36 Underground Transmission

Program Overview

Program Description
The Underground Transmission (UT) Program leads in the exploration and deployment of promising new technologies and tools to help UT owners design and operate cost-effective cable systems, diagnose problems before outages occur, and repair them at minimum cost within acceptable time periods. The program's goals are to reduce the cost of new construction, decrease maintenance, increase reliability while maintaining or improving power transfer, enhance equipment and public safety, and mitigate the environmental impact of high-voltage (HV) and extra-high-voltage (EHV) cable systems. Program products include design tools and software, training workshops, development of new technologies, impartial assessments of industry practices, modeling and laboratory validation of system design, and forensic testing of failed systems. Members further benefit through active participation in the UT Task Force (UTTF), which provides engineers and supervisors invaluable information and networking opportunities. In short, members of EPRI's UT Program will be positioned to take full advantage of environmentally acceptable buried transmission systems that have increased throughput, improved reliability, and reduced cost.

Industry Needs and Issues Addressed
- Investor, regulator, and customer pressure to reduce UT installation and operating costs, improve transmission system reliability, increase transmission capacity, and ensure health and safety
- Lack of experience with extruded dielectric (ED) cable being installed at HV and EHV levels (e.g., selection of various cable sub-types, installation designs, field commissioning tests, operation and maintenance)
- Need to extend life of pipe-type and self-contained fluid-filled (SCFF) cable systems through selective upgrades, retrofits, and an increased operating and maintenance focus

Impact
- Increases engineering staff efficiency
- Lowers installation and operating costs
- Improves transmission system reliability
- Mitigates the impacts of an aging workforce (e.g., by reducing the cost of training new technical staff)
- Enhances planning activities
- Addresses electric and magnetic field (EMF) concerns while maintaining transmission capacity needs
- Minimizes construction impacts and improves safety
- Improves efficiency and accuracy in UT system design

Key Accomplishments
- Commercial release of Version 5.0 of the Underground Transmission Workstation (UTW)
- EPRI Green Book training
- Technology transfer to commercialize new, nano-dielectric material
- Design of experimental test rigs for practical verification of thermal-mechanical (T-M) behavior in both extruded dielectric and laminar dielectric cable systems

Current Year Objectives

- Continued enhancement of EPRI's popular UTW
- Identification and assessment of advanced and low-cost designs and construction/installation techniques
- Experimental verification of T-M models for ED cables in ducts and pipes
- Development of high stress cable and accessories using nano-composites
- Testing of T-M performance in high-pressure fluid-filled (HPFF) (pipe-type) cable systems
- Detection and mitigation of steel pipe corrosion in pipe-type cable systems

Industry Involvement

- Estimated 2009 funding: $2.5M

Program Technical Lead

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Summary of Projects

Project Number	Project Title	Value
P36.001	Design and Construction of UT Systems	Improve design tools and new construction techniques to increase staff productivity, lower installation costs, and enhance public safety
P36.002	Extruded Dielectric Cable Systems	Validate design models, improve installation methods, and refine condition assessment techniques to enhance reliability and improve productivity for extruded dielectric cable systems
P36.003	Laminar Dielectric Cable Systems	Improve O&M procedures to lower costs and improve productivity, as well as to validate design models and condition assessment techniques to enhance reliability for pipe-type and self-contained cable systems

Project Descriptions

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

Issue

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. Research objectives address improving transmission system reliability, increasing transmission capacity, ensuring health and safety, and cutting costs. Specific issues include the following:

- Availability of up-to-date design tools for UT system planning and design
- Advanced, low-cost, and safer designs and construction and installation techniques (e.g., splicing vaults, ducts, cable pulling, and horizontal directional drilling)
- Management and guidance of derating effects of various electric and magnetic field (EMF) shielding methods for UT circuits
- Safety guidelines in grounding systems; installation and working procedures; and inspection, monitoring, and maintenance of UT systems

Description

This project will develop new tools and technologies, as well as enhance and validate existing solutions, to address current industry issues in planning, design, construction, operation, and maintenance of UT systems. The project will capture, enhance, and apply industry knowledge by undertaking key tasks in a broad range of design and construction activities. The project is task driven, according to prioritization by contributors and available funding. Research in 2009 will address the following areas:

- Functional update and technical enhancement of the Underground Transmission Workstation (UTW). Upgrading of EPRI's popular UTW code began in 2005 as an extended, multiyear project in which successive versions were planned to incorporate the many functional and technical improvements desired by users. UTW 5.0, the first of these new versions, was completed in 2008. It consolidated the old software into five modules—Ampacity, Economics (Cost Management), Magnetic Fields, Pulling Tension, and Hydraulics—to improve program usability and provide new capabilities. Continuing development efforts in 2009 and beyond, under the guidance of the UTW Advisory Group, will add greater functionality and technical enhancements to the code. Areas identified by the Advisory Group for code development include: optional conversion of module input/output to metric units, support of unequal loading and additional circuits, a tool to calculate ambient soil temperature, enhanced transient ampacity calculation, support of additional conductor sizes, support of magnetic field calculations with multiple current sources including overhead lines, influence of losses in shielding plates and passive shielding loops, and influence of additional number of external heat sources.
- Identification and assessment of advanced, low-cost designs and construction/installation techniques. Improved manhole and vault design, duct bank construction, conduit designs, duct cleaning methods, cable pulling techniques and equipment, conduit and vault construction materials, and designs for maintainability will contribute to lower installation costs and enhanced worker and public safety. This task is to identify and assess advanced concepts in design, construction, and installation of underground transmission systems. The work will build on results of a supplemental project offered in 2006–2008.
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Value

- Improved UTW tools will enhance transmission system planning and circuit rating activities to ensure reliability, increase engineering staff efficiency, and reduce the cost of training new technical staff.
- Identification and assessment of advanced designs and construction/installation techniques will contribute to lower installation costs and safer designs.
- Improved understanding of derating effects and effectiveness of various advanced shielding methods will help members address EMF environmental and derating concerns while maintaining transmission capacity needs.
- Safety guidelines in grounding, installation, inspection, monitoring, and maintenance will improve worker safety.
- Improved cable current rating methods will help ensure reliability and safe transmission capacity.

How to Apply Results

Underground transmission engineers, designers, and managers can use the tools, methods, and technologies that are developed, assessed, or demonstrated in this project to improve efficiency and accuracy in UT system design; improve productivity and reduce costs of UT construction; and increase effectiveness in determining the impact of special design and construction requirements on UT project planning, definition, implementation, and operating regimes. Use of the knowledge gained or the products developed in this project will reduce the need for costly mid-project adjustments such as re-routing or repairs. This knowledge can also aid in accurately estimating the effectiveness of advanced design and construction techniques before committing to a UT project. Industry knowledge captured in this project will be applied to mitigate the impacts of an aging workforce and to facilitate the training of a new generation of technical staff or the reassignment of existing staff.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
UT Workstation: Functional and Technical Enhancement: The Underground Transmission Workstation Version 5.0, completed in 2008, consolidated the previous version of the software into five modules—Ampacity, Economics (Cost Management), Magnetic Fields, Pulling Tension, and Hydraulics—to improve user interface and program usability. This task will continue the process of adding functional and technical enhancements to UTW. The UTW Advisory Group will guide the specific functionality to be added, and changes will be subject to available funding. A new commercial version will be released in 2009.	12/31/2009	Software
Advanced Design and Cost Reduction for Duct, Vault and Cable Installation: This task will identify and assess advanced designs and construction/installation techniques that contribute to lower installation costs and improved worker and public safety. The project will focus on vaults, duct banks, and conduits; installation activities; and maintainability. This task will build on results of a supplemental project offered in 2006–2008. A final report will be issued.	12/31/2009	Technical Report

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
UT Workstation: Functional and Technical Enhancement: This task will continue the process of adding functional and technical enhancements to the UTW, under the guidance of the UTW Advisory Group. A new commercial version will be released in 2010.	2010	Software
Advanced Calculation Methods for EMF Shielding and De-rating Effects: This task follows on from case studies of typical cable and EMF mitigation installations, to determine the value of the improved accuracy of advanced calculation methods relative to their cost and effort. Results will establish a plan for future research, such as building EPRI in-house services or developing a user guide for third-party software.	2010	Technical Update
Safety Guidelines of UT Systems: This task is an investigation of current, innovative ideas and opportunities for further research. Existing information not readily available will be collected and made accessible to members.	2011	Technical Update
Improved Cable Rating Methods: This task is to update and develop improved cable current rating methods to ensure reliability and safe transmission capacity, with appropriate factors of safety.	2011	Technical Update

Product Title & Description	Planned Completion Date	Product Type
Use of Fiber Optics in Spare Duct to Infer Cable Conductor Temperatures: This task will provide contributors with a real-time online software algorithm to process field measured data from a fiber optic cable in a spare duct. The task includes three phases: 1) create algorithms to calculate cable conductor temperatures from measurements in a spare duct, 2) perform verification tests, and 3) incorporate into DTCR or other stand-alone programs.	2011	Technical Update

P36.002 Extruded Dielectric Cable Systems (062105)

Issue

The amount of extruded dielectric cable being installed at high-voltage (HV) and extra-high-voltage (EHV) levels, some with transmission capacities approaching 1 gigawatt, is growing substantially. The reliability of long, high-capacity lines is very important. However, many utilities lack experience with these newer systems and are facing uncertainties associated with selection of various cable sub-types, installation designs, field commissioning tests, operation, and maintenance. Simultaneously, emerging new extruded dielectrics promise to decrease losses, extend useful length for alternating current (AC) applications, reduce cable diameter, and extend pulling lengths. Challenges that these dielectric systems pose include understanding and controlling thermally induced mechanical behavior under cyclic loading, operation at sustained high temperatures and emergency overloads, and effective application of improved condition assessment techniques, such as partial discharge (PD) measurements—especially as a commissioning test at elevated test voltages or during on-line monitoring.

At the same time, utilities need a better understanding of cable system aging and failure mechanisms and assurances that the performance and longevity of extruded dielectric (ED) EHV cable systems will be at least as good as the proven fluid-filled systems that have historically been the backbone of U.S. underground transmission technology. The costs, benefits, and risks associated with embedded temperature sensing optical fibers also need better definition. Extra-high-voltage cable splices are a major concern because of high electrical and mechanical stresses at critical interfaces, temperature-dependent aging effects, and the influence of high thermal-mechanical (T-M) forces with some splicing vault layouts.

Description

This project will investigate and improve new materials, equipment, designs, and methods to meet the needs of a growing installation base of HV and EHV extruded dielectric cable systems. Solutions will be applicable to selecting, installing, commissioning, testing, operating, and maintaining an overall system, including condition assessment of cables, splices, and terminations. The project is task driven, according to the prioritization of contributors and available funding. Research in 2009 will address the following areas:

- Experimental verification of T-M models for ED cables in ducts and pipes. Published papers have shown that cables insulated with extruded or paper tape dielectrics, when heated, expand and form complex patterns that modify the axial and lateral forces acting on the cable and on the joints in the route. It is believed that these forces could damage the cable itself under the action of sidewall force, local bending, insulation softening at high temperatures and longitudinal movement concentration. The Unified Model and the NSPAN software model, expected to be completed in 2008, are the culmination of several years of EPRI-sponsored research to formulate a theoretical basis for T-M behavior of ED cable systems. The models have not been verified experimentally. This research task will utilize a full-sized test rig containing an extruded dielectric

cable in a representative part of a duct-manhole system and a rigorous experimental procedure to obtain the data needed to permit the accuracy of the EPRI models to be validated and amended as necessary. The 2009 effort will continue efforts started in 2008 to design and fabricate the test rig and use it to collect data.
- High stress cable and accessories using nano-composites. This research supports ongoing activities to commercialize nano-dielectric materials for use in underground transmission cables. Research will apply current and new knowledge in nano-composite materials to cable and accessories. The effort in 2009 will build upon efforts by EPRI and its joint-development partner in 2008. Depending on that progress, one or more of the following directions could be taken: performance testing of model cables; development and testing of nano-composite enhanced components for high stress cable accessories; development of wet design insulation enhancements using nano-composite fillers after successful completion of nano-composite cable development; and development of reduced diameter cables using nano-composites.

Value

- Laboratory testing of thermal-mechanical behavior of ED cables in ducts and pipes will lead to standardized designs and confidence in high reliability underground transmission (UT) systems for their intended design life.
- Greater knowledge of high-temperature operation implications will assure desired reliability and possibly increased transmission capacity at low additional cost.
- Development and effective application of new nano-dielectric materials will significantly reduce initial and lifetime costs of UT.

How to Apply Results

Underground transmission engineers, designers, and managers can use the guidelines, methods, and technologies developed or assessed in this project to improve productivity and lower costs for designing, installing, commissioning, testing, operating, and maintaining extruded dielectric cable systems. The use of these results will enhance reliability, safety, and asset replacement strategies.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Experimental Verification of TM Models for Extruded Dielectric Cables in Ducts and Pipes: This multiyear task will utilize an experimental test rig to produce distress in XLPE cable samples in ducts and pipes and researchers will analyze the results to verify existing models. The task will continue efforts begun in 2008. A technical update report will be issued to document progress in 2009.	12/31/2009	Technical Update
High Stress Cable Using Nano-Composites: Model Cable Tested: This multiyear task will build upon prior year activities by EPRI and its joint-development partner to commercialize nano-dielectric materials for use in underground transmission cables. The product will be fabrication and laboratory testing of one or more model cables.	12/31/2009	Hardware

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Experimental Verification of TM Models for Extruded Dielectric Cables in Ducts and Pipes: This multiyear task will utilize an experimental test rig to produce distress in XLPE cable samples in ducts and pipes, and researchers will analyze the results to verify existing models. The task will continue efforts from prior years.	2010	Technical Report
High Stress Cable and Accessories Using Nano-Composites: This multiyear task will build upon prior-year activities by EPRI and its joint-development partner to commercialize nano-dielectric materials for use in underground transmission cables.	2010	Technical Update
Methods for Improved Installation Quality in Extruded Dielectric Cable Accessories: This task will consist of a multiphase approach to improving the quality of installation in ED cable accessories. Activities will include one or more of the following: Investigate practice and procedures currently used by different utilities; investigate current diagnostic and inspection techniques to address the main root cause of cable accessory failures; develop greater understanding of design and operation issues for EHV splices and terminations, such as electrical and mechanical stresses, temperature-dependent aging effects, and influence of high thermal-mechanical forces; develop guidelines for cable accessory installation quality assurance; assess feasibility of robotic technology and machine tools for cable end preparation; and recommend further research or development.	2011	Technical Update
Impact of High Temperature Operation on Extruded Dielectric Cable Systems: This task will increase knowledge about the reliability and cost implications of operating UT systems at high-temperature to increase capacity. It will utilize the EPRI T-M model to calculate the impact on insulation geometry for a variety of cable designs and installation and operation scenarios. It will define alternative design/operation scenarios to achieve the desired reliability and also identify the cost impact.	2011	Technical Update
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.	2011	Technical Update

P36.003 Laminar Dielectric Cable Systems (063284)

Issue

Much of the installed underground transmission (UT) infrastructure in the United States is high-pressure fluid-filled (HPFF) ”pipe-type” cable. Along with self-contained fluid-filled (SCFF) cable systems, most of these systems have performed well, meeting their original design life expectations. The growing age of many of these assets is a cause for concern, in some instances related to system integrity, including the impact of pipe corrosion and thermal-mechanical movement of cable cores inside the pipes. Replacement costs for laminar dielectric systems are very high, driving efforts to extend life through selective upgrades, retrofits, and an increased operating and maintenance focus. Cable system loadings often increase with age, such that some older systems are required to operate at ever higher loads and temperatures. Concurrently, changes in their thermal environment since commissioning have often occurred without the knowledge or control of the utility—and frequently with negative effects on ratings.

Knowledge-based cable system condition assessment and/or rerating in such circumstances is a key reliability and economic issue. Effective detection, location, and rapid repair methods are also needed to reduce the impact of leaks. Engineered optimal procedures are needed for depressurization, repair, and repressurization of pipe-type systems to reduce dependence upon contractors and improve maintenance practices. Post-construction inspection and assessment guidelines will also be valuable. Recent experience indicates that thermal mechanical bending (TMB) is a factor in cable failures within pipes, previously only thought to occur in first-generation splices. Hence, tools that will model TMB in pipes need to be developed and validated. Solutions are analogous with extruded insulation cable behavior in ducts or pipes. Partial discharge (PD) diagnostic techniques and their effectiveness for pipe-type cables are not well understood or validated; therefore, further research and development needs to be conducted so that the industry can benefit from using PD techniques.

Description

This project will investigate and develop new equipment, methods, and procedures to improve reliability and lower costs for installation, operation, maintenance, and eventual replacement of laminar dielectric cable systems. The project is task driven, according to the prioritization of contributors and available funding. Research in 2009 will address the following areas:

- Thermal-mechanical performance in HPFF (pipe-type) cable systems. This research will follow from a 2008 project to assess the feasibility of designing and utilizing experimental test rigs to produce distress in cable samples. Testing will be conducted to replicate, accelerate, and detect cable deterioration. Diagnostic methods to detect cable distress at an early stage will be evaluated. A desirable outcome is to be able to predict locations in a pipe route most at risk from TMB deterioration. The specific activities in 2009 will depend upon progress in this area in 2008. Collaboration with other members who have funded work in this area will be pursued as well.
- Corrosion of steel pipes in pipe-type cable systems. This research will help members evaluate and deploy methods for inspection of steel pipes for corrosion damage; corrosion mitigation; and pipe life prediction. Of particular concern are techniques for inspection of steel pipes in close proximity of electrified railroads, techniques for mitigation of pipe corrosion before it leads to pipe failure, and methods to predict pipe life. The research will be undertaken sequentially.

Value

- Better understanding of the condition of aging cable system assets and potential failure mechanisms (such as TMB) in pipes will lead to maintenance intervention prior to spontaneous failure, resulting in lower repair costs and higher reliability. New and replacement cables will be more tolerant of the causative conditions, and will achieve higher reliability through application of validated design models.

- Rapid detection, location, and repair of pipe leaks will reduce costs associated with extended outages and improve environmental responsiveness.
- Effective methods for protecting steel cable pipes will lead to longer underground transmission asset life and avoidance of expensive unplanned outages for repairs.

How to Apply Results

Access to the investigations, procedures, methods, and technologies developed or assessed in this project will help UT engineers, designers, and managers improve their productivity and lower costs for designing, installing, commissioning, testing, operating, and maintaining pipe-type cable systems. Through these results, reliability, safety, and asset replacement strategies will be enhanced.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Experimental Study of TM performance of HPFF Cables: In this task researchers will utilize experimental test rigs to produce distress in HPFF cable samples, cycling them to failure and analyzing results. An interim report documenting research results will be prepared and delivered in 2009. The task will continue efforts started in 2008 and is expected to continue into 2010.	12/31/2009	Technical Update
Corrosion of Steel Pipes used in Pipe-type Cable Systems: This is a new task in 2009. A report will be prepared to provide guidance for effective application and maintenance of cathodic protections systems to steel cable pipes, as described above. Duration of the work is estimated to be about one year.	12/31/2009	Technical Report

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Leak Detection and Location in HPFF and SCFF Cables: This multiyear task will identify, develop, and/or assess effective methods for leak detection, location, and rapid repair in HPFF and SCFF cable systems. This task continues effort started in 2009.	2010	Technical Update
Corrosion of Steel Pipes used in Pipe-type Cable Systems: This multiyear task will provide guidance on and methods for inspection of steel pipes for corrosion damage, corrosion mitigation, and pipe life prediction. This task continues efforts started in 2009.	2010	Technical Update
PD Diagnostics for Pipe-Type and Self-Contained Cable System: This new task will continue past EPRI research and additionally perform investigations to understand and validate PD diagnostic techniques and determine effectiveness for HPFF and SCFF cables.	2011	Technical Update