Substations - Program 37

Program Overview

Program Description

This program helps substation owners enhance safety, reliability, equipment life, and performance, as well as prioritize their asset investments and allocations of limited resources. It offers a portfolio of tools and technologies such as risk-based asset and fleet management decision support analytics and transformer monitoring. The program also provides knowledge sources such as failure databases and aging models to improve equipment life management and training materials for substation personnel.

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 substation equipment specification, procurement, inspection, assessment, maintenance, 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:

- Develop risk-based fleet management programs
- Extend equipment life with maintenance guidelines
- Reduce maintenance costs via condition-based maintenance
- Improve sulfur hexafluoride (SF_6) 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

The research applies EPRI-created knowledge of the fundamental aging and degradation process of materials, components and systems to define inspection and monitoring approaches, maintenance activities, and mitigation options. Research results will be transferred to members in reports, reference guides, easy-to-use operational and procedural guidelines, and workshops.

- Equipment aging assessment tools—failure modes, degradation mechanisms and diagnostics
- Risk-based fleet management—decision support analytics and methodologies
- Diagnostic effectiveness assessment
- Asset management and maintenance best-practices guidelines
- Reference books, guidelines, videos, field guides, and technology transfer workshops
- Industry-wide equipment performance databases
- Collaborative environments for sharing lessons learned and best practices

Accomplishments

In the past, the Substations program has delivered many highly valuable reports, guides and tools that have helped its members to increase the reliability of electric power delivery while keeping the cost of energy affordable. Some examples include the following:

- **Reference Guides:** Comprehensive references provide the technical basis to design and execute comprehensive maintenance, condition assessment and life extension programs for substation equipment, and to safely perform switching and other operations. These reference guides include the Power Transformer Guidebook, Substation Life Extension Guidelines, Switching Safety & Reliability, Fault Current Management, and Increased Power Flow Guidebook.

- **Pocket Field Guides:** Step-by-step instructions to help field personnel improve the quality and consistency of daily maintenance activities. The set of six pocket field guides includes Substation Infrared Monitoring, Circuit Breaker Lubrication, Circuit Breaker Pump and Compressor Maintenance, Transformer Root Cause Analysis and Failure Investigation, Smart Ground Meter, and Preventing Switching Errors.
- **Power Transformer Expert System (PTX) for Condition Assessment:** Power transformers are vital components of the power delivery system and their operation affects a utility's economic and reliability performance. Hence, accurately and efficiently assessing transformer condition is important for asset and risk management. EPRI developed expert fleet assessment methodologies for power transformers, using readily available data, to create an expert system for transformer condition assessment. The automated tool emulates the thought processes of industry experts, hiding from view the inherent complexities and uncertainties associated with transformer diagnostics.
- **Circuit Breaker Fleet Management:** A suite of applications that utilities can apply and adapt to their own needs— maintenance triggering, replacement or maintenance ranking.
  - Uses readily available data
  - Provides utilities with a framework for circuit breaker asset management
  - Enables trigger-driven condition and risk based maintenance
  - Spreadsheet-based approach—comes with default values that a utility expert can fine tune based on experience
  - Delivered in a format that utilities can readily apply and adapt
- **SF_6 Complete Library, Version 2.0:** The SF_6 Computer-Based Training Modules, Version 2.0, are a set of four CDs for computer-based training on SF_6 safety, handling, and analysis that include the impact of SF_6 on the environment.
- **Industry-wide Substation Equipment Performance and Failure Database—Data, Model and Results:** This product provides the following information:
  - Populated data sets of close to 40,000 in-service transformers and over 2000 failures; analysis tools and analytical techniques used for analyzing industry-wide data
  - The data set can be applied to compare a utility's transformer fleet performance with industry-wide performance through the application of statistical methods to relate performance with industry-wide data segmented by application, family, age, make, and model
  - Data model to assist utilities in data gathering
- **Annual Switching Safety and Reliability Conference:** The conference is attended by managers, supervisors, and operations personnel to exchange experiences about switching procedures contributing to improved safety and reliability practices through improved switching.

Current Year Activities

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

- New versions of Industry-wide Transformer Database, Analytical Tools and Results Library
- First version of the Industry-wide Database for Circuit Breakers
- New modules and analytical capabilities to Transformer and Circuit Breaker Fleet Management Software
- Spares strategy for substation equipment
- Investigation of recent apparent increase of transformer bushing failures
- Effectiveness assessment of transformer and circuit breaker diagnostics
- Utility field trials to validate the effectiveness of new aging markers in transformer oil
- New versions of *Substation Life Extension Guidelines* with field guides and learning modules
- First version of the Power Transformer Guidebook
- Switching safety and reliability conference and practice sharing
- Management of legacy relays and integration of the next generation

Estimated 2014 Program Funding

$6.5M

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Summary of Projects

Project Number	Project Title	Description
P37.101	Transformer Life Management	Effective transformer life management via novel research into failure prevention, life extension, life-estimation, and optimal transformer ratings
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 breakers and develops tools, methodologies, and information to enable effective methods for instituting condition-based maintenance or selecting the most appropriate material, work practices, and tasks. It includes high-voltage and medium-voltage (13.8 kilovolt [kV] to 69 kV) breakers.
P37.103	Protection and Control	Relay mis-operations can adversely impact system operation and disrupt electric service. The project aims to develop new methodologies, processes, and tools to assist utilities in the efforts of reducing complexity, human error and cost in protection system maintenance and asset management, prevention of relay miss-operations through effective configuration management processes, improving reliability and sustainability of utility industry's mission-critical protection and control infrastructure.
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, identification of suspect areas of degradation and development of corrosion mitigation approaches.
P37.105	Other Substation Equipment: Equipment Ratings, Insulators, Arresters, Current Transformers and Infrared Based Inspection and Monitoring	Inspection, monitoring, 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).
P37.108	SF6 Lifecycle Management Guidelines for Breakers, Gas Insulated Lines and Substations	This project helps members address SF_6 issues through improved safety, reduced SF_6 emissions, asset management, and enhanced knowledge capture and training.
P37.110	Switching Safety and Reliability	This project aims to develop controls and procedures that prevent errors, error-likely situations and near-misses in power switching (both in the control room and in the field), enhance worker and public safety, and improve power delivery reliability.

Project Number	Project Title	Description
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 with tasks underway to extend efforts to include other substation equipment, substation bay and extension to the complete substation.
P37.112	Industry-wide Equipment Performance Database	This project provides participating utilities with aggregated data and information resources and methodologies for equipment analysis not currently available to individual utilities to assist in developing repair/refurbish/replace strategies for aging substation fleets. The project collects equipment performance and failure data in a common format from many utility sources to establish a database that enables statistically valid analysis to better determine equipment failure rates, identify type issues early, and help identify best maintenance and specification practices.
P37.113	Effective Maintenance and Monitoring of Transformer Bushings	The objective of the proposed research is to better understand bushing problems, magnitude, operating stresses, underlying failure modes and degradation rates and provide utilities with guidelines for selection, application, procurement, maintenance and testing to insure satisfactory bushing performance.

P37.101 Transformer Life Management (072010)

Description

This project develops new tools and knowledge to help utilities anticipate and prevent failures in transformers, extend transformer life, and gather and retain key subject matter expertise. There is an increasing need for utility companies to maximize the use of their assets while maintaining system reliability. In this environment, management of the aging population of power transformers has become one of the most critical issues 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

Several activities are planned to achieve this:

- **On-line Dissolved Gas in Oil Analysis (DGOA) Monitoring Technologies:** Transformer condition assessment is evolving to online condition monitoring with several commercial solutions available. These technologies are utilizing various approaches and methods to estimate the condition of the transformer. EPRI is planning to develop an evaluation and test protocol to assess the effectiveness and limitations of the sensing technologies and analytical algorithms of the online monitoring systems. The tests will cover a three tier test protocol. The first tier will focus on small scale test in a controlled environment using the research transformer, with the capability to simulate specific condition; the second tier will utilize full size transformers at the Lenox laboratory; followed by field verification with devices installed in utility substations. The results will be included in a report that utilities will be able to use as a decision support in selecting DGOA technologies to match their needs.

- **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 robustness or a step decrease in overall costs. Research also helps members understand emerging sensors in the marketplace—both in the utility industry and in other industries where sensor advances could be translated to transformers.
- **The Copper Book (*EPRI Power Transformer Guidebook*):** A comprehensive transformer reference book that includes all aspects of transformer operation, maintenance, procurement and life-cycle management, is being completed. It is written from the perspective of a utility engineer and addresses all phases of a transformer. The Copper Book serves as a valuable training aid and guides engineers through case studies of common calculations necessary for transformer specification and management.
- **Improved accuracy of transformer remaining life estimation**: EPRI's research in the dynamic behavior of new chemical markers in the oil have the potential for improving transformer life estimates significantly. There is a possibility that using this estimation method may produce useable results without the detailed knowledge of the transformer oil history. The resulting guidelines may help utilities to request a set of specific analyses from laboratories and interpreting the results.
- **Transformer life extension**: Prior EPRI research has concluded that continuous online filtration of oxygen and moisture using membrane technologies offer the potential for low-cost, minimal maintenance without limiting the life expectancy of transformers. It is expected that life-long filtration solutions will lead to significantly extended life of the transformer. Supplemental projects are demonstrating the technology that has been successfully licensed. The findings from the demonstrations are reported back into this project.
- **Transformer forensics—linking diagnostics and maintenance with true internal condition**: EPRI research is examining retired or failed transformers and relating the evidence to both historic 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. Equally importantly, the library is helping assess how effective the diagnostic tools are in predicting the true internal condition of the transformer.
- **Transformer Ratings**: EPRI is developing TRW (Transmission Rating Workstation) to provide members with an industry-standards-based methodology for rating transformers. In addition to the transformers module, TRW includes optional modules for all of the other substation and line equipment on the circuit.

Impact

- Guidance on selection, application, and interpretation of condition-monitoring techniques
- Novel sensor development, focused on highly robust solutions for sensors that will last as long as the transformer
- 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
- Industry-standards-based loading methodologies for transformers and other equipment on the same circuit

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.

2014 Products

Product Title & Description	Planned Completion Date	Product Type
Robust sensors for transformer oil DGA: Prototype, highly robust optical sensors for on-line DGA will be taken into the field in 2014 for the first utility trials. Both a main tank and an LTC will be investigated. The member feedback on the sensor performance will be factored into the final solution that will be moved forward for licensing.	12/31/14	Technical Update
Assessment of online DGA technology effectiveness and limitation: Laboratory and field results applying open test protocols to provide members decision support for selecting transformer monitoring technology.	12/31/14	Technical Update
EPRI Copper Book Training: Workshop Training based on the completed EPRI Copper Book	12/31/14	Workshop, Training, or Conference
Interpretation guidelines for transformer remaining life assessment: Successful culmination of years of EPRI laboratory and field research into helpful guidelines on how to interpret aging markers in the oil - and how to factor in variables such as conservator type.	12/31/14	Technical Report
Transformer Forensics Library - Quantifying diagnostic efficiency: A software tool to rapidly mine the growing library of forensic investigations - helping answer two important questions: Firstly, which diagnostic tools effectively predict internal conditions and secondly, how a utility's present problem with a specific transformer compares to the outcomes seen with similar units in the library.	12/31/14	Software
Transmission Ratings Workstation (TRW V1.0) - Transformer Module: TRW provides members with an industry-standards-based methodology for rating transformers. In addition to the transformers module, TRW includes optional modules for all of the other substation and line equipment on the circuit.	12/31/14	Software

P37.102 Circuit Breaker Life Management (072011)

Description

This work will help utilities reduce the operating and maintenance costs and improve the reliability and availability of their circuit breakers. The life-cycle performance of power circuit breakers is, to a large degree, determined by the performance of constituent materials and components. Deterioration of linkages and interrupters is not time dependent, while the rate of deterioration of lubricants and seals is time dependent. Together, the performance of these elements drives the requirements for maintenance and refurbishment. Substation owners don't have a complete understanding and only a small amount of quantifiable data of breaker material and subsystem performance to design a cost-effective condition-based maintenance program that includes all necessary maintenance-appropriate work practices and tasks. This research will develop the information, and design the tools and methodologies, to address these gaps for high-voltage circuit breakers. The methods developed will be adapted that they can be applied to medium-voltage (13.8 kilovolts [kV] to 69-kV) breakers.

Approach

To address these needs, in 2014 this project will undertake the following:

Innovative techniques for circuit breaker dielectric condition assessment: The objective of proposed research is to develop, adapt and apply non-invasive approaches to better assess the condition of interrupter and dielectric in oil and gas filled circuit breakers. The emphasis will be on analysis and interpretation—for example, interpreting the composition of detected gases, identifying what other trace compounds can be measured, and what thresholds make them significant for inclusion in the analysis. Building on prior year research, the 2014 research tasks will include further methodology development, 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: The objective of the proposed research is to develop and apply assessment metrics to various high voltage circuit breaker diagnostic techniques to determine which tests prove the most useful. The ultimate goal is to provide utilities guidance on the more informative and cost effective procedures to provide information for successful condition-based maintenance. Breaker diagnostic techniques such as first trip capture, gas sampling and density assessment, dynamic resistance measurements, breaker oil analysis, and contact wear assessment will be evaluated. Building on previous year research, the 2014 research 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.

Circuit Breaker Lubrication Guides: 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. This product will document in detail the rationale, methodology and underlying approach, and test results, with the ultimate objective of providing an engineering application guide to help utilities improve their circuit breaker lubrication practices along with guides for maintenance personnel. In 2014 EPRI will:

- Continue development of an 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 to characterize the aging of circuit breakers and provide application specific guidance in a pocket guide format for utility staff.

Circuit Breaker Life Extension Guide: 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 the existing one.

- Based on direction established using the roadmap developed in 2012, review the overall content and organization of the guide.
- Continue the task to rewrite the guide in its entirety. 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) developed based on utility guidance provided in 2013.

Catalog and Assessment of Knowledge and Practices:

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

Technology Transfer: 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. Pertinent case studies and utility lessons learned will be shared.

- 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 with the 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.

2014 Products

Product Title & Description	Planned Completion Date	Product Type
Innovative techniques for circuit breaker dielectric assessment: This product will be part of a multi-year research initiative to research, develop, adapt and apply non-invasive approaches to better understand interrupter (including contacts) and dielectric medium condition in oil and gas filled circuit breakers. The emphasis is on interpretation—for example, interpreting the measurement of gases; identifying what else can or might be measured (trace compounds), and what are the thresholds for interpretation. Building on concepts developed in 2013, the 2014 research tasks will include methodology enhancement, prototyping, and additional experience gathering. Associated supplemental projects may be initiated to assist with field demonstrations and testing.	12/31/14	Technical Update
Effectiveness Assessment of circuit breaker diagnostic tests: This product will be part of a multi-year research initiative to develop and apply assessment metrics to various high voltage circuit breaker diagnostic techniques. The objective is to provide utilities guidance on the more informative and cost effective procedures to provide information for successful condition-based maintenance. Building on the research plan developed in 2013, the 2014 research tasks will include utility use case and experience collection, data analysis, and the development of assessment methodology. Breaker diagnostic techniques such as first trip capture, gas sampling and density assessment, dynamic resistance measurements, breaker oil analysis, contact wear assessment will be evaluated. Future-year work may include methodology application and solicitation of feedback through field demonstrations and laboratory tests.	12/31/14	Technical Update

Product Title & Description	Planned Completion Date	Product Type
Circuit breaker lubrication compatibility & selection—engineering application guide: 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. 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.	12/31/14	Technical Update
New versions of pictorial field guides—power circuit breaker component degradation assessment: 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—HVCB Lubrication Guide and HVCB Pumps, Compressors and Control Valves—will be updated with new material.	12/31/14	Technical Update
Life Extension Guidelines for circuit breakers: 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 were reviewed. 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) developed based on utility guidance provided in 2013.	12/31/14	Technical Update
Using relays for circuit breaker diagnostics: This product builds on prior research and adds new information to summarize the results of ongoing research and field tests: · Identify and catalogue applications of interest—for example, nozzle wear for SF6 breakers or contact wear for oil breakers. · Demonstrate application through utility field trials—ongoing trials focus on detecting "slow open" or "slow close" circuit breaker operations; it is anticipated that 2014 and future year trials will focus on developing logic and necessary setting changes for detecting nozzle wear for SF6 breakers or contact wear for oil breakers. Additional applications will be added based on feedback from the Task Force. · Document underlying methodology, logic and relay setting changes. · Provide new information in the form of triggers and thresholds for improving condition-based maintenance. Ultimately, the goal is to develop a knowledge base or field guide for circuit breaker diagnostics using relay data.	12/31/14	Technical Update
Circuit breaker life management workshop: 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.	12/13/14	Workshop, Training, or Conference
Circuit breaker component and sub-system performance: Pumps and compressors: This product builds on previous research new information to summarize the results of ongoing research to better understand failure modes and component degradation and to develop better guidance to understand effective life. · Collect and analyze field-aged samples—pumps, compressors, aged mineral oil, aged synthetic oil, aged hydraulic fluids	12/31/14	Technical Update

Product Title & Description	Planned Completion Date	Product Type
· Performance testing of commonly used pumps and compressors · Analyze performance—mineral oil versus synthetic oil · Test field-aged samples of hydraulic fluids · Provide status update—methodology, underlying approach, test, and analysis results. · Provide maintenance guidelines for gas compressors · Provide guidelines that utilities can use in selecting and standardizing on the use of one type of compressor oil		

P37.103 Protection and Control (072012)

Description

Relay mis-operations can adversely impact system operation and disrupt electric service. Dealing with the growing complexity of relaying technologies accompanied by tighter reliability regulations are challenges faced by many utilities. Setting errors and relaying equipment failure are common causes of relay mis-operations. Therefore, the reliability and performance of a protection and control (P&C) system largely rely on a well-established maintenance program together with tightly-managed configuration management processes. These two broad areas comprise the focus of this multi-year research project.

The traditional time-based maintenance approaches, when applied to the modern microprocessor-based P&C fleet, have shown their limitations including high cost, low efficiency, and potential vulnerability to human error. On the other hand, modern P&C technologies offer utilities not only the advantages of digital technology but also the opportunity to develop more effective maintenance options that can potentially replace the time-based practices or significantly improve existing practices. This project plans to explore new approaches including non-intrusive maintenance and performance-based maintenance.

In addition to equipment failure, setting errors can directly lead to protection system failure. Compared to electromechanical relays, modern microprocessor-based digital relays offer much more settable parameters and programmability. A study conducted by NERC reveals that incorrect relay settings, programmable logic, or design are the leading cause of protection system mis-operations in North America. The research work will apply the key principles of configuration management to develop systematic approaches, tightly managed processes, applicable technical tools and templates to help utilities overcome the growing challenges in maintaining the correct P&C settings consistent with the substation configuration information throughout its lifecycle.

Approach

To address utility challenges in protection and control, multi-year research will address three themes: 1) enabling technologies and engineering for non-intrusive maintenance; 2) development of an industry-wide relay performance repository; and 3) development of configuration management process and tools. Each theme will deliver near and medium term value each year through a set of meaningful milestones while staying focused on the longer term aspects. The near and medium term milestones will deliver products that members will be able to use immediately and demonstrate immediate impact at their utilities.

Enabling Technology Assessment: Modern protection, control and data acquisition technologies have the capability of self-monitoring, self-diagnosis, event capturing and alarming—for example, monitoring and diagnosing the majority of internal components, analog sensing inputs, and data communication channels. The objective of the proposed research task is to increase awareness and enhance understanding of enabling technologies, assess their effectiveness, and provide utilities with selection and application guidance that they can apply in their engineering standards and design specifications. To that end, the 2014 task will catalog emerging technologies into four groups: protective relays, pilot protection communications, voltage and current sensing inputs, and tripping circuitry. The information gathered will be shared and reviewed with task force

members, gaps identified and follow-on research tasks developed for effectiveness assessment. Ultimately the work will contribute to utilities in implementing a non-intrusive approach for continuous functional checks and verification.

Industry Wide Relay Failure Database: Reliability regulatory entities have launched a series of mandatory and enforceable standards on protection system maintenance, which require P&C asset owners to perform and document specific maintenance tasks.

This has led to utilities desiring a performance-based maintenance approach. Such approaches may assist utilities in prioritizing and enhancing the effectiveness of test and maintenance tasks that otherwise are solely based on time intervals. To assist utilities in accomplishing the goals and objectives, research under this theme proposes needs assessment, identifying drivers and needs, defining key terms such as failure of protection devices, establishing a uniform data model, and over time working with member utilities to populate an industry-wide relay database.

Resulting information through analysis of populated datasets and information collected will support utilities in establishing performance-based approaches for their protection and control systems. The effort will also allow utilities to establish a rationale and basis for other time-based tests. The 2014 task will focus on identifying needs and drivers, developing definitions for key terms, and establishing a uniform data model. Future year research will focus on data collection, populating the database, information review, and data analysis. Future year efforts will also focus on developing an approach to perform necessary research to help utilities in validating maintenance and test intervals.

Configuration Management for Protection & Control Systems: Configuration management is based on the principles established and widely adopted by the military and other industries to manage complex systems. In a protection and control (P&C) system, a large amount of highly correlated configuration information needs to be tightly and consistently managed, such as engineering designs and drawings, protection calculations and settings, relay configuration files and software, relay firmware, testing tools, and testing records. When applied to P&C systems, a well-established configuration management system ensures that the P&C configuration information and any changes to that information are systematically identified, approved, verified, and recorded in sufficient detail throughout its lifecycle. Configuration management systems also ensure that P&C configuration information conforms to functional requirements, and P&C documentation matches the actual asset status in the field. Under this theme, proposed research will review industry configuration and settings management standards and systematic configuration management approaches to identify the key configuration management principles and processes that can be adopted or tailored specifically to P&C systems. In 2014, proposed research tasks will evaluate configuration management processes, tools and develop applicable templates to assist utilities in the implementation of configuration and setting management. Future year tasks will collect use cases from utilities to generate recommended practices as well as identify the potential gaps for improvement. The ultimate outcome from the configuration management research will help utilities move towards standardized design, and automate processes such as protection setting verification.

Impact

- Prevent relay mis-operation
- Reduce human errors during maintenance and increase protection system reliability
- Lower costs by reducing unnecessary maintenance and extending maintenance cycles
- Assist utilities in meeting regulatory requirements by developing new technologies and tools
- Improve protection configuration data management throughout the lifecycle

How to Apply Results

Utilities can selectively apply the approaches, methodologies, guides, technologies, or templates developed in the project to create their own optimal maintenance programs and configuration management systems.

2014 Products

Product Title & Description	Planned Completion Date	Product Type
Guidelines for selecting and applying enabling technologies for protection systems maintenance: The ultimate objective of this deliverable is to provide guidelines for selecting and applying enabling technologies for protection systems maintenance. In 2014, this deliverable will identify and catalogue emerging technologies of protection system maintenance in four groups: protective relays, pilot protection communications, voltage and current sensing inputs, and tripping circuitry. The report will also document results of information review and list gaps in presently available technology and tasks required to bridge gaps and evaluate their effectiveness.	12/31/14	Technical Update
Industry wide Failure Database for Protective Relays: This deliverable will identify needs and drivers, developing definitions for key terms and establishing a uniform data model and process for collecting data and information for EPRI's Industry wide Relay Failure Database.	12/31/14	Technical Update
Guidelines for Configuration Management for Protection and Control Systems: This report will evaluate configuration management process, tools, and provide applicable processes, tools and templates to assist utilities in consistent management of protection settings, relay configuration files and relevant information.	12/31/14	Technical Update

P37.104 Substation Ground Grid Research (072013)

Description

A substation ground grid is an essential component of the substation and must provide the following functions to preserve system integrity and eliminate risk:

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

Substation ground grids must be designed to ensure that even the most severe faults will not harm staff or damage equipment within the substation and will not create hazards for the public outside the substation fence.

They are subject to two major types of stresses:

- Stresses during a fault or lightning
  - These stresses may break the connection of individual elements and interrupt the continuity, introducing high resistance across bonds.
  - The grounding system may have properly cleared the fault, leaving no obvious indication that it has been compromised. However it may not be able to provide the same level of protection.
- Stresses that are the expansive and persistent forces of corrosion and weather.
  - Stresses due to freezing and soil expansion may break the connection of individual elements.
  - Soil corrosivity, which is worse for low resistivity soil, constantly wears the grounding electrode away. Metal dissimilarities can accelerate this process.

The measurements of soil resistivity, ground impedances, and potential gradients in residential, commercial or industrial areas introduce a number of complexities such as difficulties in choosing a suitable direction or location for test probes for impedance measurement. It may be necessary to make multiple measurements and to plot trends. Stray currents and other factors usually interfere with the measurements. The measurement technique based on variable frequency may help to avoid interference from stray currents at power frequency

and its harmonics. As the ground grid components age over time due to the different stresses, there is a need for innovative approaches to inspect, assess, maintain and monitor the grid. Needed is a holistic approach that provides utilities with tools and methods to manage an aging fleet of substation ground grids.

Approach

In an effort to develop a holistic fleet management approach, 2014 research intends to address soil properties, above and below ground corrosion, and develop guidance to address the corrosion aspects of ground grid corrosion. The following specific tasks will be undertaken:

- Measurement and modeling of soil characteristics, including multilayer soils
- Assessment of the performance of surface materials to ensure safety from step-and-touch voltage levels and compliance with applicable performance and safety standards
- Development of criteria for proper grounding and operation of substation electronic equipment
- Development of methods to design and install new grids, bolster grids that have deteriorated, or improve grids that need upgrading because of higher fault current levels
- Enhancement of the understanding of ground grid corrosion rates as function of soil type, acidity, drainage, and effects of the influence of outside factors such as currents from electric rail lines, and aluminum smelter plants
- Development of corrosion mitigation approaches in both atmospheric and soil exposure

The methodology development will be enhanced in future years by addressing factors other than corrosion.

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 mis-operations and failures
- Optimize maintenance budgets through population assessment (targeted inspections) and predictive maintenance of coating systems, ground grids and foundations

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.

2014 Products

Product Title & Description	Planned Completion Date	Product Type
Fleet Management Approaches for Aging Substation Ground Grids: Present efforts are focused on better understanding corrosion rates and their impact on aging. This is achieved through condition assessments, sample collection, laboratory analysis and modeling of environmental factors. Other factors to be added as methodology is enhanced in future years and ultimately a guide and set of software tools will be developed for utility use.	12/13/14	Technical Update

Product Title & Description	Planned Completion Date	Product Type
Managing Corrosion and Coating Degradation in Aging Transformer and Circuit Breaker Tanks: This research is focused upon condition assessment of tank walls and floors to understand corrosion rates and the best methods for mitigation of the damage. Included in this task are the techniques necessary to judge coating integrity, methods to trend the aging process and the development of guidelines for corrosion mitigation practices.	12/31/14	Technical Update

P37.105 Other Substation Equipment: Equipment Ratings, Insulators, Arresters, Current Transformers and Infrared Based Inspection and Monitoring (065593)

Description

Maintaining and potentially increasing the reliability, safety, and life of substation equipment requires timely and effective maintenance based on accurate inspection and knowledge of equipment condition beyond transformers and circuit breakers.

Personnel need to understand the balance of substation equipment, its degradation and failure modes, thermal ratings, and the appropriate inspection, monitoring 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 developments and assessment techniques to be able to select the appropriate course for their particular circumstances. In addition, field personnel need tools and training to ensure that correct and consistent decisions are made.

This project assesses and documents the latest inspection and monitoring technologies for the balance of the substation equipment, providing industry data and research results to serve as decision support for risk-based maintenance. Results will increase the subject matter expertise through technology transfer. In addition, the Transmission Ratings Workstation (TRW) module will be created for the balance of the substation equipment, such as disconnect switches, buss work, etc. The equipment ratings software tools may be used to increase or optimize the power flowing through existing assets.

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:

Research Needs Assessment: 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.

- **Failure Modes and Degradation Mechanisms:** 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.
- **Awareness of Novel Condition Monitoring Technologies:** Identify and investigate 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.

- **Substation Equipment Ratings:** 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)
- **Research Adaptation and Application**: 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. Another example is development of algorithms for online infrared monitoring in substations.

In 2014 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 2014 material on insulators, current transformers, arresters and batteries 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).
- Final version 1.0 will be delivered in 2014.

Surge Arresters

- Continued testing of field aged and failed arresters to better understand underlying failure modes and degradation mechanisms
- Continued development, demonstration, and documentation of prototype test and measurement technology to effectively assess surge arrestors in the field without removing them from service.
- Review and update catalog of presently available online (in-service) testing and monitoring and offline testing approaches.
- Develop and deliver tutorials for selection and application of station class arresters.

Current transformers

- Document different current transformer designs in service at utilities, as well as their applications.
- Continue to catalog 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.
- Develop test plan and perform laboratory testing of field aged and failed current transformers received from member utilities to better understand fundamental failure modes and degradation mechanisms through aging tests. Document findings in a technical update and share findings at task forces in a power point presentation.

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.

Awareness of Novel Condition Monitoring Technologies: Continue to identify and investigate novel condition monitoring and 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.

Substations Equipment Infrared Monitoring: Develop an application guide for utility field staff to apply and interpret findings from the application of online and offline infrared inspection approaches. As part of this effort, the existing EPRI pocket field guide will be reviewed and updated with new material. Effectiveness assessment tests will be conducted on defective equipment monitored in a laboratory environment. Results from testing will allow identifying gaps in presently available monitoring algorithms and technology. A tutorial will be developed and delivered in the form of a technology transfer workshop for utilities.

Technology Transfer: 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. Pertinent case studies and utility lessons learned will be shared.

- Develop and deliver an annual technology transfer workshop

Combined knowledge gained about other substation equipment performance and equipment ratings from the above tasks enables utilities to develop the following:

- A quantitative understanding of aging and deterioration rates
- Expected life of other substation equipment—components, materials and subsystems
- Enhanced cost-effective methods for implementing a condition-based maintenance approach

Impact

- Reduces overall operations and maintenance (O&M) costs, 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 in a timely fashion 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. In addition, the equipment ratings software module could be used to increase and optimize the power flowing through existing assets.

2014 Products

Product Title & Description	Planned Completion Date	Product Type
Station Class Surge Arresters - guidelines for selection, application, monitoring and maintenance: 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. Based on progress made in 2014, the report will also provide guidance on in-service testing, inspection and assessment.	12/31/14	Technical Update
Substation Insulators: Resistive Glaze and RTV Coatings: 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

Product Title & Description	Planned Completion Date	Product Type
Guidelines for monitoring current transformers: 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
Application guidelines for infrared inspections for substations: 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. The 2014 report will provide utility field staff guidelines to apply and interpret findings from the application of online and offline infrared based inspection approaches for inspection and assessment of substation components. This guide will help readers understand what types of equipment are in substations, what normal operation is, what abnormal operation is, and why the equipment may be operating abnormally. The deliverable will consist of a pocket field guide and tech transfer workshop at utilities.	12/31/14	Technical Update
Transmission Ratings Workstation (TRW): The Transmission Ratings Workstation (TRW) will continue to be developed in 2014. This software will incorporate all EPRI equipment ratings-related software modules in one suite. 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
Condition Monitoring and Implementation Database: This database will contain information to help users develop and implement their condition monitoring strategy. The following will be documented as part of the database: a)sensors and technologies presently available and the issues which they are capable of detecting, b) case studies documenting how utilities have implemented the sensor technologies into their condition monitoring strategy	12/31/14	Software
Life Extension Guidelines for Other Substation Equipment: 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. It is anticipated that in 2014 material on insulators, current transformers, arresters and batteries will be reviewed and developed based on utility guidance.	12/31/14	Technical Update
Increased Power Flow Guide Book-2014: The *Increased Power Flow Guidebook* (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 topics for the guidebook are identified by industry experts and EPRI member advisory groups.	12/31/14	Technical Update
Other Substation Equipment - technology transfer workshop: 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.	12/31/14	Workshop, Training, or Conference

P37.108 SF6 Lifecycle Management Guidelines for Breakers, Gas Insulated Lines and Substations (052021)

Description

Sulfur hexafluoride (SF_6) 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_6 emissions, safety, training, leak detection, destruction, and SF_6 analysis. As pressure to reduce greenhouse gas emissions grows and cost pressures continue to escalate, energy companies need solutions to meet these challenges. Additionally, utilities are facing pressure to maintain, refurbish, and extend the life of their gas insulated lines and substations. EPRI will expand its research on SF_6SF6 replacement technologies, currently under development in Substations, and sponsored by EPRI's Technology Innovation Program.

Approach

Four broad themes guide this project's research:

- Reducing SF_6 Emissions—through application of new technology. Improved SF6 tracking and reporting—to assist with emerging regulatory requirements
- SF_6 training and knowledge transfer
- Gas-insulated line and substation life cycle management

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.

Under this project, the following tasks will be conducted in 2014 to support the research:

- Information gathering through laboratory experiments including testing on live-filling strategies
- Evaluation of available and emerging SF_6 leak detection technologies
  - Laboratory testing in the EPRI Charlotte Lab
  - Full-scale laboratory testing
  - Field testing in member substations
- State-of-the-science understanding through studies and surveys
- Engagement in industry, academic, and regulatory groups to understand the issues
- Knowledge transfer through computer-based training and task forces

Impact

- Reduces costly SF_6 emissions
- Mitigates risks of potential heath hazards via safe-handling techniques, tools, and guidelines
- Minimizes environmental emissions of SF_6
- Enhances SF_6 tracking and reporting to meet emerging regulations
- Lower life cycle cost of gas insulated systems
- 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_6 training tools, with the only requirement being a PC and a printer. Technologies for SF_6SF6 emission reduction are demonstrated to members in both the laboratory setting and in the field—allowing for easy adoption.

2014 Products

Product Title & Description	Planned Completion Date	Product Type
Field tests of the prototype novel SF6 capture technologies for emission reduction: Host utility trials of the SF_6 capture concepts for both SF_6 leaks and SF_6 analysis	12/31/14	Hardware
2014 Novel device to lower cost of testing and reporting: 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
2014 update to the Visual Field Guide of common SF6 leak locations and sealing solutions: 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
2014 Report on SF6 Replacements	12/31/14	Technical Update
2014 Report Framework for Life Cycle Management of Gas - Insulated Lines and Substations: This report will determine current best practise in life estimation, life extension, and life cycle management optimization of gas insulated lines and substations. Research gaps for future research will be identified.	12/31/14	Technical Update
Laboratory test results on Live Filling techniques: There are important open questions on the optimal strategies for live filling of SF6 equipment. This update will report on the most recent experiments focused on assessing live filling approaches under various conditions	12/31/14	Technical Update

P37.110 Switching Safety and Reliability (052029)

Description

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 or perform switching in the field must be vigilant and properly trained to prevent switching errors and near-misses, 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 and EPRI research.

Approach

This project conducts research on methodologies, human performance issues, and technological advances related to operational switching with the goal of reducing switching errors and near-misses, 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 (SS&R) Conference to transfer research results to the utility industry. Using experts knowledgeable about the details of switching both in the control room and in the field as well as experts in human performance, the project analyzes data and procedures to highlight areas that should be improved and to identify industry best practices. Specific goals for 2014 include the following:

- Continuing the development of the *EPRI SS&R Reference Book*
- Discovering weak links in switching processes, and defining remedial and preventive strategies
- Identifying safe switching work procedures that improve system integrity and worker safety
- Identifying training needs for personnel working on modern switchgear

- Monitoring new industry trends, developments and mobile communications devices (such as iPads), and assessing their usefulness in preparing switching orders and executing switching operations
- Assessing the positive impacts of new concepts such as Situational Awareness and Subconscious (Tacit) Knowledge
- Sharing lessons learned

Impact

- Increase reliability and safety while reducing errors, error-likely situations and near-misses 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.

2014 Products

Product Title & Description	Planned Completion Date	Product Type
Impact of changing grids on switching safety and reliability: Distributed, non-traditional power sources and increased automation may create additional challenges for preparation of switching orders and safe switching in substations. This product will address such issues as: how DG may change preparation and execution of switching orders;, is there a need for additional knowledge or training for the switchperson; how switching orders are communicated between the control room and the field switchperson. This report will identify gaps and future research to bridge the gaps and identify possible changes.	12/31/14	Technical Update
DMS (Distribution Management System) - Effectiveness assessment: EPRI intends on initiating a survey based approach to catalogue and document feedback from operators responsible for performing switching in substations. The feedback will include their experiences and level of comfort on the impact and use of DMS in decision making. The result will be qualitative assessment based on anecdotal experience. This product will identify challenges and lay groundwork for future research to develop appropriate responses.	12/31/14	Technical Update
Human Operational Errors Involving Control, Relay, and Auxiliary Equipment: 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. In cooperation with the Protection and Control project 37.103, this product will build on previous work by defining appropriate barriers to prevent errors and by developing training materials.	12/31/14	Technical Update

Product Title & Description	Planned Completion Date	Product Type
Technology Advances Relevant to Operational Switching: This product will monitor and catalogue technological advances such as: multifunctional mobile communications devices (for example, iPads), control room display methodologies; substation and equipment access control policies and devices; system print storage and maintenance; to name a few. It will identify relevant methodologies and devices and assess their applicability to operational power switching. It will also identify gaps and formulate a roadmap for development of needed innovations in power switching and their practical implementation into the utility operations.	12/31/14	Technical Update

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

Description

This effort provides utilities with new tools and methodologies to implement a risk-based equipment asset management program. 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 developments 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:

Generic condition assessment tools for substation equipment maintenance and asset management for utility adoption and adaptation: The work will further develop analytical software tools and document methodologies for transformer and circuit breaker fleet management. Simultaneously, in 2014 research tasks will investigate condition assessment analytics for other substation components such as disconnect switches, current transformers, potential transformers, batteries, protection, control, and data acquisition infrastructure. Results will be documented in a report that will assess needs, quantify readily available data and develop an analytical approach and, based on these, produce an action plan for development.

Develop a generic framework for incorporating condition indices, operational requirements, and business rules into a risk-based assessment and mitigation methodology: This effort will develop a broad-based framework that will provide a general approach for utilizing available data and information to combine equipment condition assessments, failure consequences, and utility business rules to provide a methodology for assessing equipment operational risks. The methodology will eventually allow for individual equipment risks to be combined, providing a station risk assessment.

Substation Equipment Maintenance and Asset Management—Utility Experience Sharing

- Document utility use cases and application notes
- Document industry maintenance practices using web-based surveys
- Provide a forum to share lessons learned from utility equipment maintenance and operation experiences

Substation Equipment Asset Management Guidelines: Develop the guidelines 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 multi-year effort with the initial 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 2015.

Risk Mitigation and Maintenance Strategies Workshop: Transfer technology and provide training. The workshop will provide a forum for disseminating the research results and gathering utility feedback on their application. Pertinent case studies and utility lessons learned will be shared.

Impact

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

Provides 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 risk 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. The research knowledge and workshop and guidelines will assist in implementations.

2014 Products

Product Title & Description	Planned Completion Date	Product Type
Power Transformer Fleet Management: The product will deliver tools and methodologies such as Power Transformer Expert System (PTX) that utilities can apply to assess individual transformer system conditions (main body, tap changer, bushings, oil quality) and to utilize the condition assessments to develop equipment risk assessments (by developing and incorporating consequences of failure index). In 2014, new version of the software will be released updated with new modules and enhancements. Simultaneously, the underlying methodology and approach also will be updated.	12/31/14	Software
Circuit Breaker Fleet Management: The product will deliver a suite of applications that utilities can apply and adapt to their own needs – maintenance triggering, replacement or maintenance ranking. In 2014, spreadsheet based algorithms developed in previous years will be packaged in a modular software application that serves the broad application suite. Algorithms will be enhanced based on lessons learned from utility deployments and new guidance for assessing a wider variety of breaker types.	12/31/14	Software

Product Title & Description	Planned Completion Date	Product Type
Analytics for the fleet management of other substation equipment: Investigate condition assessment analytics for other substation components such as disconnect switches, current transformers, potential transformers, batteries, protection, control and data acquisition infrastructure. The 2014 report will assess needs, quantify readily available data and develop an analytical approach and, based on these, produce an action plan for development.	12/31/14	Technical Update
Analytics for substation and bay risk assessment: Substation owners are interested in developing methodologies for substation bay and complete substation risk metrics by combining risks associated with individual equipment risk assessments. This report will assess needs, quantify readily available data and develop an analytical approach and based on these produce an action plan for development.	12/31/14	Technical Update
Substation Equipment Asset Management - utility experience sharing: 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	Technical Update
Substation Equipment Asset Management Guidelines: 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 multi-year effort with the initial tasks focusing on developing the outline and preliminary draft for member review and feedback. The 2014 deliverable will consist of a draft for member review and feedback. It is anticipated that the final version will be published in 2015.	12/31/14	Technical Report
Risk Based Substation Equipment Asset Management Workshop: 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

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

Description

This work provides utilities with new knowledge and data vital for effective asset management that is only available through an industry-wide effort. 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. Without historical performance data of assets with similar characteristics and the ability to predict future performance, 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 and breakers that will help accomplish these and other fleet management tasks.

This project provides participating utilities with aggregated data, information resources and methodologies for their analysis 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 utility sources to establish a database that enables statistically valid analysis to better determine equipment failure rates, recognize type issues 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 type issues early.
  - Enable the development of other useful 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 and methods for analyzing the data and applying results of analysis.

Members may consider to pursue a related supplemental project to apply the industry wide dataset and develop member-specific analysis and comparison. These supplemental efforts would populate the Industry-wide Equipment Performance Database with historical data in addition to providing the defined analysis. 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 38,500 utility power transformers. The 2014 effort will continue adding additional records to the database to increase the rigor of the statistical analysis and results. The circuit breaker database is under development and will be released in 2014 with data from real utility breakers, data models, and a first analysis report of the existing data. Tap changers and other substation equipment databases may be addressed in future years.

In addition to new versions of 2014 deliverables, the following are anticipated in 2015 and 2016:

New versions of industry wide database—circuit breakers, populated datasets—anticipated in 2015

As ongoing R&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 identify new applications, enhance results library, and 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.

Industry-wide Equipment Performance Database—application guide—anticipated in 2016

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.

Impact

Including detailed industry-wide information in asset management decisions may help members to improve reliability while managing the overall costs contributing to keep electricity affordable.

- Improve capital planning and asset management of existing infrastructure with 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 and improve data quality and value by using consistent data formats and sharing and analyses based on industry standards
- Enable identification of type issues 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 develop risk-informed maintenance and asset management programs, assess equipment risks and test and validate end-of-life models.

2014 Products

Product Title & Description	Planned Completion Date	Product Type
New Version: Power Transformer Database: Failure Database, Data Model And Analysis Tool: ***Failure Database:*** This product will compile and analyze historical failure data (transformer, tap-changer and bushings) in a common format using information provided by over 20 U.S. and international utilities. Results will be delivered in the form of Excel Workbooks and will include source data and select analysis results on descriptive statistics on transformer component and sub-system performance. ***Data Model:*** The product 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 template in Microsoft Excel spreadsheet format. ***Analysis Tool:*** The transformer data collection and analysis started in 2006 now contains records on over 38,500 utility power transformers. As ongoing R&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 using various filtering criteria. The querying capability and visualization will be enhanced with new functionality as utility feedback and new data becomes available in future years.	12/31/14	Software
Industry-wide Database - key findings and case studies: Using the Industry-wide Transformer Database and advanced statistical analysis techniques, EPRI has begun developing hazard rate functions for selected transformer groups. These functions are based on the largest known depository of utility power transformer performance data and provide insights not available elsewhere. A number of utilities have used the transformer database to assess their fleet performance and to help plan capital and spares policies. The 2014 report will summarize the transformer database development, applications as a decision support tool for asset managers, data categories and data processing, insights on transformer aging and failure, and utility applications. Over time, new reports will be added to assist users with analysis of circuit breaker, tap-changer, and other substation equipment data.	12/31/14	Technical Update

Product Title & Description	Planned Completion Date	Product Type
Circuit Breaker Database: Electronic Media: The 2014 product will document the data model to assist utilities in collecting and contributing circuit breaker data to the industry-wide database. It will also document results of prototyping the concept using data from a few member utilities.	12/31/14	Technical Update

P37.113 Effective Maintenance and Monitoring of Transformer Bushings (072017)

Description

This project will help utilities reduce costs and improve reliability and availability by decreasing the potential for bushing failures. The performance of a utility's power transformers depends on the condition of the transformer components and subsystem. Bushings are a key component. However, numerous transformer failures have been attributed to potential bushing issues. The objective of the proposed research is to better understand bushing problems, magnitude, operating stresses, underlying failure modes, and degradation rates and provide utilities with guidelines for selection, application, procurement, maintenance and testing to achieve required bushing performance.

Approach

To address these needs, in 2014 this project will undertake the following tasks:

Bushing Root Cause and Failure Analysis: This task will develop a guideline to assist utilities in performing bushing root cause and failure analysis. Topics would include pre- and post-fault data collection and review, collection of oil and paper samples, visual examination of insulation layers, collection of samples for laboratory testing (x-wax formation for example) and other electrical tests. The guidelines would also include the application of e-field modeling to better understand operational stressors. In addition, this task will develop and maintain a library of findings catalogued from utility-specific studies that would benefit the broader industry.

Bushing Diagnostic Tests Effectiveness Assessment: A multi-year research initiative to develop and apply assessment metrics to various bushing diagnostic techniques to determine which tests provide the most useful information will be initiated in 2014. The objective is to provide utilities guidance on the most informative and cost-effective procedures for condition-based bushing maintenance or replacement. Research tasks will include utility use cases and experience collection, data analysis and the development of an assessment methodology. A test set-up will be developed and constructed in the EPRI Lenox high voltage laboratory to enable energizing bushings at full voltage. This facility will be used to conduct accelerated aging tests to better understand the effectiveness of emerging online monitoring techniques and better understand both the effectiveness and optimal frequency for performing tradition offline diagnostics like power factor and capacitance testing. Future-year work may include methodology application and solicitation of feedback through field demonstrations and laboratory tests.

Bushing Reference Guide: The goal is to develop a comprehensive reference guide that provides utilities information on fundamental design description, operating, selection and application principles, maintenance, monitoring, and replacement. The guide will include an overview of different technologies, including oil filled, fixed lead, draw lead, bottom connected, and resin impregnated. The first step in an estimated three-year effort is to form a group of utility advisors and technical experts and develop an outline. Based on the outline, topics will be prioritized and technical content developed and populated. In parallel, this task will start gathering and documenting industry practices in bushing routine maintenance, diagnostic testing, and end of life criteria.

Bushing Failure Database: Under this task EPRI will initiate the development of a bushing failure database. In 2014 the framework and data model will be established and the first records already in-hand will be populated to allow for demonstration and validation of the approach. An ongoing effort will be initiated to catalog failure reports and any other information available from bushing failure events and utility root cause analyses.

Technology Transfer: EPRI will develop and deliver an annual bushing workshop presenting the research findings and providing a forum for additional utility information exchange.

Impact

The combined knowledge gained in this project will generate the following positive impacts:

- A quantitative understanding of aging and deterioration rates
- A better understanding of the expected life of bushing materials
- Enhanced cost-effective methods for implementing a condition-based maintenance and replacement approach

How to Apply Results

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

2014 Products

Product Title & Description	Planned Completion Date	Product Type
Root cause and failure investigation guide: This deliverable will develop a guideline to assist utilities in performing root cause and failure analysis of bushings.	12/31/14	Software
Effectiveness assessment of bushing diagnostic tests: This deliverable will provide utilities guidance on the most informative and cost effective procedures for condition based maintenance.	12/31/14	Technical Update
Bushings reference guide: This deliverable will develop a comprehensive reference guide for utilities on topics related to transformer bushings. This will be a multi-year effort with topics and priorities determined by the members.	12/31/14	Technical Update
Bushing failure database: initial design: Under this task EPRI will initiate the development of a bushing failure database. In 2014 the framework will be established and validated.	12/31/14	Technical Update
Technology transfer workshop: EPRI will develop and deliver an annual bushing workshop presenting the research findings and providing a forum for additional utility information exchange.	12/31/14	Workshop, Training, or Conference

Supplemental Projects

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

Background, Objectives, and New Learning

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 ¼ 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.

Sunburst Network For Geomagnetic Current (003679)

Background, Objectives, and New Learning

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.

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 Learning

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 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.

Mechanical Forces in Substations (073524)

Background, Objectives, and New Learning

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 transmission and substation equipment may cause equipment failures and system outages.

This project's objectives include the following:

- Build upon previous year research on rigid bus configurations.
- Derive from analytical and experimental investigation a realistic approach for calculating and understanding the dynamic response of substation structures to short circuit mechanical forces.
- Derive from analytical modeling and experimentation a generalized force prediction tool that is more accurate than IEEE 605 that utility engineers can use during substation design.
- Gain an understanding, from available utility information, the actual impact to substation components (e.g. insulators, disconnect switches), structures, and foundations resulting from a substation fault occurrence.
- Document and update the *Fault Current Management Guidebook* as new information related to fault current management studies and fault current limiting technologies becomes available.

Project Approach and Summary

This project addresses fault current management by investigating through analytical and experimentation the transfer of short circuit mechanical forces on substation bus, bus supports, and foundation of different configurations. This is a collaborative multiphase project with two universities and subject experts providing overall technical oversight and guidance. A member survey will be conducted that will solicit information relative to actual utility in-service experience in terms of damage sustained to station equipment, structures and foundations resulting from the resulting substation fault event. A task in this project will focus on analytical FEA modeling (electrical and mechanical) of utility structures with plans for small-scale testing The research objective is the development of a generalized force prediction tool that utility engineers can use for substation design. Substation equipment considered may 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 calibrated 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.

This project will also develop and maintain a comprehensive reference guide that provides the state of the science for limiting fault currents in transmission and distribution networks and describes possible schemes with economic benefits.

A future Phase, which is not part of this project, would include full-scale experimental lab testing at an independent high voltage laboratory of the same utility structures using the same calibration as when they were tested in the small scale setup, and compared against the analytical models developed in the first phase.

Benefits

- Avoid equipment replacement costs by reducing or eliminating equipment damage due to high fault currents
- Lower construction barriers for completing interconnection projects providing sources of low-cost power.
- Reduce cost for extended outages resulting from extensive modifications for generator interconnections
- Reduce the overdesign and associated costs of bus supporting structures and foundation needed for upgrades and new construction resulting from the conservatism inherent in IEEE 605.
- 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

Application Guides, Software Tools and Migration Strategies for the Implementation of the IEC 61850 Standard (105304)

Background, Objectives, and New Learning

Advanced communication infrastructure and standards-based interoperability are essential for next generation protection, control and automation in substations. The International Electrotechnical Commission (IEC) 61850 standard specifies *Communication Networks and Systems for Power Utility Automation.* The key elements of IEC 61850 include well-defined comprehensive substation object models, standardized information exchange mechanisms, and a unique substation configuration language.

Outside of North America, IEC 61850 has become the dominant standard for substation automation with all major vendors offering equipment that conforms to the standard. Within North America, about a dozen utilities have implemented the standard; however, there is growing interests in the adoption of the standard as well as cutting-edge technologies based on the standard.

Utilities that have implemented IEC 61850 have identified many challenges and issues in their early field deployments. These issues include difficulty in isolating, testing and maintaining IEC 61850-based equipment and systems in a networked environment, lack of vendor-neutral tools for designing, implementing and maintaining IEC 61850 equipment and systems, ambiguous areas in the standard that cause interoperability issues for multi-vendor equipment, and challenges securing IEC 61850 equipment and systems

The overall objective of this project is to conduct research and development that will address the barriers in planning, implementing, operating and maintaining the IEC 61850 standard and associated technologies.

Project Approach and Summary

This project has been segmented into two levels of participation. Level One addresses the needs of utilities with an interested in IEC 61850 but no immediate plans for implementing the standard. Level Two addresses the needs of utilities that have implemented or are planning to implement the standard.

Level One consists of the following research activities:

Lessons Learned from Utility Implementations: This activity will assess the implementation approach taken by several utilities and will capture experiences and lessons learned in planning, design, construction, testing, and commissioning of IEC 61850 systems. Implementation costs and realized benefits, both short and long term, will also be evaluated. Results from this task will be packaged into a series of case studies and will be shared at an annual workshop.

IEC 61850 Education and Training: This activity will develop training material and provide education to utilities who are interested in enhancing their knowledge of IEC 61850. Hands-on training will be offered to project participants using EPRI's Smart Grid Substation Laboratory or IEC 61850 Mobile Test Bed.

Level Two consists of the following three research activities**:**

IEC 61850 Design, Implementation and Maintenance Guidebook: This research activity will take a phased approach to develop guidelines that assist utilities in their migration towards IEC 61850. These guidelines will be segmented into three areas of design, implementation, and maintenance. Each area will identify critical elements directly affected by IEC 61850 adoption and recommend effective solutions to achieve successful deployment.

Development of Software Tools for Implementing and Maintaining IEC 61850: A variety of user-focused software tools are needed to design, implement, and maintain the IEC 61850 environment. Existing software tools tend to be vendor-specific, which introduces challenges for utilities that are working with equipment from multiple vendors. This task will work with utilities that are implementing IEC 61850 to determine the software tools that are needed and develop functional requirements for the identified tools. We will then assess the existing software tools against the requirements and perform a gap analysis. We will then develop action plans for each gap.

Identify and Address Security Challenges and Issues Relating to Deploying IEC 61850: No standard or guideline has sufficient detail to addresses security requirements to implement effective cyber security for IEC 61850. This research activity provides the exploratory first steps in understanding the needs and challenges for utilities. A survey is intended to be used to identify gaps and issues.

Benefits

Because IEC 61850 was designed to make use of the latest networking, communications and computing technologies, it provides greater capabilities and performance than legacy substation automation protocols. Implementation of the IEC 61850 standard by utilities may lower costs for installation, commissioning, and system integration, facilitate interoperability and prevent vendor lock-in, facilitate standardization and standards-based system integration, and improve system awareness and maintainability.

Development of Spares Strategy Guidelines for Substation Equipment (074573)

Background, Objectives, and New Learning

All utilities maintain inventories of spare substation equipment. These spares are utilized to mitigate the effects of equipment failures by reducing the replacement time through the elimination of procurement and delivery delays at the time of failure. There are significant costs associated with spares inventories including capital, storage, and, for some equipment, maintenance and testing. These costs and the potential benefits from spares are a function of the number of individual spares kept at hand. Keeping too few spares may prolong outages while too many spares would increase capital and operating costs. However, there are no industry standards or guidelines to help utilities determine the most appropriate number or mix of spares. Utility practices vary considerably. Spares costs may be reduced and potential benefits increased through the application of more analytical processes for determining spares strategies. New resources such as EPRI's Power Transformer Industry-wide Database could be incorporated in new approaches to determine inventory levels. Risk-based spares strategies would more fittingly align with the industry desire to incorporate asset management principles.

The objectives for this project are to investigate and assess present spares strategies, identify strengths and weaknesses and develop guidelines for selecting spares strategies for substation equipment. The guidelines would include the development of new spares strategies and analytics applying the results of fleet management and the asset and failure information contained in the industry wide substation equipment database. Strategies may include required inventory levels, allocation policies and reordering criteria. Initial work would be directed at power transformers and other substation equipment would be included as resources and utility interest allow.

There are no industry standards or guidelines to help utilities determine the most appropriate number or mix of spares. Utility practices vary considerably. Spares costs may be reduced and potential benefits increased through the application of more analytical processes for determining spares strategies. New resources such as EPRI's Power Transformer Industry-wide Database could be incorporated in new approaches to determine inventory levels. Risk based spares strategies would more fittingly align with the desire to incorporate asset management principles.

Results from the R&D may improve the quality of service by reducing the impact of unplanned outages and improving customer satisfaction. It may also improve service availability and result in fewer extended outages while helping to keep the cost of electricity affordable.

Project Approach and Summary

EPRI intends to perform the following tasks under this project:

Review and catalog prevalent, available spares strategies.

- Literature search
- Utility interviews and surveys
- Assessment of presently available modeling tools and approaches
- Assessment of approaches used in other industries

Analyze the strengths and weaknesses of available strategies. Evaluate the influence of various factors on strategy selection and utility characteristics and identify any gaps.

- Utility size
- Geographic distribution
- Equipment model mix
- Capital constraints
- Dependence on the availability of reliable equipment failure rates
- Sensitivity to variability in restocking times
- Ability to incorporate results of related EPRI fleet management work

Depending on findings, it may be appropriate to develop new strategies and supporting analytics for one or more equipment types. New developments would be directed at risk-based approaches to managing spares inventories and incorporate results of related EPRI fleet management work as appropriate.

- Develop analytics and strategies
- Test strategies with utility data
- Evaluate results

Benefits

Risk-based spares strategies would more appropriately align with the industry desire to incorporate asset management principles. Results from the R&D may improve the quality of service by reducing the impact of unplanned outages and improving customer satisfaction. It may also improve service availability and result in fewer extended outages. Capital and maintenance costs associated with spares inventories may be reduced.

Transformer and Circuit Breaker Fleet Management - Tools and Methods - Utility Application and Technology Transfer (105305)

Background, Objectives, and New Learning

This project applies EPRI's base fleet and asset management research results to provide enhanced tools and methodologies adapted to individual utility service territories, fleet profiles, and business rules. Generic tools will be modified and custom implementations developed to maximize a utility's benefits from the existing work. When appropriate, new algorithms may be developed to address special circumstances or requirements.

Fleet management requires the tools and methodologies to better assess equipment performance and risk and provide quantitative information to drive asset management decision processes. In addition, fleet management risk and performance assessment tools can be integrated into smart grid implementations, turning smart grid-generated equipment status data into information and providing timely equipment and system condition and risk exposure metrics to improve operating reliability and efficiency. For practical implementation, fleet management tools should be based on actual equipment condition and rely on readily available data. EPRI has developed a foundation for a suite of integrated risk and performance assessment tools for substation equipment and successfully demonstrated the concepts in the application of algorithms.

Because of the adverse demographic distributions common in many utilities, improvements are needed to provide more effective management of aging transformer and high-voltage circuit breaker fleets. Operating such equipment reliably and with a low risk of failure at or beyond typically assumed design lives is a subject of interest for many utilities. Consequently, developing and justifying a repair/refurbish/replace management strategy for these populations, and the rational basis for it, are increasingly important. The work provides a set of customized, integrated substation equipment risk and performance assessment tools designed to provide the utility-specific information required to better assess equipment performance and risk and provide the quantitative information needed for best-practice fleet management.

Project Approach and Summary

Building on an established framework, the objectives of this project are to address utility-specific concerns, issues, and needs for managing aged substation transformer and high-voltage circuit breaker fleets by assessing data availability, quality, and its potential for short- and longer-term application to fleet management; to formulate and assess applicability of innovative methodologies for fleet management applications; to further develop and apply the new methodologies to quantitative business case analyses for a range of specific host utility fleet management strategies; to populate and exercise models with utility data; and to carry out sensitivity analysis for business cases being considered.

Actual tasks will depend on utility fleet characteristics, data availability and business requirements and may include:

- Adapting the generic fleet management algorithms to address utility-specific requirements
- Providing resources to assist with input data collection and entry into the fleet assessment tools
- Performing an initial assessment of a utility's fleet and periodic reassessments over the duration of the project.
- Utilizing data provided by the utility to continue to enhance the fleet assessment algorithms
- Delivering a customized assessment tool and appropriate documentation on the methodology, approach, and results
- Developing customized transformer failure rates
- Customizing algorithms to be used to develop risk-based strategies for transformer and circuit breaker fleet management

Benefits

Project results will help asset managers and maintenance personnel deal with the problem of populations of aged transformers and circuit breakers by formulating utility-specific innovative, risk-based analytical methodologies to address emergent issues, maintenance strategies, monitoring strategies, and longer-range investment strategies. Benefits include:

Reduce overall maintenance costs, forecast capital requirements, minimize unplanned expenses, and maximize the benefit and value of planned work

- Improve reliability and availability via reduced reliance on time-based maintenance by using asset health and condition analysis to determine maintenance actions
- Enable more effective use of existing infrastructure and data and efficient use of maintenance personnel to manage operational risk
- Provide objective, fact-based support rationale for equipment risk management decisions, including replacement strategies.

Transmission Grid Resiliency (105306)

Background, Objectives, and New Learning

In the context of the transmission system, 'resiliency' is the ability to lower the vulnerability of the system to incur damages caused by low frequency, high impact (HILF) events, and quickly to recover from such events. Recent extreme weather events, including the U.S. hurricanes Katrina and Sandy, a severe Nor'easter storm in 2012, a breakout of severe tornadoes in Tennessee and Alabama in 2011, as well as the Tohoku earthquake and ensuing tsunami in Japan have demonstrated the need for resiliency.

Additionally, acts of vandalism have focused the industry's interest on physical security. In an incident in 2013, several high-voltage transformers were damaged in a west coast substation. This demonstrated the need to understand the technical options for physical security and how the transmission grid can be resilient to such attacks.

At the same time, the society-at-large is increasingly dependent on electricity. The possible economic disruption and resulting damages caused by power outages is matched only by the frustration experienced by society not being able to use their smart phones, tablets, and social networking applications.

This project has the objective to develop a framework to assess and prioritize options to increase the system's resiliency. The framework is intended to cover all classes of HILF events. This project will attempt to apply the framework systematically to events for which the industry already has attained a high level of experience.

Related HILF supplemental projects may apply the framework to lesser understood events, such as physical security and geomagnetic disturbance. In addition these projects will evaluate, test and develop technologies designed to mitigate the effects of such events.

At the EPRI Transmission Resiliency Summit in April 2013, executives from transmission owners and operators together with subject matter experts identified potential gaps that must be filled to enhance resiliency to HILF events. These gaps include technologies to harden the existing infrastructure, accelerate recovery, and enhance consumer survivability.

It is expected that this project will significantly increase the understanding of the effectiveness of mitigation technologies in increasing the resiliency of the transmission system. It may help transmission owners and operators selecting cost effective measures to minimize the impact of high impact low frequency events.

Project Approach and Summary

The project plans to develop a decision support framework to evaluate the efficacy, and to prioritize mitigation options to various events. The framework is expected to include the following elements:

- **Characterization of Events**: Methods to identify and characterize the events or threats.
- **Vulnerability Assessment:** Methods will be developed to determine the potential for damaging equipment / assets function based on the event's characteristics.
- **Impact Determination:** Impacts include threats to human health and safety, economic impact, number of un-served customers, and regulatory compliance. Key research will include how to determine the criteria for selection of cases for the impact analysis.
- **Decision Support Tool**: A decision support tool may be developed to prioritize the mitigating measures. It is the intention that this tool will take into consideration existing operating practices, maintenance plans and spare policies.

Case studies will be developed for a set of natural events to verify the decision tool and framework

Evaluation of Mitigation Effectiveness: Technologies will be evaluated that have the potential to lower the asset vulnerability to incur damage, or lower the impact by accelerating the recovery and easing the restoration process. Only technologies will be considered that help mitigate the effects of natural events such as high wind, flooding and wildfires. Other supplemental projects may center on mitigation technologies that deal with other events such as Geomagnetic Disturbances and Physical Security.

There will be three possible research levels for the selected technologies:

- **Technology Identification:** Identify and share the experience of using existing or emerging technologies
- **Technology Testing and Assessment:** Test the performance of selected technologies
- **Technology Development:** Where gaps exist develop the technology. This research may be pursued under a different supplemental project

In addition, an annual conference followed by a member only workshop will be held to facilitate the experience sharing and to report results of the research project.

Benefits

This project may provide the following benefits:

- Increase the understanding of the effectiveness of mitigation technologies
- Provide a technical basis for the selection and application of technologies to enhance resilience of transmission assets and improve recovery
- Enable the prioritization of applying the technologies to increase grid resiliency and accelerate recovery
- Help protect public and employee health and safety caused by power outages