Underground Transmission - Program 36

Program Overview

Program Description

Underground transmission (UT) faces a number of challenges. Utilities need better understanding of the condition of an aging UT infrastructure, which in many cases has exceeded its 40-year life expectancy, to strengthen existing cable systems and help asset managers make difficult upgrade and replacement decisions. Increased system robustness, higher capacity, and longer life will require development and use of newer polymer insulations at extra-high-voltage (EHV) levels with integrated sensors. An ability to exploit the dynamic overload capacity of buried power cables promises better asset utilization at marginal extra cost.

Transmission systems must deliver high power quality for the digital society, ideally immune from weather extremes and in many cases serving urban centers with limited space for infrastructure expansion. To meet these needs, the industry must accommodate increased use of buried power cables with greater power throughput, which places great importance on orderly replacement of mature cables with care that new advanced systems are at least as reliable. Transmission owners need guidance on the safe and more efficient use of new materials, equipment, and construction methods for UT systems to boost economic productivity and prosperity. Also needed are advanced design tools to increase the effectiveness of engineering resources, as well as to aid technology transfer to new knowledge workers. Efficient use of component materials with lower losses, less construction impact, easier replacement, and high recycle value would benefit the environment and increase sustainability for generations.

EPRI’s Underground Transmission program is made up of five research projects: Design, Construction and Operation of UT Systems, Extruded Dielectric Cable Systems, Laminar Dielectric Cable Systems, Cable Dynamic Rating and Increased Power Flow Guidebook and Develop and Deploy Superconducting Technologies. This research leads the industry in exploring and deploying promising new technologies and tools to help UT owners design and operate cost-effective cable systems with increased power capacity and longer lives, diagnose problems before outages occur, and repair them at minimum cost and within acceptable time periods.

Research Value

With the knowledge acquired through this research program, members will have access to information and products that can help them:

- Increase engineering staff efficiency and expertise
- Improve efficiency and quality in UT system design
- Lower installation and operating costs
- Improve transmission system reliability and safety
- Gain more accurate and timely knowledge about asset condition and life expectancy
- Develop tools and methods to design and operate the system with increased power flow
- Acquire strategic intelligence on emerging technologies
- Participate in new technology designs, testing standards, and equipment demonstrations

Approach

EPRI research in underground transmission will yield a variety of data and knowledge that will benefit members of the program. This information will be provided in a number of forms, and is expected to include the following:

- Software programs
- Reference books
- Manual of advanced and low-cost designs and construction/installation techniques
• Improved safety procedures, technologies, and tools
• Experimental verification of design models
• Development and demonstration of a number of monitoring assets
• User conferences, stakeholder meetings, and coordination with institutional funders
• Training workshops

Accomplishments
This program has delivered value to members in a number of ways. Recent examples include:

• Commercial release of Version 5.0 and subsequently 5.1 and 5.2 of the Underground Transmission Workstation (UTW) (1019980)
• Development of the EPRI Green Book (1014840)
• Successful manufacture of over 1000 feet of nano-dielectric cable for performance testing (1015926)
• Development and testing of pressurization procedures for high-pressure fluid-filled (HPFF) and high-pressure gas-filled (HPGF) cable systems (1015930)
• Increased Power Flow Guidebook (1015971), a state-of-the-science and “best practices” guidebook on optimizing the power flow capacities of underground cables and entire transmission circuits
• DTCR 5.1.1 (1022662), a computer program to calculate underground cable ratings in real time or in simulated mode
• Cryogenics Workshop (1008699) and Tutorial (1010897)
• Annual HTS Cable Technology Watch reports (1017792, 1019995)

Current Year Activities
In 2012, the projects in this research area are expected to:

• Continue development, enhancement, and validation of underground transmission design tools and models
• Apply advanced sensors to enable more cost-effective inspection and condition assessment in all cable types
• Find solutions for detecting and mitigating pipe corrosion that leads to oil leaks in fluid-filled cable systems
• Update state-of-the-science increased power flow guidebook
• Update and improving software tools and methodologies for increasing/optimizing the power capacity of underground transmission circuits
• Disseminate strategic technology and demonstration project information about superconducting technologies and coordinating with industry and government stakeholders as they seek to commercialize the technology

Estimated 2012 Program Funding
$2.5M

Program Manager
Steven Eckroad, 704-595-2717, seckroad@epri.com
Summary of Projects

<table>
<thead>
<tr>
<th>Project Number</th>
<th>Project Title</th>
<th>Description</th>
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<tbody>
<tr>
<td>P36.001</td>
<td>Design, Construction and Operation of UT Systems</td>
<td>This project provides tools, guidance, and resources for the planning, design, construction, operation, and maintenance of underground transmission systems.</td>
</tr>
<tr>
<td>P36.002</td>
<td>Extruded Dielectric Cable Systems</td>
<td>This project provides greater understanding of performance factors, design procedures, and improved inspection tools, and techniques to enhance the viability and operation of extruded dielectric cable systems.</td>
</tr>
<tr>
<td>P36.003</td>
<td>Laminar Dielectric Cable Systems</td>
<td>This project provides understanding of cable degradation and life-limiting factors, effective methods for maintaining the integrity of cable system components, and tools and techniques for inspection to enhance reliability and manage the life cycle of laminar dielectric cable systems.</td>
</tr>
<tr>
<td>P36.004</td>
<td>Cable Dynamic Rating and Increased Power Flow Guidebook</td>
<td>This project provides state-of-the-science reference and training materials for optimizing and increasing power flow through underground cables and entire transmission circuits. It also provides software tools to optimize power transfer capabilities in real-time for predictive assessments and for performing off-line rating studies.</td>
</tr>
<tr>
<td>P36.005</td>
<td>Develop and Deploy Superconducting Technologies</td>
<td>This project supports hardware demonstrations, disseminates vital technology development information, and promotes informed interaction among all potential participants in the developing market for superconducting power solutions.</td>
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</table>

P36.001 Design, Construction and Operation of UT Systems (063283)

Key Research Question

To satisfy performance-driven expectations from investors and customers, energy companies require research results and guidance for planning, design, construction, operation, and maintenance of underground transmission (UT) systems. Specific issues include the following:

- Up-to-date tools for planning, life-cycle costing, and design
- Considerations when comparing underground and overhead transmission options
- Safety practices in construction, operation, and maintenance
- Quality installation methods and materials
- Low-cost and effective construction and installation techniques
- Proper system characterization to support protection and control
- Lessons learned and failure information from system design, construction, operation, and maintenance
- Strategies for timely replacement of aged UT systems

As pressure for constructing more underground transmission lines increases, these issues have become more prominent at all stages, from planning and decision-making to long-term, reliable, and safe operations.

Approach

To address the industry issues and provide adequate tools and information, this project will capture and apply industry knowledge, enhance and validate existing solutions, and develop new tools and technologies by undertaking key tasks in a broad range of activities, such as the following:
Identify and document best practices in planning, design, construction, and operation
Determine and develop effective calculation and measurement methods
Evaluate current technologies, requirements, and limitations of transmission cable system configurations
Develop guidelines and specification recommendations for assuring quality installation
Identify gaps and opportunities for innovative tools and methods
Develop and validate new technologies and knowledge in effective inspection, monitoring, and maintenance

Impact
The design, construction, and operation tools and methods developed through this project may help members:
Make more informed decisions in planning new transmission lines
Improve efficiency in UT system design
Improve productivity and quality in UT system construction
Reduce overall installation, construction, operation, and maintenance costs
Improve system reliability and safety
Assess conditions of existing lines and plan timely replacements

How to Apply Results
Underground transmission engineers, designers, and managers can use the tools, methods, and technologies developed in this project to more effectively plan, design, operate, and maintain their UT systems for the benefits described above. Industry knowledge captured in this project can be applied to mitigate the impacts of an aging workforce and facilitate the training of a new generation of technical staff or the reassignment of existing staff.

2012 Products

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<tr>
<th>Product Title &amp; Description</th>
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<tr>
<td>begun in 2010 and continued in 2011 that focus on industry electrical safety issues in</td>
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<td>grounding, induced voltage, and current. Results of the three-year project will be</td>
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<td>documented in a final Technical Report that also will include evaluation of uniformity,</td>
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<td>effectiveness, and viability of current utility safety practices and identification of</td>
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<td>innovative approaches to improve safety.</td>
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<tr>
<td>Underground Transmission System Protection: A new multi-year investigation of challenges</td>
<td>12/31/12</td>
<td>Technical Update</td>
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<td>and experiences of system protection for underground and hybrid overhead/underground</td>
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<td>transmission lines and development of effective methods to calculate and measure circuit</td>
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<td>parameters of underground transmission cables and circuits both with increasingly complex</td>
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<td>construction configurations. Interim results will be documented in a Technical Update.</td>
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<tr>
<td>Guide for Specifying Quality Installation of Transmission Cable Accessories: Research</td>
<td>12/31/12</td>
<td>Technical Update</td>
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<tr>
<td>to develop a greater understanding of installation and assembly issues of transmission</td>
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<td>cable splices and terminations, to investigate and identify root causes of accessory</td>
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<td>failures, and to evaluate practices and procedures for commissioning and diagnostic tests</td>
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<td>and inspection techniques for quality installation. This is a new, two-year task to</td>
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<td>produce a guide for specifying quality installation of transmission cable accessories. In</td>
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<td>2012, the interim results will be documented in a Technical Update.</td>
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<td><strong>UT Workstation: Functional and Technical Enhancements:</strong> Continuation of work begun in 2011 to implement a new module that calculates induced voltage and current and estimates ground potential rise in splice vaults. UTW Version 6.1 will be released.</td>
<td>12/31/12</td>
<td>Software</td>
</tr>
<tr>
<td><strong>Pulling of Extruded and Laminar Dielectric Transmission Cables:</strong> Investigation of current and innovative transmission cable pulling/pushing technologies, requirements, and limitations for different cable configurations, especially for long distance cables. This product will be incorporated as an appendix into the EPRI <em>Underground Transmission Cable System Construction and Installation Practices Manual</em> (EPRI 1019982) and the updated <em>Manual</em> delivered as a Technical Update.</td>
<td>12/31/12</td>
<td>Technical Update</td>
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**Future Year Products**

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<tr>
<td><strong>Underground Transmission System Protection:</strong> Continuation of the study begun in 2012 to provide cable engineers with adequate tools and information to support their company's protection engineering department</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<tr>
<td><strong>Guide for Specifying Quality Installation of Transmission Cable Accessories:</strong> Continuation of the effort begun in 2012 to develop guidelines and specification recommendations for quality assurance of cable accessory installation</td>
<td>12/31/13</td>
<td>Technical Report</td>
</tr>
<tr>
<td><strong>Underground Transmission Vault Inspection Using Robotic Techniques:</strong> Building on work funded by EPRI's Technology Innovation program, an investigation of an underground transmission vault inspection technique using a track/rail system installed or retrofitted within the vault. Various concepts would be explored such as optimal inspection path, rail design and material, and robotic inspection capabilities (for example, optical image and infrared temperature measurements).</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<tr>
<td><strong>Life-cycle Costing of Underground Transmission Systems:</strong> Identification and assessment of approaches and influential components for life-cycle cost analysis of UT systems. The results would be used to improve life-cycle costing models and to expand the costing functionality in Underground Transmission Workstation.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<tr>
<td><strong>Database on Lessons Learned in Underground Transmission Design, Construction and Operation:</strong> A database to gather information from utilities, manufacturers, contractors, and consultants on lessons learned in planning, design, construction, installation, and testing. The database would include a search engine for the lessons learned in key phases of an underground transmission cable project. It may also include case studies on, and analysis of, cable failures in North America.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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**P36.002 Extruded Dielectric Cable Systems (062105)**

**Key Research Question**

Extruded dielectric (ED) cable systems at extra-high voltages (EHV) are a new and growing feature of North American underground transmission systems. At the same time, utilities are increasingly relying on new ED systems at all voltages to meet growing demands for new underground transmission. The growing installed base of ED systems presents challenges to utility planners, engineers, and operators that must be adequately...
met in order to provide assurances that the performance and longevity of ED cable systems will be at least as good as the proven fluid-filled systems that have historically been the backbone of the U.S. underground transmission system. Research issues that are key to developing that assurance include the following:

- Improved materials and designs for increased capacity in constrained transmission corridors
- Solid engineering-based design and installation procedures to accommodate mechanical as well as electrical requirements
- Effective methods for acceptance testing and real-time condition assessment
- Better understanding of cable system aging and failure mechanisms

**Approach**

This project investigates and seeks to improve new materials, equipment, and methods for HV and EHV extruded dielectric (ED) cable systems. Solutions would be applicable to designing, selecting, installing, commissioning, testing, operating, and maintaining an overall ED system. The project is task driven, as prioritized by members and available funding year by year. The project will answer the key research questions and address the industry issues for ED cable systems through the following types of activities:

- Laboratory testing to validate engineering models or to demonstrate capabilities of commercially available or prototype diagnostic equipment
- Development of field procedures specific to ED system for maintenance and operation
- Establishment of engineering guidelines, methods, and best practices
- Development and evaluation of innovative tools, methods, and technologies for inspecting and assessing the condition of ED cable systems (for example, advanced sensors and on-line diagnostics)
- Innovative product and materials development

**Impact**

Project research will produce new materials, devices, and methods that may substantially improve the ability of extruded dielectric HV and EHV cable systems to meet system reliability, maintainability, and safety requirements and contribute to the establishment of technical design standards that can help extend the life of these systems.

- Laboratory testing may validate and improve theoretical understanding of the behavior of ED cables, which would support improved specifications and standardized designs leading to higher reliability, fewer customer outages, and lower lifetime system costs.
- Greater understanding of the implications of high-temperature operation may help achieve desired reliability and possibly increase transmission capacity at lower additional cost to customers.
- Development and deployment of advanced sensors and inspection techniques may reduce maintenance costs, improve utility operations staff effectiveness, and increase system reliability.
- Development and effective application of new materials may significantly reduce the initial and lifetime costs of UT.

**How to Apply Results**

Underground transmission engineers, designers, and managers can use the guidelines, methods (including software), and technologies developed or assessed in this project to improve productivity and reduce the costs of designing, installing, commissioning, testing, operating, and maintaining extruded dielectric cable systems. Engineers will use improved understanding of the behavior of XLPE cable under normal and emergency loading scenarios plus analytical or software-based tools to achieve effective, economical duct and vault designs. Operators and maintenance departments will deploy new sensors and tools to obtain real-time and near real-time information on cable system health. Planners will take advantage of smaller-diameter, longer-lived nanodielectric cables to provide additional options for increasing transmission system throughput and extending cable life.
## 2012 Products

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<th>Product Title &amp; Description</th>
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<tr>
<td><strong>Experimental Verification of Thermo-Mechanical (TM) Models for Extruded Dielectric Cables in Ducts and Pipes:</strong> This is an ongoing multi-year project begun in 2009. Experimental test rigs installed at EPRI's Charlotte laboratory to produce distress in XLPE cable samples in ducts and pipes will be utilized to verify existing models and develop understanding of system design fundamentals. The deliverable in 2012 will be an interim report documenting the results of initial testing using the rig.</td>
<td>12/31/12</td>
<td>Technical Update</td>
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<tr>
<td><strong>More Efficient and Effective Commissioning Tests:</strong> Field testing using very low frequency (VLF) sources has become accepted practice for medium-voltage cables. This technology is starting to be implemented at higher voltages for transmission cables. This product would report on research into topics such as the following:</td>
<td>12/31/12</td>
<td>Technical Update</td>
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<td>- State-of-the-art for available VLF sources at higher voltages</td>
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<td>- Relationship between applied test voltage at very low frequency, test duration times, and ability to identify defects</td>
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<td>- Correlation between partial discharge measurements taken with more traditional resonant test sets and VLF for transmission applications</td>
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<td>Interim results of this new, two-year project will be documented in a Technical Update.</td>
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<tr>
<td><strong>Advanced Sensors and Inspection Techniques for Extruded Dielectric Transmission Cable Systems:</strong> Research and development of advanced sensors and monitoring techniques for on-line inspection of cable system condition and operational status. This multi-year project begun in 2010 will include field trials on a host utility circuit to evaluate commercial diagnostic technologies and determine research needs. A Technical Update report will document interim results.</td>
<td>12/31/12</td>
<td>Technical Update</td>
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## Future Year Products

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<tr>
<td><strong>Advanced Sensors and Inspection Techniques for Extruded Dielectric Transmission Cable Systems:</strong> Continuation of a study of advanced sensors and monitoring techniques for on-line inspection of cable system condition and operational status.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<tr>
<td><strong>Advanced Use of Integral Fiber Optic Cables in Extruded Dielectric Cable Systems:</strong> Prior EPRI research indicates that fiber optic cables integrated within extruded dielectric cables or outside the sheath for applications beyond temperature monitoring may be used to assess transmission cable health by monitoring electrical, mechanical, or thermal behaviors. This product would investigate and report on the fiber optic system design and implementation. Research areas include the following:</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<td>- Method/design for PD measurement and fault location</td>
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<td>- Design of suitable opto-electronics for novel use</td>
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<td>- Methods for effective detection of fiber damage during installation and operation</td>
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<td>This is the first year of a multi-year project that may ultimately result in development and/or validation of new diagnostic tools.</td>
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<tr>
<td>Experimental Verification of Thermo-Mechanical (TM) Models for Extruded Dielectric Cables in Ducts and Pipes: This product will deliver a final report on the validation of EPRI TM Models for Extruded Dielectric Cables in Ducts and Pipes, using experimental test rigs installed at EPRI's Charlotte laboratory to produce distress in XLPE cable samples in ducts and pipes.</td>
<td>12/31/13</td>
<td>Technical Report</td>
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</table>
| More Efficient and Effective Commissioning Tests: Field testing using very low frequency (VLF) sources has become accepted practice for medium-voltage cables. This technology is starting to be implemented at higher voltages for transmission cables. This product would report on research into topics such as the following:  
- State-of-the-art for available VLF sources at higher voltages  
- Relationship between applied test voltage at very low frequency, test duration times, and ability to identify defects  
- Correlation between partial discharge measurements taken with more traditional resonant test sets and VLF for transmission applications  
This is the final year in a two-year project; a final report will be delivered. | 12/31/13           | Technical Report |
| EHV XLPE Cable Workshop: This task is a workshop to inform and help utilities apply results reported by EPRI in Cable System Technology Review of XLPE EHV Cables, 220 kV to 500 kV (2002) and Mechanical Effects on Extruded Dielectric Cables and Joints Installed in Underground Transmission Systems in North America (2004). Development and deployment experiences of XLPE transmission cables in recent years will be addressed in the context of these reports. Lessons will be drawn for application to current or planned cable systems. | 12/31/14           | Technical Update |
| Guidelines for Thermo-mechanical Design of Extruded Dielectric Cable Systems: This task will build on previous EPRI work on TM behavior of ED cables in ducts, pipes, and manholes. It will provide a concise source of practical engineering knowledge to help cable engineers successfully design ED cable systems with respect to TM effects in all common installation configurations. For various cable types, recommendations would consider design factors such as duct/cable diameter ratio; vault dimensions as a function of cable type, joint dimensions, and relative duct/pipe diameter; cable and joint orientation in vault; cable and joint clamp spacing and clamp design, including non-axial-symmetric forces; and cable and joint clamp type and dimensions. | 12/31/14           | Technical Report |
| **P36.003 Laminar Dielectric Cable Systems (063284)**  
**Key Research Question**  
Much of the installed UT infrastructure in North America is made up of laminar dielectric cable systems: high-pressure fluid-filled (HPFF), high-pressure gas-filled (HPGF), and self-contained fluid-filled (SCFF). Most of these systems have performed well, surpassing their original design life expectations. However, the growing age of many of these assets is a cause for concern, in some instances related to system integrity. Replacement costs for laminar dielectric cable systems are high and the consequences of electrical failures or cable system fluid leaks due to pipe corrosion are significant. Research is needed to enhance the understanding of the corrosion mechanism and improve detection; develop inspection and monitoring techniques to assist in operations, maintenance, and replacement strategies; and better understand the thermo-mechanical behavior of cables in pipes. |
Approach

This project will investigate and develop new equipment, methods, and procedures for laminar dielectric cable systems. Efforts will focus on life extension, improved reliability, reduced operation and maintenance costs, and improved support for asset replacement decision-making protocols. The project is task driven as prioritized by members and available funding. Research will be directed to one or more of the following areas:

- Pipe-type cable system corrosion research, to include the following: improved understanding of coating disbondment in older pipes; impact of pipe environment (internal and external) on corrosion; and improved methods of detecting and preventing corrosion.
- Condition assessment of laminar dielectric cable systems, to include the following: characterization of new approaches and tools for dissipation factor, fluid condition, or other effective assessment methods; development and validation of sensors, digitizers, recorders, and telemetry systems to deliver distributed, near real-time in-situ data during on-line monitoring; and fiber-optic and semiconductor sensor technology.
- Leak detection in HPFF and SCFF cables, to include novel methods for economical, easy-to-use, and rapid leak detection. Research will focus on new inspection techniques or tools to give near real-time results at very low levels of leak rate or lost volume.
- Thermo-mechanical bending in HPFF cable systems, to include research into understanding and predicting distress in pipe-type cable systems, including the possibility of diagnostic methods to detect cable distress at an early stage. Research may include development of experimental protocol and testing of sample cables to replicate, accelerate, and detect cable deterioration. Research will follow a path similar to that taken for extruded dielectric cables (see Project 36.002).

Impact

This research will produce new understanding, methods, and tools that could substantially improve the ability of engineers and planners to assess the condition of laminar dielectric cable systems and take proactive steps in operating and maintaining these systems to extend asset life and prevent unexpected outages.

- Better understanding of potential failure mechanisms (such as pipe corrosion or thermo-mechanical behavior) and prevention procedures may result in longer asset life, reduced customer outages, improved customer satisfaction, and lower operations costs.
- Real-time monitoring of aging cable system assets may lead to increased asset utilization, maintenance intervention prior to spontaneous failure, higher reliability, and lower repair costs.
- New inspection techniques and tools may increase staff productivity and reduce overall maintenance costs.
- Rapid detection of fluid leaks may improve environmental responsiveness and public safety and reduce repair times and costs.

How to Apply Results

Underground transmission engineers, designers, and managers can use the knowledge base, guidelines, methods, and technologies developed in this project to improve productivity and lower the costs of operating, maintaining, and extending the life of laminar dielectric cable systems. Reliability and safety can be enhanced and asset replacement strategies improved. Maintenance personnel will make effective use of staff time and budget resources by applying new inspection methods and monitoring technology. Planners will learn where to apply selective upgrades and retrofits through better understanding of the relative condition of their asset fleet as well as where, and under what circumstances, cable systems are most susceptible to damage. Members may apply the knowledge of corrosion mechanisms and detection to fine-tune the monitoring of their systems to enhance public and environmental safety.
2012 Products

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<tr>
<td><strong>New Techniques for On-line and Off-line Condition Assessment of Laminar Dielectric Cable Systems:</strong> A continuation of an evaluation and characterization of new techniques for condition assessment of laminar dielectric cables begun in 2011. Techniques may include both off-line and on-line systems. On-line system evaluations would incorporate the sensors, telemetry, and communications necessary to facilitate near real-time monitoring of cable systems. Interim results will be documented with a Technical Update report.</td>
<td>12/31/12</td>
<td>Technical Update</td>
</tr>
<tr>
<td><strong>Corrosion Effects and Prevention in Pipe-Type Cable Systems:</strong> A continuation of the multi-year project begun in 2011 utilizing EPRI's recently installed, state-of-the-art pipe-type cable corrosion laboratory in Charlotte. Research will lead to a better understanding of coating disbondment in older pipes, corrosion occurrence and rates as a function of pipe environment (internal and external), and improved methods of detecting and preventing corrosion in pipe-type cable systems. A technical update will document interim results.</td>
<td>12/31/12</td>
<td>Technical Update</td>
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<tr>
<td><strong>Guide to Condition Assessment Techniques for Laminar Dielectric Cable Systems:</strong> This is an update of popular but dated EPRI guidelines for condition assessment techniques based on the most recent industry knowledge. Hardware, application, and limitations of various techniques such as dissipation factor and dissolved gas analysis will be discussed.</td>
<td>12/31/12</td>
<td>Technical Report</td>
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<tr>
<td><strong>Impact of High Dissipation Factor of In-service Fluid on Cable Insulation Performance:</strong> Investigation of the significance and impact of high-dissipation factor of in-service fluid on fluid-filled cable, joint, and termination insulation performance, including its effects on dielectric losses, potential heating, breakdown strength, and life expectancy. Interim results of the research will be documented in a technical update.</td>
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<td>Technical Update</td>
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<tr>
<td><strong>Corrosion Effects and Prevention in Pipe-Type Cable Systems:</strong> A continuation of the multi-year project begun in 2011 utilizing EPRI's recently installed, state-of-the-art pipe-type cable corrosion laboratory in Charlotte. Research will lead to a better understanding of coating disbondment in older pipes, corrosion occurrence and rates as a function of pipe environment (internal and external), and improved methods of detecting and preventing corrosion in pipe-type cable systems. A technical update will document interim results.</td>
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<td><strong>New Techniques for On-line and Off-line Condition Assessment of Laminar Dielectric Cable Systems:</strong> Evaluation and characterization of new techniques for condition assessment of laminar dielectric cables. Techniques may include both off-line and on-line systems. On-line system evaluations would incorporate the sensors, telemetry, and communications necessary to facilitate near real-time monitoring of cable systems. This task is a conclusion of work begun in 2011 and will be documented with a Technical Report.</td>
<td>12/31/13</td>
<td>Technical Report</td>
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New Insulating Fluids for HPFF and SCFF Cable Systems: Research building on past EPRI work on a functional test matrix for fluid evaluation (EPRI Reports 1007615, 1001923, and TR-111722), as well as current EPRI research on alternative transformer fluids (Program 37). Investigate and assess new dielectric fluids from natural and synthetic hydrocarbons with improved environmental properties, as well as sources to provide alternatives to commonly used cable insulating fluids. New fluids would be expected to ensure high biodegradability in accordance with international standards, even in a low-oxygen environment such as underground. The scope of the task would include identification and development of potential fluids and laboratory studies using paper tapes as well as cable models and field trials.

Development of HPFF & XLPE Transition Joints up to 345 kV: Transition joints are needed to connect laminar insulation cables to extruded dielectric systems at voltages up to 345 kV. CIGRE WG B1.24 is in a process of defining test regimes for transition joints and associated cables for type, routine, sample, and after-laying tests. Planned research may include the following:

- Investigate and assess prior EPRI/ConEd/ABB transition joint development work
- Work with cable accessory manufacturers to develop and/or field test transmission joints that would be smaller, cheaper, and more reliable for voltage levels up to 345 kV.

Interim results will be documented in a technical update report.

Test Rig for Experimental Study of TM performance of HPFF Cables: This multi-year task will develop experimental protocols and test rig designs to support improved understanding and development of predictive diagnostics for "in-pipe" thermo-mechanical bending events in pipe-type cable systems that may lead to cable failure.

P36.004 Cable Dynamic Rating and Increased Power Flow Guidebook (069263)

Key Research Question

The demand for electric power over transmission circuits is increasing faster than transmission assets can manage. This trend has pushed the capacity of many existing transmission circuits to their design limits. In addition, much of the grid has already aged beyond its original design specifications. These issues are impacting the grid with an increasing number of bottlenecks and other congestion and reliability problems. Power companies are realizing that the electric power infrastructure requires attention, and there is a need to identify methods and obtain tools for delivering more power through their existing assets.

Approach

In order to meet the research needs, EPRI will do the following:

- Develop software tools and methodologies related to the design, engineering, system planning, and operation of underground transmission cables (and other transmission circuit components)
- Investigate and document information on the state-of-the-science and best-practices on increasing and optimizing power flow through existing assets
- Identify, develop, and document information on improvements in applications, thermal models, instrumentation, secure telemetry, and case studies
- Develop training and technology transfer activities and tools, such as tutorials, guides, workshops, and conferences, in parallel with the research and development work.
This project focuses on underground cables and is executed in coordination with corresponding projects for overhead transmission lines (Project P35.013) and substation equipment (P37.018). Feedback from EPRI member engineers, operators, designers, and planners will be sought during advisory meetings and workshops to identify future improvements.

Application of the R&D products that result from this project will aid power companies to more fully utilize their existing assets more economically and with continued reliability, safety, and public acceptance.

Impact

The results from this project will provide the tools and information needed by power companies to identify and implement increased power flow strategies for their specific needs and with continued reliability, safety, and public acceptance. These include the following:

- Guidance for experienced technical staff as well as reference and training materials for the next generation of power industry technical leaders
- Increase and optimize power flow through cables and entire transmission circuits
- Defer capital expenditures and new construction
- Improve transmission circuit reliability and safety
- Optimize energy transactions through rating forecasts
- Ride out emergency situations safely and reliably
- Avoid unnecessary system outages

How to Apply Results

Transmission engineers, operators, planners, researchers, and information technology (IT) personnel will use the computer programs and methodologies of this project to increase and optimize the ratings of their circuits. Software products can be applied for the benefits described above, and the methodologies on how best to apply all results can be obtained through EPRI guidebooks, reports, and training materials.

Members can use delivered reports as a reference source and guide for implementing increased power flow strategies and for training their engineers in increased power flow technologies. Reports and references also compare the economic benefits of increased power flow technologies, enabling EPRI members to make informed decisions when choosing increased power flow options for their specific applications. An Increased Power Flow Transmission Circuit Rating Wizard software program also will help utility engineers decide on options.

2012 Products

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<tr>
<th>Product Title &amp; Description</th>
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<td><strong>Increased Power Flow Guidebook - 2012:</strong> The <em>Increased Power Flow Guidebook</em> 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. Topics specific to underground cables include the forced cooling and slow oil circulation for pipe-type cables, an updated summary on the state of superconducting cables, an expanded discussion on the use of passive heat pipes, guidance for a methodology for increasing power flow by controlled damage and replacement of hot spots, methodologies for validating ampacities, and other topics recommended by the EPRI member Task Force. An Increased Power Flow Wizard will be included with the guidebook to comprise a kit.</td>
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Transmission Ratings Workstation (TRW) 1.0: The Transmission Ratings Workstation (TRW) will be initiated in 2012. This will incorporate EPRI's Dynamic Thermal Circuit Rating software (DTCR) and other ratings-related software modules under one roof. The product will be designed for performing rating studies, evaluating and optimizing static ratings, real-time ratings, and forecasted ratings for underground cables and entire transmission circuits.  

Specifications and Applications for Distributed Temperature Sensing for Cable Ratings: This Technical Update will provide documentation on distributed temperature sensing technologies that are used for rating applications for underground cables. Topics will include types of systems, pros and cons of different systems, how they work, who the manufacturers are, what the costs and hidden costs are, how they are installed, how difficult they are to use, their accuracy and speed, how the data is integrated into supervisory control and data acquisition (SCADA) and rating programs, maintenance issues, expected reliability, telemetry and data archiving, security issues, interpreting results, and more.

Future Year Products

Increased Power Flow Guidebook - 2013: An updated version of the IPF Guidebook is planned for release in 2013, along with its Increased power Flow Wizard.

Transmission Ratings Workstation (TRW) 2.0: The Transmission Ratings Workstation software will be further improved, and a new version of the software will be delivered.

Applications of Increased Power Flow Strategies for Underground Cables: A Technical Update will be developed covering mature and novel concepts for increasing power flow of underground cables.

P36.005 Develop and Deploy Superconducting Technologies (102090)

Key Research Question

Substations of the future will likely use technologies vastly different from those applied for more than half a century. Already, both solid-state switching devices and superconductors are making their debuts in transmission and distribution substations. As transmission corridor constraints increase, studies and demonstrations are confirming the value of high-capacity high-temperature superconductor (HTS) cables in the power grid. However, the design, fabrication, and installation of superconducting equipment presents challenges, particularly in a utility substation environment. Research needs include the following:

- Hardware demonstrations to validate equipment performance and cost
- Stakeholder dialogues to increase understanding and define equipment design and testing requirements
- Guidelines for business case development to help early adopters justify investment
- Education of utility personnel: regular, timely, and informative technology status information on superconducting power system research, development and demonstration (RD&D).
**Approach**

This project supports RD&D of superconducting technologies for the power delivery system. It utilizes the extensive investments of the U.S. government, host utilities, and other organizations in emerging technology demonstrations by reporting results to inform a wider audience and solicit a larger base of support for such activities. The project answers the key research questions and addresses industry issues through a variety of information gathering and sharing activities, as follows:

- Annual technology watch reports on demonstrations and developments in the United States and worldwide of superconducting power equipment, such as high-temperature superconducting (HTS) cable, fault current limiters, and other devices
- Technology assessments and implementation guidelines
- Documentation of design specifications, installation, and operation experience
- Periodic technical conferences and stakeholder workshops as needed by technology observers, early adopters, and mature market participants to take full advantage of new superconducting systems
- Participation in stakeholder dialogues in coordination with The Department of Energy (DOE), the U.S. Department of Homeland Security, and other institutional funders and research organizations as occasions arise, with the goal of increasing stakeholder dialogue, improving access to RD&D results, and promoting the early adoption and commercialization of superconducting power delivery technology

**Impact**

The project promotes informed business decisions related to the assessment, procurement, deployment, and operation and maintenance of superconducting assets in the power delivery system. The research in this project will produce informational materials and support stakeholder interaction and information exchange to encourage the continued development and deployment of superconducting power delivery technology. Deployment of superconducting systems could accomplish the following:

- Alleviate existing transmission corridor capacity constraints by integrating superconducting components into the transmission and distribution (T&D) system
- Reduce energy losses through the higher efficiency of superconducting cables and transformers
- Improve system reliability and security through the deployment of superconducting equipment (for example, fault current mitigation, voltage compensation, and immunity from external factors such as weather and heat)

**How to Apply Results**

This project provides transmission owners and operators with the tools to understand and evaluate the technical, economic, business, and operational issues associated with deploying superconducting technologies into the T&D system. Through economic comparisons with conventional alternatives, field performance results from demonstrations, reliability and availability assessments, and studies of the impact of superconducting equipment on system operations, members can make informed decisions on how to position themselves as this technology matures. Overall results support a range of actions, from a simple "technology watch" posture to an aggressive first-adopter strategy.

**2012 Products**

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### Stakeholder Workshop on Superconducting Power Equipment:

Workshop for superconducting power equipment stakeholders, including electric utilities, equipment suppliers, members of standards committees, and public/private research institutions. EPRI will seek to collaborate with research funding organizations (for example, federal organizations) in the sponsorship of this workshop. The workshop will focus on promoting commercial introduction of superconducting technology for power delivery. One or more topics will be selected from the following research issues: increasing understanding and defining equipment design and testing requirements; developing guidelines for business case development to help early adopters justify investment; and education of utility personnel.

**Planned Completion Date:** 12/31/12

**Product Type:** Workshop, Training, or Conference

### Future Year Products

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| **EPRI Superconductivity Conference:** Bi-annual conference convening all superconductivity stakeholders, including electric utilities, equipment suppliers, members of standards committees, and public/private research institutions. Conference will provide attendees opportunities to network and will provide an international venue for reporting on current research activities and results. A proceedings CD is produced. | 12/31/13 | Workshop, Training, or Conference |
Supplemental Projects

Framework for Comparison of Overhead and Underground Power Transmission (072008)

Background, Objectives, and New Learnings

Electric transmission forms the backbone of bulk power grids. An increasing number of power transmission lines are planned to meet energy supply and demand and to improve reliability of the power grids. While overhead transmission lines represent more than 98% of the total transmission circuit length worldwide, there are significant instances where lines must be placed underground (for example, for long water crossings and in dense urban areas) in spite of the increased cost of doing so in most cases. In a growing number of instances, electric utilities face the challenge of evaluating the relative merits of and choosing between overhead and underground transmission line alternatives.

A variety of factors must be taken into account to arrive at a sound engineering-based decision in planning for and building a new transmission line. However, there is no industry-established framework for identifying the relevant factors to assess or quantify their impact and to guide the planner.

The objectives of this project are to identify major factors in making comparisons between overhead and underground transmission lines, develop procedures for the comparisons (especially for utilities in North America), and demonstrate results on representative applications.

This project will establish a framework for evaluating specific transmission line options.

Project Approach and Summary

Various reports and technical brochures have been issued by state agencies, electric utilities, independent consultants, and international organizations such as CIGRE (International Council on Large Electric Systems). Many of the reports are accessible to the public and provide excellent background information on the subject.

A joint team consisting of both overhead and underground transmission industry experts will be formed. The team will work closely with utility participants to develop easy-to-use procedures for making the comparisons. The team will address key considerations in evaluating overhead versus underground transmission line alternatives, such as the following:

- Transmission line planning and impacts to existing power grids in terms of reliability, system stability, charging current limitations, losses, operation, and maintenance
- Environmental impacts in terms of right-of-way, electric and magnetic fields, lightning, storm, flood, and dig-in
- Initial and life-cycle cost estimation

The team will develop case studies to demonstrate the concepts and procedures.

Benefits

The project will benefit the public to ensure that relevant factors are taken into account in planning new transmission lines.

The project will benefit funders by providing objective information, evaluation methods, and factual positions to regulatory agencies, local constituencies, the public at large, other utility companies, and other interest groups.

The project seeks to accomplish the following:

- Optimize both power system reliability and construction and operation cost
- Lead to better understanding of unique attributes of overhead and underground transmission alternatives
- Lead to better understanding of factors when comparing overhead and underground power transmission
Quality Guidelines for Grouting Procedures for Large Casings (072009)

Background, Objectives, and New Learnings

Underground transmission cables are most commonly installed in urban areas where overhead construction is not feasible or practical. Congestion constraints from traffic intersections or other underground utilities can often make open trench construction difficult or impossible. This situation may lead to directional drilling of large bore holes (36+ inches diameter), also called micro-tunnels or jack-and-bore. These bores are lined with a casing, fitted with conduits for the HV cables, and grouted with concrete of specially designed thermal and structural properties for the application.

Construction of this nature is unique due to the critical requirements for thermal conductivity of the grout section, elimination requirements for voids, and structural requirements. Potential consequences of improper grouting include de-rating of HV cable circuits, overheated cables, blockage of conduits due to blow-outs, or collapse of the bore hole due to heavy traffic.

Objectives of this research will be development of guidelines for proper design and construction of large bore sections with an emphasis on grouting procedures and techniques.

Project Approach and Summary

The project will survey and analyze existing techniques for large bore drilling and grouting. Investigations may include parallel industries with similar underground construction. Prior cases of this construction method will be studied. Best practices will be highlighted and recommendations developed. Topics may include the following issues:

- Grout formulation for thermal and structural requirements
- Grouting equipment and procedures to fill casings of various materials, dimensions, and duct types
- Grout location selection
- Pumping rates and pressures
- Displacement monitoring
- Grout volume requirement calculations

Benefits

Benefits to the public include the following:

- Reduced electricity costs due to more efficient construction practices
- Improved system reliability with reduced risk of outage due to cable thermal runaway

Benefits to the funding utilities include the following:

- Risk mitigation for UG transmission projects with large bore casings
- Increased quality of HV construction methodology and practices
- Reduced risk of thermal hot spots in a bore section due to improper grouting
- Improved contractor selection criteria