Underground Transmission - Program 36

Program Overview

Program Description

Underground transmission systems have evolved over the last decades from a laminar dielectric technology to extruded polymers. While a significant fraction of the installed base of cables (approximately 80% in the United States) are laminar, most new installations utilize extruded dielectric cable technology.

This program is structured to support utilities with the operational and maintenance challenges associated with aging laminar dielectric cables as well as design, implementation, operation, and maintenance of new extruded cable systems. Laminar dielectric condition assessment research focuses on pipe corrosion, coating disbondment, cable diagnostics, and fluid analysis. Extruded dielectric cable research focuses on thermo-mechanical performance of cables and joints, effective cost-efficient test methodologies, advanced sensing, monitoring, and inspection to aid operations and maintenance functions. Cross-cutting issues such as safety, construction, installation, design calculations, and dynamic ratings are grouped in non dielectric-specific projects.

New for 2013 is a project specifically focused on knowledge capture and transfer to new cable engineers and those utilities new to underground transmission due to public and other pressures to place lines underground. The project will include educational outreach, industry engagement, and member technical support in various formats.

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 underground transmission (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, and
- 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
- Educational workshops

Accomplishments

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

- Release of Version 6.0 of the Underground Transmission Workstation (UTW) (1021706)
- *Underground Transmission Cable System Construction and Installation Practices Manual* (1019982)
- Development of the *EPRI Underground Transmission Systems Reference Book (*Green Book*)* (1014840)
- Development of *EMF Management User's Guide for Underground Transmission Systems* (1015925)
- 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* (1021877), a state-of-the-science and "best practices" guidebook on optimizing the power flow capacities of underground cables and entire transmission circuits
- DTCR 6.0 (1021703), a computer program to calculate underground cable ratings in real time or in simulated mode
- Annual *HTS Cable Technology Watch* reports (1017792, 1019995, 1021890)

Current Year Activities

In 2013, 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;
- conduct thermo-mechanical performance evaluations and quantify the associated forces on extruded dielectric cables;
- 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; and
- update and improving software tools and methodologies for increasing/optimizing the power capacity of underground transmission circuits.

Estimated 2013 Program Funding

$3.2M

Program Manager

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Summary of Projects

Project Number	Project Title	Description
P36.001	Design, Construction and Operation of UT Systems	This project provides tools, guidance, and resources for the planning, design, construction, operation, and maintenance of underground transmission systems.
P36.002	Extruded Dielectric Cable Systems	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.
P36.003	Laminar Dielectric Cable Systems	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.
P36.004	Cable Dynamic Rating and Increased Power Flow Guidebook	This project develops technologies and methodologies for economically optimizing and increasing the power capacity of existing transmission assets, and provides state-of-the-science reference and training materials. It also provides software tools to optimize power flow in real-time, for predictive assessments of power capacities, and for performing off-line rating studies.
P36.006	Knowledge Capture & Tech Transfer Coordination	This project will coordinate industry knowledge capture and transfer, as well as education of engineering staff related to the design and implementation of highly reliable and cost-effective underground transmission systems.

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

Key Research Question

Cost effective and reliable underground cable systems depend on sound engineering practices for design, construction, operations, and maintenance. This research project develops technologies, software tools, guides, and best practices to assist utilities to accomplish safe, reliable, and efficient underground transmission systems for both extruded and laminar dielectric cables.

Specific research needs being addressed include cable system characterization for circuit protection, effective construction and installation techniques, quality installation methods and materials, and electrical safety practices in construction, operation, inspection, and maintenance.

By addressing these issues, utilities are better equipped with knowledge, methods, and tools to execute required tasks throughout the life cycle of the cable systems.

Approach

To address the industry issues and provide adequate tools and information, this project will evaluate and apply industry knowledge, enhance and validate existing solutions, and investigate and develop tools and technologies by undertaking key tasks in a broad range of activities.

Impact

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 system design
- Improve productivity and quality in system construction
- Reduce overall installation, construction, operation, and maintenance costs
- Improve safety and system reliability
- 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 underground transmission systems.

- Software tools such as Underground Transmission (UT) Workstation can be used to validate system designs meeting required power transport capabilities.
- Guide documents including the EPRI Green Book, UT Construction Manual, and Electromagnetic Field (EMF) Management Guide can help engineers design and implement reliable and effective cable systems.
- Documentation of electrical safety issues can be used to develop safe work practices at member utilities to ensure health and safety of personnel working with underground systems.
- Development of advanced calculation and measurement procedures in determining cable characteristics for circuit protection can ensure proper operation of cable circuits and enable development of advanced fault location techniques.

2013 Products

Product Title & Description	Planned Completion Date	Product Type
Underground Transmission Vault Inspection Using Robotic Techniques: To improve human worker safety and reduce circuit outage requirements, this project is to investigate underground transmission vault inspection techniques using a robotic inspection tool travelling on a rail system installed or retrofitted within the vault. Various concepts may be explored, such as, visual and thermal imaging inspection tools and capabilities, and rail designs and materials.	12/31/13	Technical Update
Underground Transmission System Protection: Begun in 2012, this multi-year investigation is to study challenges and experiences of circuit protection for underground and hybrid overhead/underground transmission lines and to develop effective methods to calculate and measure circuit parameters of underground transmission cables with increasingly complex construction configurations.	12/31/13	Technical Update
Guide for Specifying Quality Installation of Transmission Cable Accessories: Begun in 2012, this research is to develop a greater understanding of installation and assembly issues of transmission cable accessories, to investigate and identify root causes of accessory failures, to evaluate practices and procedures for commissioning and diagnostic tests and inspection techniques, and to develop guidelines and specification recommendations for quality assurance of cable accessory installation.	12/31/13	Technical Report

Product Title & Description	Planned Completion Date	Product Type
Study of Reliable Performance of Transmission Cable Outdoor Terminations with Composite Insulators: This new project is to investigate reliable performance of outdoor terminations with composite insulators as compared with those of porcelain insulators. It would study electric field stresses on the insulators and their aging and failure mechanisms, comparing with EPRI extensive research on line insulators. Based on the knowledge gained, the project would develop a scope to perform aging tests and investigate condition assessment tools.	12/31/13	Technical Update
UT Workstation: Functional and Technical Enhancements: This project will continue functional and technical enhancements on Underground Transmission Workstation. UTW 6.2 will be released.	12/31/13	Software

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Underground Transmission Vault Inspection Using Robotic Techniques: This project is a continuation of the previous year investigation on underground transmission vault inspection techniques using a robotic inspection tool travelling on a rail system within the vault.	12/31/14	Technical Update
Underground Transmission System Protection: Begun in 2012, this multi-year investigation is to study challenges and experiences of circuit protection for underground and hybrid overhead/underground transmission lines and to develop effective methods to calculate and measure circuit parameters of underground transmission cables with increasingly complex construction configurations. Final results will be documented in a Technical Report with case studies and technology demonstration.	12/31/14	Technical Report
Database on Lessons Learned in Underground Transmission Design, Construction and Operation: This project would develop 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.	12/31/14	Technical Update
Soil and Backfill Long-term Performance and Cost-effective and Practical Low Thermal Resistivity Backfills: This project is to investigate and develop easy-to-use techniques to assess performance of soils and backfills to ensure their thermal resistivity stability during lifetime, especially when the cable systems are to be up-rated. Based on the assessment results, this project would also develop more cost-effective and practical low and stable thermal resistivity backfills.	12/31/14	Technical Update
Life-cycle Costing of Underground Transmission Systems: This project is to identify and assess approaches and influential components for life-cycle cost analysis of underground transmission systems. The results would be used to improve life-cycle costing models and to expand the costing functionality in Underground Transmission Workstation.	12/31/14	Technical Update

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 (UT) 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 and 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 high-voltage (HV) and extra high-voltage (EHV) extruded dielectric cable systems. Solutions are 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 cross-linked polyethylene (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.

2013 Products

Product Title & Description	Planned Completion Date	Product Type
Advanced Sensors and Inspection Techniques for Extruded Dielectric Transmission Cable Systems: This multi-year project is a continuation of the study on advanced sensors and monitoring techniques for inspection of cable system condition and operational status. Based on the previous project status, this project would include field trials on host utility circuits to demonstrate technologies and collect measurement data.	12/31/13	Technical Update
Advanced Use of Integral Fiber Optic Cables in Extruded Dielectric Cable Systems: 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: • Method/design for PD measurement and fault location • Design of suitable opto-electronics for novel use • Methods for effective detection of fiber damage during installation and operation This is the first year of a multi-year project that may ultimately result in development and/or validation of new diagnostic tools.	12/31/13	Technical Update
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.	12/31/13	Technical Report
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

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
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
Advanced Sensors and Inspection Techniques for Extruded Dielectric Transmission Cable Systems: This multi-year project is a continuation of the study on advanced sensors and monitoring techniques for inspection of cable system condition and operational status. Based on the previous project status, this project would include field trials on host utility circuits to demonstrate technologies and collect measurement data.	12/31/14	Technical Update

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 may be a cause for concern.

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 rate of corrosion and improve detection of both corrosion and disbonded coatings. Development of advanced inspection, diagnostics, and monitoring techniques to assist in operations, maintenance, and replacement strategies may improve reliability and reduce costs.

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. Project tasks will be driven and 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.
- Development of guidelines to aid utilities with Dissolved Gas Analysis (DGA) techniques, equipment, and data interpretation to enhance evaluation of aging assets.

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 and prevention procedures may result in longer asset life, reduced customer outages, improved customer satisfaction, and lower operations costs.
- Real-time monitoring of 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.

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 may make effective use of staff time and budget resources by applying new inspection methods and monitoring technology. Planners may 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.

2013 Products

Product Title & Description	Planned Completion Date	Product Type
Guide to Condition Assessment Techniques for Laminar Dielectric Cables: This is project will create an up-to-date and comprehensive guide to condition assessment of laminar cables, with emphasis on dissolved gas analysis (DGA) with discussion of available equipment, sampling techniques, storage, sample processing, and data interpretation.	12/31/13	Technical Update
Corrosion Effects and Prevention in Pipe-Type Cable Systems: Using the underground pipe-type cable corrosion test facility at the Charlotte Lab, the project will continue prior research on pipe corrosion and pipe coating disbondment mechanisms and novel detection techniques.	12/31/13	Technical Update
New Techniques for On-line and Off-line Condition Assessment of Laminar Dielectric Cable Systems: This project will evaluate and characterize of new techniques for condition assessment and diagnostics of laminar dielectric cables, with emphasis on techniques that provide localization information on potential defects or degradation.	12/31/13	Technical Report
Stray Current Issues and HPFF Pipe Cathodic Projection: The project will investigate and document leading practices for cathodic protection of high-pressure fluid-filled (HPFF) cable systems including detection and mitigation strategies for stray direct currents from sources such as railroad, water lines, and gas lines.	12/31/13	Technical Report

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Impact of High Dissipation Factor of In-Service Fluid on Cable Performance: Investigation of the significance and impact of high dissipation factor fluid on laminar cable, joint and termination performance including its effects on losses, heating, breakdown strength, and life expectancy.	12/31/14	Technical Update
Retrofitting of HPFF pipes with XLPE cables: The project will investigate alternatives and strategies for replacement of HPFF cables with XLPE cables while utilizing the existing steel pipe asset. World-wide case studies and success stories will be documented, as well as evaluation of novel approaches.	12/31/14	Technical Report
Techniques for Advanced Leak Detection: The research project will evaluate new techniques and methodologies for leak detection and investigate the application of novel sensors and algorithms to rapidly detect slow fluid leaks.	12/31/14	Technical Update

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

Key Research Question

The demand for electric power over transmission circuits is increasing at a faster rate than transmission assets can manage. This trend is pushing 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 affecting the grid with an increasing number of bottlenecks, brownouts, and other congestion and reliability problems. The power industry has identified the need to develop methods and tools for increasing and optimizing the power throughput of existing assets. In addition, there have been recent mandated regulatory requirements on the establishment of transmission circuit ratings, and power companies need to have tools to establish line ratings in a scientifically rigorous manner.

Approach

To meet the research needs of the power industry in this area, EPRI will continue to develop software tools and methodologies related to the design, engineering, system planning, and operation of underground cables (and other transmission circuit components). The project will also investigate and document information on the state-of-the-science and best-practices of increasing and optimizing power flow through existing assets. Information on improvements in applications, thermal models, instrumentation, secure telemetry, and case studies will be identified, developed, and documented. Training and technology transfer activities and tools, such as tutorials, guides, workshops, and conferences, will continue to be developed in parallel with the research and development work.

This project focuses on underground transmission and is executed in coordination with corresponding projects for overhead lines (Project P35.013) and substation equipment (P37.107). 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 electric power companies to more fully utilize their existing assets economically, and with continued reliability, safety, and public acceptance.

Impact

The results from this project will provide the tools, information, training, and guidance needed by power companies to assess and implement increased and optimized power flow strategies for their specific needs, and with continued reliability, safety, and public acceptance. These results will help enable power companies to

- provide 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 underground 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; and
- avoid unnecessary system outages.

How to Apply Results

Transmission engineers, operators, planners, researchers, and 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 reference sources and guides for implementing increased power flow strategies, and for training their engineers on 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 options for their specific applications.

2013 Products

Product Title & Description	Planned Completion Date	Product Type
Increased Power Flow Guidebook - 2013: The *Increased Power Flow Guidebook* (Platinum Book) will continue to be augmented with updated and additional material on the state-of-the-science and best-practices for increasing and optimizing power flow through existing (or new) underground cables and their associated circuits. The needs for the guidebook are identified by industry experts and EPRI member advisory groups. An Increased Power Flow Wizard is to be included with the Platinum Book to help further guide users in identifying and prioritizing strategies for their specific needs.	12/31/13	Technical Update
Transmission Ratings Workstation (TRW) Beta Version: The Transmission Ratings Workstation (TRW) will be initiated in 2012. This will incorporate EPRI's Dynamic Thermal Circuit Rating (DTCR) software and other ratings-related software modules into one comprehensive computer program. The product will be designed for performing rating studies, evaluating and optimizing static ratings, real-time ratings, and forecasted ratings for overhead lines and entire transmission circuits. A special off-line rating tool for underground cables (UGLOAD) will ultimately be included. This will be a multi-year effort, and in 2013 it is expected that a beta version will become available for EPRI member use and evaluations.	12/31/13	Software
Applications of Increased Power Flow Strategies for Underground Cables: A Technical Update will be developed covering mature and novel concepts for increasing power flow strategies of underground cables. The document will identify and make recommendations for further developments of the viable strategies.	12/31/13	Technical Update

P36.006 Knowledge Capture & Tech Transfer Coordination (TBD)

Key Research Question

Reliability of any underground transmission system depends on highly skilled and educated staff throughout the design, construction, installation, operations and maintenance life-cycle of the cable system. The challenge of retaining cable system institutional knowledge and supporting younger engineers is especially true for those utilities for whom underground transmission (UT) is not a solution implemented in a regular basis.

This project will provide educational resources and technical support to member utilities. By addressing the need for educational materials, knowledge capture, technical support, and technology transfer participants will be better equipped to execute reliable and cost-effective cable systems.

Approach

This project will provide semi-annual educational sessions on various topics related to the design, installation, operations, and maintenance of underground transmission systems. EPRI will enhance member's engagement with industry resources and support their technical and educational requirements.

Impact

Knowledgeable engineering staffs and heightened industry engagement in technical developments provides the following benefits:

- Improved knowledge of system design options
- More efficient interface with consultants and vendors of underground systems
- Superior project execution when underground circuits are required
- Retention of institutional knowledge

How to Apply Results

Funding utilities will be able to leverage the results of the project through the following:

- EPRI guides on principals such as cable system design, construction, and installation
- Attendance at semi-annual educational sessions, which may help educate new cable engineers

2013 Products

Product Title & Description	Planned Completion Date	Product Type
Underground Transmission Education Workshop: Education workshops will be held in conjunction with the Underground Transmission Task Force meetings two times per year. Topics will include design, construction, installation, operations, and maintenance of laminar and solid dielectric UT systems utilizing internal resources such as the EPRI Green Book and UT Workstation design software.	12/31/13	Workshop, Training, or Conference
EPRI UT Design and Construction Guide: This guide is intended as an educational introduction to principals and concepts related to design, construction, and installation of UT systems. A more in-depth and detailed analysis is provided in other EPRI reference materials such as the *Underground Transmission Reference Manual* (Green Book).	12/31/13	Technical Update

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 insulated cables must be used instead of bare overhead lines. Examples include

- long water crossings,
- dense urban areas,
- congested substation exits,
- expanding airport runways,
- cases where public objections to overhead lines necessitate underground alternatives, and
- sensitive environmental areas such as city, county, and state parks.

In most of the above cases the underground cable alternative will be more expensive than overhead lines. 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 and an analytical framework 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 and identify technical and economic trade-offs between design options for initial installation and long-term operations of the circuit.

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 overhead and underground transmission design experts and utility planners will be formed. The team will work closely with utility participants to develop easy-to-use procedures for making the comparisons and an analytical tool to quantify the comparison. 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
- Identification of electrical system parameters such as impedance, capacitance, and reactance of underground cables, which may affect load-flow studies and which are not commonly known or understood among planners at utilities with few or no underground cable circuits
- Environmental impacts in terms of right-of-way, electric and magnetic fields, lightning, storm, flood, and dig-in
- Repair and restoration considerations for natural disaster recovery
- Emergency and overload capability differences between overhead and underground options due to drastically differing time constraints and hardware thermal response times from changes in load
- Initial and life-cycle cost estimation

The team will develop case studies to demonstrate the concepts and procedures based on real-world examples brought forward by project participants.

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 costs
- 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

Superconducting Technology for Power Utility Applications (073521)

Background, Objectives, and New Learnings

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 and fault current-limiting superconducting substation devices. 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).

Project Approach and Summary

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 globally of superconducting power equipment such as HTS cables, fault current limiters, motors, and generators
- 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 U.S. Department of Energy (DOE), the U.S. Department of Homeland Security, and other institutional funders and research organizations that 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

Benefits

This project will benefit the public through increased education, awareness, and understanding of the advantages, challenges, and hurdles to adoption of superconducting technology for power applications.

This project will benefit funders by increased understanding of the potential benefits and efficiencies of using HTS devices. These benefits and efficiencies may include the following issues:

- Higher-capacity cables in smaller rights-of-way with reduced magnetic field generation
- Smaller substation footprint requirements for HTS devices due to increased power density of superconductors
- Increased efficiencies due to decreased resistive losses in equipment
- Improved system reliability and security through deployment of HTS equipment (for example, fault current mitigation, voltage compensation, and immunity for external factors such as weather and heat).

Underground Transmission Workstation (UTW) Interest Group (073522)

Background, Objectives, and New Learnings

EPRI Underground Transmission Workstation (UTW) is a tool for utility engineers to plan, design, operate, and maintain their extruded and laminar dielectric cable systems. UTW calculates ampacity for transmission power cables installed in a variety of configurations, performs economic evaluations for conventionally trenched cable circuits, calculates magnetic fields and pulling tensions, determines pipe-type cable hydraulic parameters, and calculates induced voltages or currents on adjacent out-of-service cables or metallic pipelines.

With the increasing functionality of this program, current UTW users show a considerable interest in effectively using UTW for various applications. This interest group can help participants share experience and knowledge to improve engineering staff efficiency and develop in-house utility expertise.

The software is based on procedures defined by cable industry standards and EPRI or other industry-accepted studies, including IEC Standard 60287 and Neher/McGrath's methods for ampacity calculations, R.C. Rifenburg's methods on pulling tension calculations, Biot-Savart's law, and recent EPRI studies for magnetic field and induced voltage and current calculations. UTW also includes an extensive search feature with links to various reference titles, cable-related terms, and the 2006 *EPRI Underground Transmission Systems Reference Book.* Typical example cases are also provided with the software package.

UTW offers the following to the utility engineers:

- An easy-to-use tool to independently perform ampacity calculations or to verify calculations performed by contractors or suppliers. The calculations are supported for dissimilar cable constructions of the same type, unequal circuit loading, cross-bonding with unequal length minor sections, ground continuity conductors, and parallel or crossing external heat sources.
- An option to perform detailed economic evaluations of trenched cable systems. The data provided in an example case assists users to setup an initial case.
- A method to calculate aboveground magnetic fields of extruded dielectric, self-contained fluid-filled, and pipe-type cable systems. Non-ferromagnetic shielding plates can be modeled for extruded and self-contained cable types.
- A tool to calculate pulling tensions, including effects of power cables and pulling ropes.
- A tool to calculate basic pipe-type cable hydraulic parameters.
- A method to calculate induced voltages and currents on adjacent out-of-service cables or metallic pipelines.
- Scaled 3-D installation diagrams of buried cable systems for quick geometry and input parameter check.

Project Approach and Summary

The objective of this interest group is to share experiences and issues in using UTW on various applications. This group can provide results in the following areas.

- Application experience, including calculation parameter settings and knowledge-based assumptions
- Technical knowledge shared among cable engineers and invited industrial experts
- Cable project management knowledge, such as up-to-date information on material cost and project duration
- Challenges and issues in using UTW
- Recommendations of new features for future implementation
- Case studies demonstrating economical benefit of advanced circuit design and project execution through modeling using UTW

The project will include a group webcast or in-person workshop to facilitate education on standard and advanced software functionality. The meeting will also support and encourage group discussions to identify and prioritize technical challenges and propose future research that can be separately undertaken by EPRI. Outcomes of the users group will help guide future enhancements to UTW.

Benefits

This project will benefit the funders by

- maximizing benefits of using EPRI Underground Transmission Workstation (UTW),
- increasing understanding of UTW capabilities and improving technical knowledge in general,
- sharing experiences in using UTW for various applications,
- indentifying and prioritizing future research needs,
- making informed and technically sound decisions through cable project management,
- reducing the costs of underground transmission cable projects, and
- providing technical support by EPRI staff for users of UTW.

Feasibility Assessment of Pipe-Type to XLPE Cable Conversions (073523)

Background, Objectives, and New Learnings

High-Pressure Gas-Filled (HPGF) and High-Pressure Fluid-Filled (HPFF) cable systems make up a vast majority of the installed base of underground transmission infrastructure in the United States. Many of these assets are near or beyond their original design life. While many systems continue to provide reliable service for the utility, some failures are being reported. In addition, load growth in America's urban areas continues to grow and require greater capacities in underground transmission cable systems.

These factors pressure utilities to consider new options for future system growth and enhancement to meet increased capacity requirements. The ability to leverage the installed steel pipe from the existing cable system for installation of new, modern cross-linked polyethylene (XLPE) cables drastically reduces overall project costs. Civil construction costs for installation of a duct bank for a new XLPE cable circuit can account for as much as 50% of the total project.

Several options are available to install XLPE cables into these pipes. Challenges arise due to diameter constraints which result in complex trade-offs in design of the system such as conductor sizes and dielectric stress in the cable insulation. Several global cable manufacturers have proposed high-stress designs to overcome these challenges and commercial projects have been realized throughout the world.

Objectives of the project are to conduct a feasibility assessment of available solutions and provide funders with guidance on leading practices. Commercial solutions will be reviewed and novel concepts presented and discussed.

New learnings of the project will include a summary of design challenges, industry success stories, and project shortcomings. Leading practices and guidance will be provided to assist funders with similar implementations.

Project Approach and Summary

A project team of industry experts will be formed to review technical challenges of retrofit applications, including diameter constraints, increased voltage stress in reduced wall cable insulation and accessories, thermal stresses, and induced currents in the steel pipe. Available commercial solutions and existing projects executed in the Unted States, Europe, Asia, and Russia will be analyzed. A literature review will be conducted and manufacturers will be consulted to understand their solutions to challenges associated with retrofit of pipe-type cable steel pipes.

The project team will summarize available information and present any novel ideas for design and installation of XLPE cables under these conditions. Leading industry practices will be identified and recommended guidelines will be developed for successful retrofit of existing steel pipes with XLPE cables.

One project outcome may be the identification and recommendations for future EPRI research to develop solutions to ongoing challenges and shortcoming with retrofit project design and implementation.

Benefits

The project may benefit the public through ongoing utilization of existing underground assets. This may reduce the impact of new circuit installations and minimize construction work in urban city streets.

The project may benefit the funder in the following ways:

- Increased asset utilization by reusing existing underground pipes
- Reduced overall project costs and time durations through avoidance of civil construction
- Reduced risk through leading industry practices for retrofit applications
- Increased system efficiencies and staff utilization