Results

This initiative provides participating utilities with data and information resources that are not currently available to an individual utility to help develop a repair/refurbish/replace strategy for aging substation equipment fleets. Participants can use the project results to test and validate end-of-life models, assess equipment risks, and develop risk-informed maintenance and asset management programs.

### 2013 Products

Product Title & Description	Planned Completion Date	Product Type
<p><b>New Versions of Industry-wide Database: Power Transformers – Data Model &amp; Analysis:</b> This product will compile and analyze performance and failure data of transformers, tap-changers, and transformer accessories. Results will be delivered in the form of a PowerPoint electronic media presentation. The product also will develop and annually update the schema for the underlying data models for the efficient and effective collection of test, diagnostics, performance, and failure data for use in industry and utility database applications and performance analysis. The data model will be delivered in the form of a Microsoft Access schema file.</p>	12/31/13	Software

Product Title & Description	Planned Completion Date	Product Type
<p><b>New Versions of Industry-wide Database: Power Transformers – Populated Data-Sets:</b> The transformer data collection and analysis started in 2006 now contains records on over 34,500 transformers. As ongoing R&amp;D validates the effectiveness of data models and underlying data, populated sub-sets of transformer performance and failure data will be released in a phased manner. This product will deliver data sub-sets and underlying data models. An interactive user interface will be provided to allow users to query data and visualize results. The querying capability and visualization will be enhanced with new functionality as utility feedback and new data becomes available in future years.</p>	12/31/13	Software
<p><b>Industry-wide Equipment Performance And Failure Database: Application Guide:</b> This deliverable documents the underlying methodology and approach to analyze equipment performance and failure data in the EPRI database using different analytical techniques—for example, statistical analysis and trending. The objective of applying analytical techniques is to uncover performance characteristics and develop meaningful metrics. The initial versions of the application guide will focus on transformer data. Over time, new material will be added to assist users with analysis of circuit breaker, tap-changer, and other substation equipment data.</p>	12/31/13	Technical Update

### Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<p><b>New Versions of Industry-wide Database: Power Transformers – Populated Data-Sets:</b> The transformer data collection and analysis started in 2006 now contains records on over 34,500 transformers. As ongoing R&amp;D validates the effectiveness of data models and underlying data, populated sub-sets of transformer performance and failure data will be released in a phased manner. This product will deliver data sub-sets and underlying data models. An interactive user interface will be provided to allow users to query data and visualize results. The querying capability and visualization will be enhanced with new functionality as utility feedback and new data becomes available in future years.</p>	12/31/14	Software
<p><b>New Versions of Industry-wide Database: Circuit Breakers – Populated Data-Sets:</b> As ongoing R&amp;D validates the effectiveness of data models and underlying data, populated sub-sets of circuit breaker performance and failure data will be released in a phased manner. This annually updated product will deliver data subsets and underlying data models. An interactive user interface will be provided to allow users to query data and visualize results. The querying capability and visualization will be enhanced with new functionality as new data become available in future years.</p>	12/31/14	Software
<p><b>Industry-wide Equipment Performance And Failure Database: Application Guide :</b> This product documents the underlying methodology and approach to analyze equipment performance and failure data in the EPRI database using different analytical techniques—for example, statistical analysis and trending. The objective of applying analytical techniques is to uncover performance characteristics and develop meaningful metrics. The initial versions of the application guide will focus on transformer data. Over time, new material will be added to assist users with analysis of circuit breaker, tap-changer, and other substation equipment data.</p>	12/31/14	Technical Update

## P37.113 Next Generation Condition Monitoring and Diagnosis (072017)

### Key Research Question

Condition monitoring of substation equipment has an inherent value based on preventing failure, maximizing future operation of the equipment, appropriately scheduling and determining the extent of inspections and maintenance, providing for personnel safety, and protecting the environment. New and emerging sensing and diagnostic technologies play a strong role in helping utilities achieve this goal. Many utilities are unaware of these technologies and how best to interpret and implement them. This project documents the latest inspection, monitoring, and diagnostics technologies for substations, as well as early adopter's experiences, thus providing supporting industry data and research results to make these decisions. It also researches new technologies and develops methodologies to help develop the foundations for improved condition-monitoring strategies.

### Approach

Each year, results are delivered through tasks performed to address three broad themes. The stability in the themes supports a clear multi-year plan approach:

- **Awareness of Novel Condition Monitoring Technologies:** Continuous identification and investigation into novel condition maintenance technologies and implementation methodologies. Early adopters of new technologies will be identified and surveyed. Case studies will be written based on the approach taken and their experiences. This knowledge will be delivered through Condition Monitoring and Implementation Database.
- **Condition Monitoring Technologies:** Each year a particular condition monitoring technology will be identified and investigated in depth.
- **Condition Monitoring Application Guidelines:** Every year one substation asset will be tested and fundamental research performed to investigate possible diagnostic guidelines.

### Impact

Monitoring can take many forms and should be applied when a cost-benefit value results from its use over alternatives without monitoring. The greatest challenge is to gather the combined benefit of sensing technologies, physical properties associated with aging mechanisms, and system integrators to develop seamless delivery of equipment condition information in an effective, efficient, and economic manner.

### How to Apply Results

By being aware of the latest technologies and implementation mechanisms and having easy access to other utilities' experiences through the database, members can improve and extend their monitoring programs. Results obtained from this project can support the development of effective business cases for substation inspection, monitoring, and diagnostics. In addition, members can further validate their business decisions by having easy access to other members' experiences and laboratory research results designed to closely simulate the field environment.

In addition, the underlying results from the fundamental R&D can help utilities get more value from their present condition monitoring practices.

## 2013 Products

Product Title & Description	Planned Completion Date	Product Type
<b>Condition Monitoring and Implementation Database:</b> This database will continue the previous year's efforts and expand information to help users develop and implement their condition monitoring strategy. It will focus on: 1) sensors and technologies presently available, and the related issues which they are capable of detecting, 2) available condition assessment and criticality algorithms, and 3) further case studies documenting how other utilities have implemented the sensor or technology into their condition monitoring strategy, and inclusion of them as part of the database.	12/31/13	Software
<b>Condition Monitoring Technologies: Infrared Inspection:</b> This technical update will be part of a multi-year research and testing initiative to investigate the signatures and thresholds that indicate high-risk components. The impact of environmental and operational conditions will be investigated.	12/31/13	Technical Update
<b>Application Guide: Monitoring of Surge Arresters:</b> This technical update will be part of a multi-year research and testing initiative to document and record the failure and degradation modes and how surge arresters may be monitored and assessed.	12/31/13	Technical Update

## Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<b>Condition Monitoring and Implementation Database:</b>	12/31/14	Software
<b>Application Guide: Monitoring of Current Transformers:</b> This technical update will be part of a multi-year research and testing initiative to document and record failure and degradation modes and how current transformers may be monitored and assessed.	12/31/14	Technical Update
<b>Condition Monitoring Technologies: Infrared Inspection:</b> This technical update will be part of a multiyear research and testing initiative which will investigate the signatures and thresholds which indicate high risk components. The impact of environmental and operational conditions will be investigated.	12/31/14	Technical Update

## Supplemental Projects

### Solid State Fault Current Limiter Development - Phase 2 - 3 Phase, 15 kV, 1200 Amp SSCL (072018)

#### Background, Objectives, and New Learnings

The increase in available fault current levels due to added distributed generation and increased load has stressed many transmission and distribution substations to their limits. In some cases fault current levels are exceeding the interrupting capability of existing substation circuit breakers. This increase in fault current levels either requires the replacement of a large number of existing substation breakers with higher rating breakers or the development of some means to limit fault current. By using a Solid State Current Limiter (SSCL), fault currents can be interrupted or current limited within  $\frac{1}{4}$  cycle (4 ms). This will allow near instantaneous breaking of bus ties in transmission and distribution substations to reduce the available short circuit current and allow existing circuit breakers to clear at lower fault current levels.

The Electric Power Research Institute (EPRI) is already collaborating with the U.S. Department of Energy (DOE) to develop a 15 kilovolt (kV) distribution-class, single-phase, solid-state current limiter prototype. Additional efforts are under way to develop a three-phase, 15 kV distribution-class, solid-state current limiter in collaboration with utilities, DOE, and the California Energy Commission (CEC). After successful implementation of a 15 kV, distribution-class, solid-state current limiter in the field, research will be continued to develop a 69 kV, transmission-class, solid-state current limiter. In addition, EPRI is collaborating with the U.S. Navy and DOE to develop fault current limiters using "super-gate turn off" devices (S-GTOs) with advanced materials such as silicon carbide (SiC) and gallium nitride (GaN). The lessons learned from these collaborative projects will support fault current limiter development in 2013 and beyond. EPRI will continue to seek further collaborations with utilities, government agencies, and vendors to enhance and develop cost-effective solid-state fault current limiters.

#### Project Approach and Summary

EPRI has been working on the development of a transmission-class, solid-state current limiter for several years. Phase 1 of the project is the development of a single-phase 15 kV, 1200 ampere (A) power stack for a solid-state current limiter with key functional tests completed in the third quarter of 2011.

The scope of work for Phase 1 was to build and factory test a power stack consisting of six building blocks connected in series and two of the six building blocks in parallel. This single-phase power stack is rated for 1200 A and is suitable for 15 kV class applications. The testing of this power stack is for the key functionality of continuous current operation and current limiting capability.

As a multi-phase approach for this project, Phase 2 of the project was started in 2012. Phase 2 would see the build and factory test of a 15 kV, 1200 A, three-phase system, ready for field testing.

#### Benefits

- Reduce fault currents using fault current limiters. This mitigates equipment failures, which may lead to power outages and high repair or replacement costs.
- Reduce environmental impacts by better utilization of the existing power delivery infrastructure.
- Relieve system congestion via better use of existing resources.
- Reduce energy losses at transmission, substation, and distribution levels via improved controllability.
- Improve reliability and power quality through the use of various power electronics technologies at substations and mitigate events such as momentary outages, voltage sags/surges, and harmonics.

## Testing Guidelines and Utility Practices for Multi-vendor Equipment and Systems Based on IEC 61850 Standard (071643)

### Background, Objectives, and New Learnings

The next-generation substations will use advanced communication infrastructure and protocols to allow interoperability for multi-vendor intelligent electronic devices (IEDs) and provide advanced features for protection, control, and automation. The IEC 61850 standard not only enables interoperability by providing a standardized framework for substation components and communications, but also introduces new features, such as station bus and process bus, to innovate current substation practices and reduce project costs.

The IEC 61850 standard is complex and feature-rich. However, one outstanding challenge for the industry is lack of a testing methodology and guideline to assist utility in implementation, testing, and maintenance of IEC 61850-based equipment and systems. The testing methodology and guideline are required not only for the purpose of conformance to the standard but also for those practical and essential applications, which include factory and site acceptance, commissioning, and maintenance testing in a field environment.

The goal of this project is to research and develop testing guidelines that can be used in the field to assist in function and performance testing for multi-vendor equipment and systems based on the IEC 61850 standard. The objectives of the project include the following:

- Work with utilities to identify key IEC 61850 testing issues in critical processes, including acceptance tests and field and maintenance tests within substation environment. Perform R&D on key requirements and create use cases based on the most recent release of the standard (Edition 2 or later).
- Develop guidelines, good practices, and testing tools to support field deployment of the IEC 61850 standard.
- Develop an IEC 61850 testbed system in EPRI laboratories to demonstrate the developed methodologies and approaches, and use it as a vehicle for a technology transfer workshop.

### Project Approach and Summary

This proposed research will apply the following approaches:

- Collaborate extensively with utilities, standard organizations, equipment vendors, and subject matter experts to address the challenges
- Develop testing guidelines and demonstrate testing concepts and methods by using the state-of-the-art multi-vendor digital relays and communication facilities in EPRI smart grid substation laboratories
- Document the good practices and field experiences by working closely with member utilities

### Benefits

This project can provide substantial new learning in application and deployment of the IEC 61850 standard for next-generation substation development. This work will be in support of National Institute of Standards and Technology (NIST) SGIP (Smart Grid Interoperability Panel) testing and conformance committee activities and contribute to the maturity of the IEC 61850 standard. The work will benefit the public in that it provides an important step in achieving the smart grid specified in the 2007 Energy Independence and Security Act. This act clearly described the benefits to society of a smart grid and the application of interoperability standards, such as IEC 61850, which is a key aspect of migrating today's power system infrastructure to a smart grid.

## Sunburst Network For Geomagnetic Current (003679)

### Background, Objectives, and New Learnings

The Electric Power Research Institute's (EPRI) SUNBURST network is both an organized method for measuring geomagnetically induced currents (GICs) and their effects, and a source of data for continuing research studying the cause, effects, and mitigation of GIC impacts on electrical power systems. While the primary focus is operating the monitoring network, the data collected in this project will be used for feedback into new prediction models that will serve as advance warnings—that is, the NASA Solar Shield project. The SUNBURST project also supports an annual event where relevant scientists from the field of solar phenomena/space weather come together to discuss common issues and concerns related to GICs.

The SUNBURST network consists of a consortium of member utilities that perform near-real-time continuous monitoring of large power transformers to assess the impact of impinging solar storms on the grid. By measuring these GICs along with current and voltage harmonics, the SUNBURST system communicates the breadth, intensity, and localized transformer saturation impact as these storms occur.

Solar storms can be described as magnetic field lines looping out of and into the sun. Often associated with these disturbances are discharges of tremendous amounts of superheated matter, called *coronal mass ejections*, consisting of mostly ionized hydrogen and helium. When these subatomic particles reach Earth, their interaction with the Earth's magnetosphere has the potential to afflict electric power systems, resulting in everything from minor upsets to major outages.

The full solar cycle consists of two half-periods of 11 years each, marked by reversals of the sun's polarity. During one half-cycle, solar disturbances are in alignment with the Earth's magnetic field; in the other, they are antiparallel. Peaks in these disturbances occur midway through the half-cycles and are sometimes more severe during the odd-numbered 11 year periods. The next cycle of solar activity peaks around 2013.

EPRI has supported research in this area for a number of years, and organized a conference on the subject in 1989 (collected as EPRI Proceedings TR-100450). Based on encouragement that came out of the conference, EPRI funded a basic study of how a reporting network might be set up and what quantities it might usefully measure (summarized in EPRI report TR-104167).

Over the last decade, EPRI has accumulated a body of data and experience about correlations between space and Earth conditions associated with problems on the grid. In addition, EPRI has measured geomagnetically induced currents and their effects and created a user organization to study the causes, effects, and mitigation of GIC impacts on electric power systems.

### Project Approach and Summary

Participation in this project will support new prediction models that can serve as advance warning for the effects of solar activity on the North American power grid. At the same time, utilities will receive processed results from existing monitors during actual events. New participants will have an option to deploy their own monitor(s), adding to these research data.

### Benefits

This activity generates substantial new learning on how geomagnetically induced currents progress during a solar storm—and how this data relates to prior observations from satellites or solar observations. The results from all SUNBURST sites will help improve the prediction tools. There is significant public benefit derived from the new learning and data gathered. The public benefit is that through a deeper understanding of Space Weather impacts in the electric grid, steps can be taken to mitigate these effects. The resulting benefits would be in improved reliability of the electricity supply.

## Substation Seismic Studies (049551)

### Background, Objectives, and New Learnings

The Institute of Electrical and Electronics Engineers (IEEE) Standard 693, Recommended Practice for Seismic Design of Substations, is used by electric power utilities to qualify substation equipment for seismic movements. Deficiencies exist in the present standard, and information is unavailable for dynamic response that may be used to better analyze equipment and permit their evaluation in case of limited configuration changes, such as insulator substitution. Representatives from utilities who had participated in the IEEE 693 Working Group, as well as several other utilities, were contacted for participating in a collaborative project to address deficiencies in the standard, and most had expressed interest.

A representative from each participating utility forms the governing body (under the direction of EPRI) for the project. Testing would be performed at appropriate test facilities as directed by EPRI, with input from the participants. The project is managed by an EPRI manager. Technical services are provided by the EPRI Technical Manager. The project addresses the deficiencies that exist in the present standard, especially those related to details left unspecified, by performing tests in the laboratory. These tests are intended to gather dynamic response information that may be used to better analyze the equipment, and permit their evaluation in case of limited configuration changes, such as insulator substitution. Equipment qualified using the recommended practice thus will perform acceptably under reasonably anticipated strong ground motion.

The knowledge gained from this project is intended to seismically qualify substation equipment using IEEE Standard 693, IEEE Recommended Practice for Seismic Design of Substations. An important part of the project is to determine what deficiencies exist in the present standard, especially those related to details left unspecified. Tests are to be performed by a laboratory to gather dynamic response information that may be used to better analyze the equipment and permit their evaluation in case of limited configuration changes, such as insulator substitution. As stated in IEEE 693, equipment qualified using the recommended practice should "perform acceptably under reasonably anticipated strong ground motion."

### Project Approach and Summary

EPRI adopted the following approach:

EPRI will select the item(s) of equipment that is (are) to be tested for each year. EPRI will establish equipment support structure specifications and vibration test requirements, electrical equipment specifications, and test specifications. EPRI also will select a vibration testing facility (and electrical testing laboratory, if required) to perform tests and draw a contract for laboratory services.

The EPRI Technical Manager will prepare a Request for Proposal and issue it to equipment manufacturers. Equipment manufacturer(s) will then be selected to participate in the project. The Technical Manager will prepare a test plan in conjunction with the testing laboratory and the equipment manufacturer. The testing laboratory will perform qualification tests of one or more item of equipment under the overview of the Technical Manager. The manufacturer and the testing laboratory will prepare qualification documentation for the equipment that is qualified following IEEE 693 requirements. The Technical Manager will prepare a project report describing the project.

The test procedure described below will be followed.

#### **Test Procedure**

*Governing Standard:* EPRI intends to conduct testing under the governing standard, IEEE 693-2005, with modifications that are deemed appropriate. In general, the input motions, instrumentation, test sequences, functional tests, and other requirements specified by the referenced standard will be used. Improvements recently recommended for inclusion in the standard will be used in this project to the extent possible.

*Test Sequence:* Each item of equipment is expected to undergo tests required by IEEE 693-2005, with modifications as determined by the EPRI Technical Manager, with input from the participants. It will first be

qualified at the Moderate Required Response Spectrum (RRS) level, then the High RRS level. If lower level tests are completed, and there is reasonable assurance that higher level tests can be achieved, tests up to the High Performance Level (PL) of IEEE 693 will be performed. Failure of a test article beyond the RRS level(s) will not be deemed as a failure of a qualification test, provided that the test article met all qualification requirements at the lower level.

### Benefits

The project addresses deficiencies in the existing standard that evaluates performance of substation equipment, to ensure that qualified products will have higher probability of surviving earthquakes. As a result, both repairs of damaged equipment and power interruptions will be reduced, thus enhancing continuity of power supply to the public and lowering operating costs of electric power utilities.

## Improved Bushing Current Transformer Models (072022)

### Background, Objectives, and New Learnings

Current transformers (CTs) are ubiquitous in substations. They are components of circuits, as are lines and transformers, and they too have ratings associated with their operation. In some cases, they are the lowest-rated component in a circuit, and, therefore, limit the entire circuit's rating, particularly for emergency operations. While much work has been done on increasing, improving, or optimizing the ratings of lines, transformers, cables, and other CT components, CT ratings have been virtually ignored. The ratings used by power companies for CTs are typically the nameplate ratings, and these are generally unnecessarily conservative, especially during high-load contingency situations. Some power companies and equipment providers will define a "Rating Factor," which is the amount above (or below) the nameplate rating that a CT can be confidently operated continually, or for limited periods. But these ratings factors are not always known, and power companies must assume a value of 1.0, thereby restricting the CT rating to its nameplate rating, even during emergencies. The thermal ratings and rating factors of older units are particularly not well characterized. In this project, EPRI will perform theoretical and experimental studies to better define the rating factors of CTs for continuous and emergency operation.

This is an R&D project that will develop methodologies for optimizing the power flow through an already congested power grid. Any direct benefit to the funders will be incidental to the main objective of providing a public benefit in the form of a safe, reliable, and optimized power grid. The results of the new learnings will complement and enhance EPRI's work in Program 37.

### Project Approach and Summary

EPRI will purchase samples of new CTs and obtain aged samples donated by interested members for study. Heat run tests will be performed, some to the point of failure. The tests will involve instrumenting samples with thermocouples and running them at ranges of current levels and time periods in order to assess their rating factors under various operating conditions. A methodology will be developed for defining rating factors for classes of CTs. An aging model for CTs also will be assessed.

### Benefits

The results will provide a scientific means for power companies to better understand the operating characteristics of the current transformer and provide the basis to operate the CTs and circuits safely. They may give utilities the decision support to keep the existing instrumentation in place, or target replacement programs for groups of CTs to maintain reliability when operating the system with high operating current while keeping cost low.

## Fault Current Management Issues (073524)

### Background, Objectives, and New Learnings

Utilities worldwide are experiencing increased fault current levels due to increased distributed energy sources as well as systems being operated at higher power levels than in the past. Increased fault currents in the transmission and substation equipment may cause equipment failures and system outages.

This project's objectives include the following:

- To document the latest fault current limiting technologies in the *Fault Current Management Guidebook*.
- To investigate systematically the mechanical forces in substation equipment and foundations at increased fault current levels, and to validate the present design criteria documented in standards such as IEEE.
- To develop substation design, maintenance, and operating practices under increased fault current scenarios.
- To study the impact of increased fault currents on protection and metering systems.
- To assess the fault current levels in existing utility systems.

Utility members can use project results to make informed decisions when choosing options for limiting fault currents. By implementing one or more of the options, participants can obtain increased power flows without damaging equipment due to high fault currents. Project funders also will be able to understand whether their existing protection and metering systems are adequate at increased fault currents or whether their protection equipment needs replacement.

### Project Approach and Summary

This project addresses fault current management systematically by investigating issues such as the impacts of fault currents on substation equipment, including foundations, protection, and metering. It also addresses the substation design guidelines under increased fault levels, and documents the latest fault current limiting methods such as solid-state fault current limiters and superconducting fault current limiters in the *Fault Current Management Guidebook*. It will also help utilities assess the fault current levels in their systems and propose ways to mitigate these increased fault currents so that the existing circuit breakers can be used without going for higher rated circuit breakers.

**Fault Current Management Guidebook (the Maroon Book):** This comprehensive guidebook documents the state of the science for limiting fault currents in transmission and distribution networks and describes possible schemes with economic benefits.

#### **Study of Mechanical Forces in Primary Equipment and Foundations at Increased Fault Currents:**

Substation equipment considered will include not only electrical equipment such as busbars and circuit breakers but also civil structures such as bus supports, pothead stands, and concrete foundations. Lab tests will be conducted on full-scale support structures to evaluate mechanical forces in the substation equipment, and the results will be used to develop mathematical models using finite element methods. Existing IEEE standards will be reviewed to determine whether they are acceptable at high fault current scenarios. The impact of mechanical forces for both momentary and steady state fault currents will be evaluated. It is anticipated that the existing electrical equipment and foundations can absorb momentary (short duration) fault currents, and thus avoiding the necessity to upgrade substation equipment in some cases.

#### **Development of Substation Design, Maintenance, and Operation Practices at Increased Fault Current Levels:**

Present design guidelines based on standards such as IEEE will be reviewed and recommendations will be made for high fault current levels. Best operation and maintenance practices will be documented.

**Impact of Fault Currents on Protection and Metering:** The impact of increased fault currents on the operation of protection and metering equipment will be studied using lab testing and modeling. Recommendations will be made.

**Assessment of Fault Currents in the Existing Systems:** System studies will be conducted to evaluate fault current levels at individual utility sites considering both conventional and renewable generation.

### Benefits

- Avoid equipment replacement costs by reducing or eliminating equipment damage due to high fault currents
- Avoid costs due to system outages
- Realize more revenue by increasing power flows using existing assets
- Contribute to improved grid reliability by avoiding equipment damage and subsequent outages
- Increase safety in substations and on transmission corridors by avoiding equipment explosions
- Reduce overall costs of transmitting power over the grid
- Improve customer satisfaction with reduced interruptions and energy rate