Underground Transmission - Program 36

Program Overview

Program Description

There are a number of challenges in underground transmission (UT). Utilities need a 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 with 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 application of buried power cables with greater power throughput, which places great importance on orderly replacements of mature cables with care that new advanced systems are at least as reliable. Transmission owners need guidance on 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 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 three research areas; design, reliability and performance, increasing power flow and superconductivity. This research leads in the exploration and deployment of 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, 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 be beneficial to members of the program. This information will come in a number of forms and is expected to include:

- 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 such as DOE
- Training workshops

Accomplishments

The current program has three project sets: traditional underground transmission, increased power flow for cables, and superconductivity. In the past, traditional underground transmission has delivered valuable information that has helped its members and the industry design, operate, and maintain both conventional and emerging cable system technology. Some examples include:

- Commercial release of Version 5.0 of the Underground Transmission Workstation (UTW) (1015924)
- EPRI Green Book (1014840)
- EMF Management User's Guide for Underground Transmission Systems (1015925)
- Successful manufacture of over 1000 feet of nano-dielectric cable for performance testing (1015926)
- Development and testing of pressurization procedures for HPFF and HPGF cable systems (1015930)

The increased power flow for cables program has delivered valuable information such as:

- 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 4.1 (1013761), a computer program to calculate underground cable ratings in real-time or in simulated mode
- DAP 1.0 (1015974), a computer program designed to work in conjunction with DTCR

Superconductivity has delivered strategic information and stakeholder meetings to help participants stay abreast of this new technology and contribute to its development. Some examples are:

- Cryogenics Workshop (1008699) and Tutorial (1010897)
- Annual HTS Cable Technology Watch reports (1012430, 1013990, 1015988)

Current Year Activities

EPRI's research program consists of continuing the set of projects focused on underground transmission issues and technologies (i.e., a continuation of the former Program 36), but has expanded to include projects in cable dynamic rating and increased power flow as well as superconductivity. Objectives in the traditional Base Underground Transmission Project Set are:

- Continued development/enhancement/validation of design tools and models
- Application of advanced sensors to enable more cost-effective inspection and condition assessment in all cable types
- Solutions for mitigating sources of oil leaks and cost-effectively locating them if they occur

Objectives in the Cable Dynamic Rating and Increased Power Flow Project Set are:

- Update of state-of-the-science increased power flow guidebook
- Update and improvement of software tools and methodologies for increasing/optimizing the power capacity of underground transmission circuits

Objectives in the Superconductivity Project Set are:

- Continued dissemination of strategic technology and demonstration project information, and coordination with industry and government stakeholders as they seek to commercialize the technology

Estimated 2010 Program Funding

$2.5M

Program Manager

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Summary of Projects

PS36A Design, Reliability and Performance for Underground Transmission (069261)

Project Set Description

The Design, Reliability and Performance for Underground Transmission Project Set leads the industry in the exploration and deployment of promising new technologies and tools to help underground transmission owners design and operate cost-effective cable systems, diagnose problems before outages occur, and repair them at minimum cost within acceptable time periods. Project 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. 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 the Design, Reliability and Performance for Underground Transmission Project Set will be positioned to take full advantage of environmentally acceptable buried transmission systems that have increased throughput, improved reliability, and reduced cost.

Project Number	Project Title	Description
P36.001	Design, Construction and Operation of UT Systems	This project provides tools, guidance and resources for planning, design, construction, operation, and maintenance of underground transmission systems.
P36.002	Extruded Dielectric Cable Systems	This project provides understanding of performance factors, tools and techniques for inspection, as well as novel materials 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 on-line inspection to enhance the reliability and manage the life cycle of laminar dielectric cable systems.

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

- Up-to-date design tools for UT system planning and design
- Improved safety for installation, inspection, monitoring, operation and maintenance of UT systems
- Low-cost and effective construction and installation techniques
- Application of advanced sensor technology to the operation of UT systems

- Understanding construction and operation cost differences between underground and overhead transmission line systems
- Strategies for timely replacement of aged UT systems
- Procedures for planning new systems

Approach

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, as prioritized by members and available funding. Research 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. EPRI will continue to develop the code through annual updates to add functionality and technical enhancements under the guidance of the UTW Advisory Group.
- Safety in underground transmission construction, installation, operation, and maintenance. The elements in this task include: categorization of basic safety issues in underground systems; assessment of current utility practices with respect to uniformity, effectiveness, and practicality; and identification of gaps and opportunities for innovative tools, methods and new understanding as applied to meeting needs and improving current practice. Subsequent research will seek to develop and validate new technology or knowledge, as deemed necessary. Issue areas to be investigated will follow recommendations of an advisory group. Candidates include: jointing vault, terminal and deep tunnel grounding systems, safe installation and working procedures, and safe inspection, monitoring, and maintenance methods (e.g., the use of robots, safety blankets, and advanced sensors). This task may extend over more than one year depending on initial results.
- Underground transmission cable system installation and construction practices manual. This two-year project starting in 2009 will develop a best-practices manual, describe example projects, and investigate and assess innovative construction and installation techniques.
- Underground Transmission Systems Reference Book ("Green Book"). The 2006 EPRI Green Book will be updated. New material will include more in-depth coverage of operation and maintenance for extruded dielectric cable systems.

Impact

The tools, technologies and knowledge gained in this project will lead to more cost-effective design and installation of underground transmission cable systems with improved reliability and safety for workers and the public.

- Improved design software and reference 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.
- Worker and public safety in installation, inspection, monitoring, and maintenance activities will be enhanced through improved practices, new and innovative tools and sensors, and increased knowledge.
- Identification and assessment of innovative installation and construction techniques will contribute to lower installation costs without compromising performance, environmental impact, and safety.

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. This knowledge can also help members accurately estimate 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 facilitate the training of a new generation of technical staff or the reassignment of existing staff.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
UT Workstation: functional and technical enhancements: 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.	12/31/10	Software
Underground transmission cable system installation and construction practices manual: This final report will be a design manual documenting results of a two-year project begun in 2009 to establish innovative techniques in underground transmission civil work and construction.	12/31/10	Technical Report
Safety in underground transmission construction, installation, operation, and maintenance: This product will evaluate the uniformity, effectiveness and viability of current utility safety practices, with a focus on a particular industry safety issue, and recommendations for implementation or development of improved procedures using advanced technology and/or new understanding. The industry issue area will be selected in consultation with project advisors.	12/31/10	Technical Update
Update of EPRI Underground Transmission Systems Reference Book – 2006 Edition: This task will update the “Green Book” and add a section on Operation and Maintenance for Extruded Dielectric Transmission Cable Systems. Funders will receive a full version (PDF file) of the 2006 Green Book plus the revisions added in 2010.	12/31/10	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Database on Lessons Learned in Underground Transmission Design, Construction and Operation: This task will develop a central database using common industry format to gather information from utilities, manufacturers, contractors, and consultants on lessons learned in planning, design, construction, installation, and testing, and then provide a search engine for members to benefit from lessons learned in key phases of an underground transmission cable project. It could also include information on, and analysis of, cable failure in North America.	12/31/11	Technical Update
UT Workstation: Functional and Technical Update: 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 2011.	12/31/11	Software
Guide for comparison of underground and overhead transmission lines : This project will develop a guide to compare the technical characteristics and environmental impacts of underground and overhead transmission lines, and investigate various factors that determine construction and operation cost. This guide will help members make informed decisions when planning new transmission systems.	12/31/11	Technical Report

P36.002 Extruded Dielectric Cable Systems (062105)

Key Research Question

The amount of extruded dielectric (ED) cable being installed at HV and EHV levels, some with transmission capacities approaching 1 GW, is growing substantially. The reliability of long, high-capacity lines is very important. However, many utilities lack experience with these newer systems and face uncertainties associated with selecting 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 applications, reduce cable diameter, and extend pulling lengths. Challenges posed by these dielectric systems 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. The costs, benefits, and risks associated with embedded temperature sensing optical fibers also need better definition.

At the same time, utilities need a better understanding of cable system aging and failure mechanisms, and 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 U.S. underground transmission technology. EHV 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.

Approach

This project will investigate and improve new materials, equipment, and methods for HV and EHV ED cable systems, including use of advanced sensors and techniques. Solutions will be applicable to selecting, installing, commissioning, testing, operating, and maintaining an overall system. The project is task driven, as prioritized by members and available funding. Research will address:

- Experimental verification of T-M models for ED cables in ducts and pipes. EPRI-sponsored research has formulated a theoretical basis for T-M behavior of ED cable systems. The models have not been verified experimentally. A full-sized test rig containing an extruded dielectric cable in a representative part of a duct-manhole system is being constructed at EPRI's Charlotte lab. A rigorous experimental procedure will obtain the data needed to validate the accuracy of the EPRI models and amend them as necessary. Guidelines for T-M-resistant designs will be developed after validation of the models.
- Inspection and condition assessment for ED cable systems. The research team will first identify and evaluate opportunities for innovative tools and methods. A prime focus will be assessment of cable health with advanced sensors monitoring electrical, mechanical or thermal behaviors (e.g., on-line PD detection/monitoring and T-M damage). Solutions to transmitting data in near real time will be explored. A key technology is the design and use of fiber optics for PD measurement or other novel applications. Research will address effective detection of fiber damage during installation and operation, and the long-term impact of integral fibers on the health of transmission cable.
- 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 be directed toward performance testing of model cables; development and testing of suitable accessories; understanding and development of wet design insulation enhancements; and development of reduced-diameter cables using nano-composites.

Impact

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

- Laboratory testing of thermal-mechanical behavior of ED cables in ducts and pipes will lead to standardized designs and confidence in high-reliability UT systems for their intended design life.
- Greater knowledge of high-temperature operation implications will ensure desired reliability and possibly increased transmission capacity at low additional cost.
- Development and deployment of advanced sensors and inspection techniques will reduce maintenance costs and increase system reliability
- 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. Engineers will use T-M model validation results to implement T-M-resistant 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 nano-dielectric cables to provide additional options for increasing transmission system throughput and extending cable life.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
Experimental Verification of TM Models for Extruded Dielectric Cables in Ducts and Pipes: This product comprises experimental test rigs to produce distress in XLPE cable samples in ducts and pipes to verify existing models. Contingent upon adequate funding, fabrication and deployment of the test rig in Charlotte will be completed and data collection and analysis begun. The rigs will provide validation results for one or more cable construction types.	12/31/10	Hardware
Advanced Sensors and Inspection Techniques for Extruded Dielectric Transmission Cable Systems: This is a multiyear task beginning in 2010. A technical update will document interim results of research and development on advanced sensors and data transmission techniques for on-line inspection of cable system condition and operational status, with a focus on the use of fiber-optic sensor systems.	12/31/10	Technical Update
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. In 2010, results from host utility demonstrations will be reported.	12/31/10	Technical Report

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Guidelines for Thermo-mechanical Design of Extruded Dielectric Cable Systems: This task in 2011 will build on previous EPRI work on T-M 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 T-M 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.	12/31/11	Technical Report
Experimental Verification of TM Models for Extruded Dielectric Cables in Ducts and Pipes: This project will employ experimental test rigs to produce distress in XLPE cable samples in ducts and pipes to verify existing models. The rigs will provide validation results for one or more cable construction types. An interim report will provide an update on research results.	12/31/11	Technical Update
Advanced Sensors and Inspection Techniques for Extruded Dielectric Transmission Cable Systems: This is a multiyear task that began in 2010. A technical update will document interim results of research and development on advanced sensors and data transmission techniques for on-line inspection of cable system condition and operational status, with a focus on the use of fiber-optic sensor systems.	12/31/11	Technical Update
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. An interim report will document research and solutions to commercialization issues such as developing and testing suitable accessories, and understanding and developing wet design insulation enhancements.	12/31/11	Technical Update
Integrity of Laminated Moisture Barriers in XLPE Cable: Increased use of foil laminate moisture barriers in XLPE cable presents increased potential for failure associated with thermal and mechanical stresses in cable in ducts (e.g., extreme bending). Researchers will obtain cable samples and use experimental bending rigs to cyclically stress the cables to failure at operating temperatures in order to determine their resistance to potential failure. This product will be an interim report on experimental testing of foil laminate cables in EPRI's TMB bending rig.	12/31/11	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 practices 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 the feasibility of robotic technology and machine tools for cable end preparation; and recommend further research or development.	12/31/12	Technical Update

Product Title & Description	Planned Completion Date	Product Type
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 also define alternative design/operation scenarios to achieve the desired reliability as well as identify the cost impact.	12/31/12	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.	12/31/12	Technical Update

P36.003 Laminar Dielectric Cable Systems (063284)

Key Research Question

Much of the installed 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, surpassing 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 focus on operation and maintenance. 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 rerating in such circumstances is a key reliability and economic issue. The following are specific research needs for HPFF and SCFF cable systems:

- Effective methods for rapid leak detection and location to reduce operational and environmental impacts
- Effective methods for maintaining corrosion protection of pipes, including location and repair of compromised pipe sections
- Engineered optimal procedures for depressurization, repair, and re-pressurization of pipe-type systems to reduce dependence on contractors and improve maintenance practices
- Post-construction inspection and assessment guidelines
- Development and validation of research and tools that will model thermal mechanical bending (TMB) in pipes. Solutions are analogous to extruded insulation cable behavior in ducts or pipes.
- Partial discharge (PD) diagnostic techniques are known to have limited effectiveness for pipe-type cables, but continued research and development may ultimately enable the industry to benefit from using PD techniques on these cable types.

Approach

This project will investigate and develop new equipment, methods, and procedures to improve reliability and reduce costs for installation, operation, maintenance, and eventual replacement of laminar dielectric (LD) cable systems. The project is task driven, as prioritized by members and available funding. Research will address the following areas:

- Corrosion of Steel Pipes used with Pipe-type Cable Systems. This two-year project, which began in 2009, assesses corrosion prevention and mitigation techniques as well as innovative corrosion inspection and monitoring techniques through field tests at the Klondike corrosion test facility, laboratory tests in Charlotte, and an industry practices survey. Laboratory studies also investigate pipe corrosion rates and other characteristics to assist in pipe life prediction. Of particular concern are techniques for inspecting steel pipes in close proximity to electrified railroads, techniques for mitigating pipe corrosion before it leads to pipe failure, and methods to predict pipe life. A guide on cathodic protection system operation and maintenance will be developed.
- Leak Detection and Location in HPFF and SCFF Cables. This multiyear task will build on prior EPRI research to develop novel methods for economical, easy-to-use, and rapid leak detection and location in HPFF and SCFF cable systems. Research will focus on new inspection techniques or tools that will give near real-time results at very low levels of leak rate or lost volume, and provide rapid location of leaks without extensive staff or equipment infrastructure. Efforts will build on results from a supplemental project in 2009, but will seek to exploit different, simpler techniques.
- Condition assessment techniques for LD cable systems. This multiyear task will provide advanced techniques for in-field condition assessment of LD transmission cable systems. Research will explore new methods and tools for: on-line PD detection, tan delta, fluid condition or combustible gas measurement, continuous PD monitoring, and other effective condition assessment systems. Development and validation of sensors, digitizers, recorders and telemetry systems to deliver distributed, near real-time in-situ data during on-line monitoring will be pursued. Fiber optic and semiconductor sensor technology will be evaluated.
- Thermal-mechanical bending in HPFF (pipe-type) cable systems. Researchers will follow a path similar to that taken for extruded dielectric cables. An experimental protocol and designs for test rigs to produce distress in cable samples will provide the basis for testing. Test rigs will be constructed at an EPRI lab and testing conducted to replicate, accelerate, and detect cable deterioration. Diagnostic methods to detect cable distress at an early stage will be evaluated. Collaboration with other members who have funded work in this area will be pursued as well.

Impact

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

- Methods for inspecting steel pipes for corrosion damage, enhanced corrosion protection, and pipe life prediction will improve the longevity and reliability of pipe-type cable systems and help avoid expensive unplanned outages for repairs.

- Rapid detection and location of fluid leaks will reduce costs associated with extended outages and improve environmental responsiveness.
- Development and deployment of advanced sensors and inspection techniques will reduce maintenance costs.
- Real-time monitoring of the condition of aging cable system assets and better understanding of 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.

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 costs for operating, maintaining and extending the life of laminar dielectric cable systems. Reliability and safety will 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 and where cable systems are most susceptible to damage from corrosion, TMB, and other potential failure mechanisms.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
Corrosion of Steel Pipes used in Pipe-type Cable Systems: This product is a final technical report on steel pipe corrosion mechanisms, corrosion prevention and mitigation techniques, assessment of innovative corrosion inspection and monitoring techniques, common industry practices, laboratory studies on corrosion rates to insist in pipe life prediction, and a guide on cathodic protection system operation and maintenance.	12/31/10	Technical Report
Leak Detection and Location in HPFF and SCFF Cables: This product is an interim progress report on the development of effective methods of rapid leak detection and location in HPFF and SCFF cable systems.	12/31/10	Technical Update
Condition Assessment Techniques for Laminar Dielectric Cable Systems: This report will describe progress in finding and developing advanced techniques for in-field condition assessment of LD transmission cable systems.	12/31/10	Technical Update
Experimental Protocol and Test Rigs for Study of TM performance of HPFF Cables: This report will describe progress in the development of experimental protocols and test rig design.	12/31/10	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Test Rig for Experimental Study of TM performance of HPFF Cables: This multiyear product comprises design and construction of a test rig to produce distress in HPFF cable samples, cycling them to failure and analyzing the results.	12/31/11	Hardware
Condition Assessment Techniques for Laminar Dielectric Cable Systems: This product continues research in finding and developing advanced techniques for in-field condition assessment of LD transmission cable systems.	12/31/11	Technical Update
Leak Detection and Location in HPFF and SCFF Cables: This multiyear task develops novel methods for economical, easy-to-use, and rapid leak detection and location in HPFF and SCFF cable systems. Research will focus on finding new inspection techniques or tools that will give near real-time results.	12/31/11	Technical Update
PD Diagnostics for Pipe-Type and Self-Contained Cable System: This product will report on investigations to understand and validate PD diagnostic techniques and determine their effectiveness for HPFF and SCFF cables.	12/31/12	Technical Update

PS36B Cable Dynamic Rating and Increased Power Flow Guidebook (069262)

Project Set Description

This Project Set develops and delivers reference materials, training, software tools, and methodologies to increase or optimize the power capacity of underground transmission circuits without the capital costs of major new construction and permitting. Dynamic thermal circuit rating tools will help engineers, operators, and planners optimize the power transfer capabilities of transmission cables safely, reliably, and in a scientifically justified manner that helps to meet the requirements of regulatory bodies such as FERC. A state-of-the-science guidebook, along with workshops and conferences, educate power industry engineers about the concepts in general and how best to apply them.

Project Number	Project Title	Description
P36.004	Cable Dynamic Rating and Increased Power Flow Guidebook	Provide state-of-the-science reference and training materials for optimizing and increasing power flow through transmission circuits. Provide tools to optimize the power transfer capabilities of transmission cables safely, reliably, and in a scientifically justified manner that helps to meet the requirements of regulatory bodies such as FERC.

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 the construction of new transmission facilities. 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, resulting in an increasing number of bottlenecks, brownouts, and other severe reliability issues. With the proper technology, training and guidance, greater power capacities can be reliably and safely realized without making large capital investments, and can be used to meet mandated FERC (and other regulatory bodies') requirements for establishing transmission circuit ratings.

Approach

This project develops and delivers an industry guidebook, training, software tools, and methodologies for increasing the power capacity of transmission circuits without the capital costs of major new construction and permitting. The *Increased Power Flow Guidebook* (the "Platinum Book") documents state-of-the-science technical options for increasing power flow on transmission and substation equipment. The guidebook, along with its *IPF Wizard* and training materials, can guide engineers, operators, designers, and planners in applying increased power flow strategies for transmission circuits, and provides learning materials for the next generation of power industry personnel. In 2010, EPRI will publish an updated edition of the *IPF Guidebook*, which will add case studies related to design, engineering, system planning, and operations. In addition, existing material will be updated with the latest developments for underground cables, and the presentation of visual materials will be improved. Information on improvements in applications or design of thermal models as well as development of new instruments and other hardware will be included. The *IPF Wizard* and training materials will also be updated with the latest information.

This project will also continue to develop dynamic thermal rating software and methodologies for increasing and optimizing the power transfer capabilities of underground cables. The software products being developed can be used for real-time ratings, for rating studies to help meet FERC requirements regarding setting reliable and safe line ratings, and for forecasting circuit ratings hours or days into the future to facilitate bulk power transfer planning. The software allows users to perform statistical data analyses of rating data for the purpose of optimizing approaches to static ratings. The ability to quickly simulate rating scenarios is particularly useful

in responding to emergency situations as well as for optimizing power flows daily. The software being developed includes:

- Dynamic Thermal Circuit Rating (DTCR)
- Data Analysis Program (DAP)

The DTCR and DAP programs will be significantly improved to make them more accurate, robust, user friendly, and acceptable to a conservative utility culture, and many new features will be added. Ultimately, they will be combined into an integrated computational environment to make their features more widely applicable. The project also develops methodologies for establishing thermal circuit ratings to optimize transmission capacity within the practical constraints of a member's operating philosophy, while helping to fulfill FERC and other requirements.

This project focuses on underground cables, and is executed in coordination with corresponding projects for transmission lines (Project P35.013) and for substation equipment (P37.012).

Impact

This program may have the following impacts:

- Provide guidance and training to new and experienced technical personnel
- Increase and optimize power flow through entire transmission circuits
- Defer capital expenditures
- Improve transmission circuit reliability and safety
- Help to meet mandatory FERC requirements for circuit ratings
- Optimize power transfer planning
- Optimize energy transactions through rating forecasts
- Ride out emergency situations safely and reliably
- Avoid unnecessary system outages

How to Apply Results

Utilities can use the *IPF Guidebook* as a reference source for implementing IPF strategies and training their engineers in IPF technologies. The *IPF Guidebook* compares the economic benefits of each available IPF technology, enabling EPRI members to make informed decisions when choosing IPF options for their applications. IPF Transmission Circuit Rating Wizard software will also help utility engineers decide on options. Transmission operators, planners, researchers, IT personnel, and engineers will use the computer programs and methodologies to optimize the ratings of their circuits. Software products can be applied for the various reasons described, and the methodologies on how best to apply all results can be obtained through EPRI reports, training materials, and regular workshops.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
Increased Power Flow Conference: As part of its technology transfer activities, EPRI sponsors a biennial conference on the topic of Increased Transmission Capacity. This project will cosponsor the conference in 2010, and will present sessions on recent developments and applications of the technology.	11/30/10	Workshop, Training, or Conference

Product Title & Description	Planned Completion Date	Product Type
IPF Guidebook (Platinum Book), Third Edition: A technical report will be published as an updated version of the *IPF Guidebook* (also known as "Platinum Book") as part of the EPRI color book series.	12/31/10	Technical Report
IPF Trans Circuit Rating Wizard, 2.0: The IPF Wizard will be updated to reflect the latest IPF developments discussed in the *IPF Guidebook*.	12/31/10	Software
DTCR 5.1: The DTCR will continue to be developed and enhanced in 2010 to make it more accurate, robust, and user-friendly to a conservative utility culture. Several significant features will be added.	12/31/10	Software
DAP 2.0: A software product designed to work in conjunction with other programs, particularly DTCR, for the accommodating different data formats, performing statistical data analyses, and providing data plots and graphical user interfaces for ease of application, including rapid simulation of contingency rating scenarios.	12/31/10	Software

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Transmission Circuit Ratings Workshop: A workshop covering the Transmission Circuit Rating Workstation, including presentation of the underlying concepts and hands-on software exercises.	11/30/11	Workshop, Training, or Conference
Integrated DTCR/DAP: Updated versions of the DTCR and DAP software will be combined into an integrated computational environment that will include underground cables. Feedback from EPRI member engineers, operators, designers, and planners will be sought to determine the future implementations of this software, whether it is to be a stand alone engineering workstation or integrated into utility EMS systems for use by operators, or both.	12/31/11	Software
Increased Power Flow Guidebook, Technical Update: New material on the latest IPF technologies will be produced as a Technical Update.	12/31/12	Technical Update
Increased Power Flow Conference: This project will cosponsor and participate in an open technical transfer activity, such as an IPF Conference.	11/30/13	Workshop, Training, or Conference
Increased Power Flow Guidebook, Fourth Edition: Following four years of application and new developments, an updated version of the *IPF Guidebook* will be planned for release in 2014.	12/31/14	Technical Report

PS36C Superconductivity (063315)

Project Set Description

This Project Set provides longer-term solutions for a large increase in transmission capacity. It was created to deal with transmission bottleneck problems through the integration of superconducting components into the transmission and distribution system. This project's research paves the way for and validates early adoption technologies that are currently technically and economically feasible and that can establish the foundation for a superconducting power grid of the future. This Project Set consists of one project: Develop and Deploy Superconducting Technologies.

Project Number	Project Title	Description
P36.005	Develop and Deploy Superconducting Technologies	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.

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 debut 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:

- 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. The project also promotes informed business decisions related to the assessment, procurement, deployment, and operation and maintenance of superconducting assets in 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. Project tasks include technology watch reports, assessments, guidelines, annual conferences, and stakeholder workshops as needed by technology observers, early adopters, and mature market participants to take full advantage of new superconducting systems. The project is task driven, as prioritized by members and available funding, and will include:

- Publishing a Technology Watch on HTS cable system demonstrations in the United States and worldwide, with reports on operations and performance of three U.S. cable projects as well as international projects as available. New projects sponsored by DOE, if initiated, will also be reported.
- Publishing a Technology Watch on HTS fault current limiters. Available information on expected DOE-sponsored demonstrations of this technology will be gathered and reported, including project goals, design specifications, installation, and operation experience.
- Sponsoring an annual conference and participating in stakeholder dialogues in coordination with 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 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:

- Alleviate existing transmission corridor capacity constraints by integrating superconducting components into the transmission and distribution (T&D) system
- Reduce energy losses due to higher efficiency of superconducting cables and transformers
- Improve system reliability and security through deployment of superconducting equipment (e.g., 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 possible courses of action to take, from a simple "technology watch" posture to an aggressive first-adopter strategy.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
HTS Cables - Technology Watch: This product is an annual update of the series of technology watch reports on HTS cables.	12/31/10	Technical Update
HTS Fault Current Limiters - Technology Watch: This product is an annual update of the series of technology watch reports on HTS fault current limiters.	12/31/10	Technical Update
EPRI Superconductivity Conference: This product is an annual two-day conference open to the public for the purpose of promoting information exchange, stakeholder dialogue, and networking.	12/31/10	Workshop, Training, or Conference

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Development of business case for superconducting power delivery equipment: This product is an interim report on a survey of the experience of first-adopter energy companies in justifying procurement and operation of superconducting substation and power delivery equipment.	12/31/11	Technical Update
HTS Cables - Technology Watch: This product is an annual update of the series of technology watch reports on HTS cables.	12/31/11	Technical Update
HTS Fault Current Limiters - Technology Watch: This product is an annual update of the series of technology watch reports on HTS fault current limiters.	12/31/11	Technical Update
EPRI Superconductivity Conference: This product is an annual two-day conference open to the public for the purpose of promoting information exchange and stakeholder dialogue and networking.	12/31/12	Workshop, Training, or Conference