

30 Underground Distribution Systems

Program Overview

Program Description

Utility distribution systems are *challenged* by an aging infrastructure, *conventional* designs, and increasing customer demands for higher reliability and power quality. Electricity distribution companies are under pressure to improve reliability and system performance while dealing with these ongoing challenges. Budget and investment constraints require electric utilities to manage their distribution systems more efficiently.

The Electric Power Research Institute's (EPRI's) Underground Distribution Systems program (Program 30) addresses these challenges, guiding utilities as they manage distribution assets, reduce O&M costs, and improve reliability and system performance.

In close collaboration with its members, EPRI has developed a strategic plan to articulate the objectives of EPRI research for the next 10 years and to ensure that its research focus is aligned with those objectives.

The strategic plan provides the basis for research in Underground Distribution Systems (Program 30), and as a result the program has three project sets, structured as follows:

- Underground Cable Systems and Structure (PS30A). This project set focuses on the underground cable systems and structures associated with underground distribution systems.
- Urban Underground Systems (PS30B). This project set focuses on urban underground network systems, with the intent of capturing and documenting "best practices" for key functional areas and delivering practice and reference guides, best-in-class field guides, and job aids.
- Underground Distribution Technical Transfer and Knowledge Development (PS30C). This project set is new in 2009. The goal is to document a wide range of topics relevant to underground distribution systems planners, designers, and operators by capturing the expertise and knowledge of world experts for future generations' use.

Industry Needs and Issues Addressed

- Ensure safety of utility workers and the public
- Increase and ensure the reliability of underground distribution systems
- Reduce operations and maintenance (O&M) costs for underground distribution systems
- Reduce design and construction costs of new underground distribution systems
- Use of high-performance components for underground distribution
- Aging of underground distribution assets
- Loss of institutional knowledge

Impact

- Improved understanding of advanced cable diagnostic systems and technologies
- Improved management of aging underground distribution system components
- Improved assessment tools and techniques
- Reference tools for everyday use
- Shared best practices

Key Accomplishments

- Manhole event research has led to installation of new manhole frame and covers.

- Cables and accessories have been evaluated.
- Commercialization efforts continue on nano-dielectric cable designs.
- Workshops on underground distribution cable diagnostics have been conducted.

Current Year Objectives

- Publish the First Edition Underground Distribution Reference: the “Bronze Book.”
- Understand advanced diagnostics techniques, modeling, and methods.
- Apply sensor technologies and conduct laboratory testing and field demonstrations.
- Expand manhole event research.
- Advance nano-dielectric medium-voltage cables.
- Share urban network best practices and conduct workshops.

Industry Involvement

- Estimated 2009 funding: \$1.8M

Program Technical Lead

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Summary of Projects

PS30A Cable Systems and Structures (063275)

Project Set Description: This project set focuses on the underground cable systems and structures associated with underground distribution systems. Participating utilities can benefit from reduced costs through improved component selection and appropriate application when designing new or refurbished facilities.

Currently available diagnostic techniques have not proven to be accurate, effective, and reliable. Utilities are faced with issues of cost justification, accuracy, and false positive results, and thus require research that will support a strategy to move forward. Recently completed EPRI research of both off-line and on-line nondestructive diagnostic test methods reveals the potential of several new nondestructive diagnostic test methods.

New sensor technologies are being developed and evaluated. The EPRI research will help utilities apply these technologies, based on field experience, technology assessments, and test results.

Research continues on new manhole designs to prevent problems during explosions and on tests that can improve understanding of cable aging and failure prediction that can optimize cable replacement strategies.

EPRI recently developed a new dielectric system based on nano-composite dielectrics. It demonstrates improved defect tolerance and electric endurance, which will lead to a thinner wall cable and possibly an increased operating temperature. The dielectric strength of the new nano-filled polymer is more than two times greater than existing insulations, and the voltage endurance is close to two orders of magnitude better in laboratory tests.

Project Number	Project Title	Value
P30.001	Advanced Diagnostics for Underground Cable and Cable Systems	Development of methods to determine conditions of underground cables. Benefits include <ul style="list-style-type: none"> • Technology and Case Study reviews; • methods to establish the condition state of aged extruded distribution cables; and • prioritization of cable replacement, minimizing the present value cost of cable replacement programs.
P30.002	Sensors for Underground Systems	Application of sensor technology for low-cost, practical monitoring of underground systems. Benefits include <ul style="list-style-type: none"> • increased system reliability, ultimately improving regulatory and customer relations; and • improved safety and health of general public and utility personnel.
P30.003	Manhole Events	Decrease in the number of manhole events, mitigating the severity of any event that does occur and minimizing collateral effects of events. Benefits include <ul style="list-style-type: none"> • reduced damage-related costs, by millions of dollars; • reduced liability associated with collateral damage and injuries to third parties; • significantly improved plant equipment life expectancy and performance; and • a reduced number of outages.
P30.004	Nano Dielectrics for UG Distribution cables and cable systems	Development of a new dielectric system. Benefits include <ul style="list-style-type: none"> • reduced costs of underground distribution, • increased operating capacity of underground distribution systems utilizing existing infrastructure, and • reduced life cycle costs of underground cables via longer life dielectrics.

Project Descriptions

P30.001 Advanced Diagnostics for Underground Cable and Cable Systems (063276)

Issue

North America has a significant underground electric distribution system that is nearing the end of its design and service life. Global replacement of aging underground facilities is not an option, and utilities require better diagnostic methods, technologies, and tools to assess the condition of installed systems, so they can develop and prioritize cost-effective strategies to address aging facilities.

Knowledge of the cable condition provides utilities with a basis for implementing a staged rejuvenation or replacement program over a number of years and helps them avoid unpredictable peaks and unexpected rises in costs associated with increasing failure rates.

The utility industry has focused on cable diagnostics for many years, but it is still facing uncertainty and confusion regarding the effectiveness and accuracy of cable diagnostic testing techniques and methods. Currently available diagnostic techniques have not proven to be accurate, effective, and reliable. As a result, utilities are faced with issues of cost justification and accuracy. To develop a workable replacement strategy, it is necessary to conduct research that will support the development of effective diagnostic techniques.

Moreover, research is needed to understand how to interpret diagnostic information and apply this information to replacement and rejuvenation strategies.

Description

This project expands on earlier EPRI work to correlate the results of common condition-assessment techniques for distribution cables with actual and accelerated aging of cross-linked polyethylene (XLPE) insulated cables.

Recently completed EPRI research of both off-line and on-line nondestructive diagnostic test methods reveals the potential of several new nondestructive diagnostic test methods. Techniques such as off-line polarization and depolarization and isothermal return current and return voltage, when combined with conventional partial discharge dissipation-factor diagnostic techniques, could enhance the prediction of future performance and service life of XLPE cable.

EPRI intends to expand the scope of this project and build on its collaborative effort with the help and partnership of other industry expertise such as the National Electric Energy Testing, Research and Applications Center (NEETRAC) and the Cable Diagnostic Focused Initiative (CDFI).

Value

- Delivers Technology and Case Study reviews.
- Provides methods to establish the condition state of aged extruded distribution cables
- Enables prioritization of cable replacement, minimizing the present value cost of cable replacement programs
- Fosters improved reliability through enhanced knowledge of condition states of installed underground assets and active replacement of those with the least remaining life

How to Apply Results

Utility engineers will be able to apply information from the planned July 2009 Industry Summit Workshop on Advanced Diagnostics. They will be able to apply degradation models for each diagnostic method and correlate this information with the life model developed from the accelerated cable life test to determine what diagnostic methods best serve their needs.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Industry Summit Workshop on Advanced Diagnostics for Underground Cable and Cable Systems	8/1/2009	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Advanced Diagnostics for Underground Cable and Cable Systems	2010	Technical Update

P30.002 Sensors for Underground Systems (060491)

Issue

As utilities implement and refine their processes for developing optimum investment plans in their distribution assets (that is, implement asset management processes), it is necessary to decide how to use the information they have been and will be collecting via remote sensing technology to help inform investment decisions.

Many utilities record distribution asset performance information. The types of data collected and the application of this data can vary greatly among utility companies. The data collected can range from information about asset type (such as rated voltage, vintage, and manufacturer) to records of asset performance and condition (such as number of operations, number of failures, inspection findings, and diagnostic measures such as voltage or temperature).

This information is collected in a variety of ways—from personal inspections to the use of advanced sensors and communication systems that gather information remotely and transmit it electronically.

Utilities are increasingly using remote sensor technology to collect this data. Collection of substation data has increased substantially, and more and more utilities are using low cost sensors to understand distribution asset condition outside the substation. As utilities increase the application of advanced sensors for monitoring and understand distribution asset performance, they will build an information database that can be factored into asset investment decisionmaking.

Description

This project seeks to integrate advanced sensor technology that monitors underground distribution assets with asset management processes for developing optimum asset investment plans.

This project will address the industry need to develop new ways to manage and invest in underground distribution assets by taking advantage of asset condition information conveyed through advanced sensors.

This use of sensors will enable the industry to move from traditional cyclical inspection, maintenance, and replacement approaches to more cost-effective targeted approaches enabled by asset condition information.

EPRI will produce a set of guidelines that are developed from the project survey results and other research. Members will be able to use these guidelines to develop and implement asset management process steps that consider asset condition information.

Value

- Members will be better able to achieve their financial, customer service, and reliability goals through more effective investment and maintenance strategies.
- Members will be able to increase system reliability, ultimately improving regulatory and customer relations.
- Members will be able to improve safety and health of the general public and utility personnel by gaining knowledge of potentially dangerous components on the verge of failure.

How to Apply Results

Utility members can apply the results of this project in the following ways:

- Participating in expanded trials of advanced sensor technology to monitoring distribution asset condition
- Applying learned methods for tying in monitored information with other asset information to create an overall picture of asset condition
- Learning how the industry is utilizing information monitored from advanced sensors and other asset information to ascertain asset health
- Applying methods for using this information to perform risk analysis and quantification
- Understanding methods for incorporating this information into the processes for making investment decisions and optimizing maintenance approaches (Asset Management Processes)
- Employing tools that capitalize on monitored information to help utilities decide on optimum investment plans

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Sensors for Underground Distribution Systems	12/31/2009	Technical Update

P30.003 Manhole Events (060493)

Issue

Explosions and related events in underground structures are rare, involving less than one percent of underground structures. Such events may range from “smokers” with little collateral effect to “flyers” with very serious collateral damage, injury, and even death. Nevertheless, no utility is immune from the prospect of underground explosions, and predictability is difficult. These events can be caused when an arc is combined with a flammable gas, which can come from many potential sources.

Manhole events such as fires, explosions, and smoke generation have the potential to damage plant equipment, cause failures and outages, and create potential liabilities to third parties.

Description

This work focuses on developing methods to decrease the number of manhole events, mitigate the severity of events, and minimize collateral effects of events. In the past, EPRI has taken several approaches, including research into explosion characteristics, root causes, types and composition of gases involved, development of unique test facilities, workshops and rapid response meetings following manhole events, development of explosion mitigation, and cover restraint and pressure relief systems. EPRI has access to information and technologies in other industries that operate underground systems and may experience similar problems.

This project will concentrate on the following tasks:

- Development and validation through tests of comprehensive mitigation strategies and development of covers with controlled pressure relief systems.
- Development of software models of manhole events that will enable users to explore a range of strategies quickly. The software will be validated through selected laboratory tests.
- Research into mechanisms of multiple cover dislodgements in an event and prevention approaches.

- Preparation of the Manhole Event Risk Management Handbook
- Development of a database of manhole events throughout the industry

Value

- Reduce significantly the number and severity of events
- Reduce damage-related costs by millions of dollars
- Reduce liability associated with collateral damage and injuries to third parties
- Improve significantly plant equipment life expectancy and performance
- Reduce the number of outages, damage to equipment and surroundings, and costs associated with damage or injury to third parties

How to Apply Results

Participants in this project have direct and immediate access to research results such as test data. They may apply results immediately to the development of event mitigation strategies for their own particular applications.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Multiple Event Mechanisms and Prevention Approaches: A comprehensive summary report on research into multiple events and mitigation approaches, enabling definition of response strategies and deployment of repair crews and traffic control units.	12/31/2009	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Manhole Event Risk Management Handbook: A comprehensive summary of the state-of-science on manhole events, prevention and mitigation strategies, and risk management approaches.	2010	Technical Update
Field Testing of Gas Sensors for Manhole Applications Installation of gas sensors in selected manholes at participating utilities and monitored over at least one year (four seasons). Performance will be evaluated and reported.	2010	Technical Update
Event-immune Equipment and System Design: A comprehensive report on design approaches to minimize the occurrence and severity of manhole events.	2011	Technical Update

P30.004 Nano Dielectrics for UG Distribution Cables and Cable Systems (063277)

Issue

As demands on the power delivery system increase, advanced materials are needed to extend the capabilities of the system. A new high-stress dielectric material would enable utilities to utilize underground distribution circuits in new ways—with smaller cables, fewer manholes, fewer joints, smaller duct sizes, and easier handling.

Description

EPRI recognized the potential for nanotechnology in power distribution and began exploring the possibilities of using nanotechnology to enhance the properties of distribution-class voltage cables and cable systems. This project will support scale-up efforts to commercialize the technology for the utility industry.

EPRI has developed a new dielectric system based on nano-composite dielectrics. It demonstrates improved defect tolerance and electric endurance, which will lead to smaller diameter cable and possibly allow an increased operating temperature.

In 2008 work focused on evaluation of sample materials using established long-term wet electrical test protocols. On the basis of initial results on both dry and wet electrical tests, the research will proceed to demonstrate the new polymer on model cables and begin practical applications and commercialization.

In 2009 the effort will shift to include cable system accessories.

Value

- Reduce costs of underground distribution, enabling greater response to societal demands for undergrounding of distribution systems
- Increase operating capacity of underground distribution systems utilizing existing infrastructure
- Reduce the life cycle cost of underground cables via longer life dielectrics

How to Apply Results

Distribution designers will use the results to modify economic models and plans for underground system implementation. Members will provide direct input to the ongoing development of the cable design to maximize the benefit for future distribution system designs.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Nano Dielectrics for UG Distribution Cables and Cable Systems	12/31/2009	Technical Update

PS30B Urban Underground Systems (063278)

Project Set Description: This project set focuses on urban underground network systems, with the intent of capturing and documenting “best practices” for the key functional areas. It also focuses on delivering practice and reference guides, best-in-class field guides, job aids, and where possible, commissioning field demonstration pilots to address application issues. Participating members can expect to improve safety and reliability and reduce costs associated with planning, designing, engineering, constructing, and operating their urban network system.

Project Number	Project Title	Value
P30.005	Urban Network Systems Practices	Provide members with relevant practice information, guidelines, technologies, and training to manage aging network system assets. Benefits include <ul style="list-style-type: none">• improved reliability of urban underground distribution networks;• improved safety in utility activities involving construction and operation of underground systems; and• reduced costs associated with planning, designing, engineering, constructing, and operating urban network systems.
P30.006	Urban Network Simulation Tools	

Project Descriptions

P30.005 Urban Network Systems Practices (063279)

Issue

Urban underground network systems are a crucial part of the industry and deliver high levels of reliability and customer service. Underground networks also present challenges, such as high costs for construction and maintenance. Moreover, the loss of experienced engineering staff to mergers and attrition has left many utilities with a gap in the expertise needed for optimal planning, design and engineering, construction, and operation and maintenance of underground network systems.

Description

This project focuses on urban underground network systems. This project produces guidelines and helps members reduce the time, cost, and uncertainty of dealing with network systems. Tasks include the following:

- Provide members with relevant practice information, guidelines, technologies, and training to manage aging network system assets.
- Provide an industry-leading handbook on best practices for underground network systems.
- Develop information to aid in the selection and application of components.
- Ensure safe operations of the network system.
- Develop tools and techniques to identify high-risk components.
- Assess populations of components to determine whether to refurbish or replace them.
- Address the loss of institutional knowledge by providing educational tools for both engineering and field personnel.
- Increase understanding of component aging and life expectancy, resulting in better application and more durable products.

Value

- Improve reliability of urban underground distribution networks.
- Improve safety in utility activities involving construction and operation of underground systems.
- Reduce costs associated with planning, designing, engineering, constructing, and operating urban network systems.

How to Apply Results

Members can use practice and reference guides, best-in-class field guides, job aids, and information

gathered from field demonstrations to manage their aging network assets. With results of this project in hand, end-users will have the ability to enhance safety, improve liability, and lower costs.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Urban Network Systems Practices	12/31/2009	Technical Update

P30.006 Urban Network Simulation Tools (067435)

Issue

Utilities that serve customers using networked secondary systems require technologies to be able to model the system and perform load flow and other circuit analyses on both the primary and networked secondary. Utilities may utilize commercially available load flow products to model their radial systems, but many older products are unable to accurately model and perform analyses on meshed secondary network systems sourced from multiple primary feeders. Consequently, many utilities are using legacy systems to perform network analysis—systems which may lack the ties to GIS systems, graphical display ability, ability to easily analyze “what if” scenarios, ability to reflect real-time system condition changes, and other features of newer, vendor-developed products.

Utilities can benefit from assistance in understanding what vendor products are currently available to model and perform analyses on network systems and what features are contained within these products.

Description

EPRI will research commercially available tools for modeling network systems (primary and secondary) and performing network circuit analyses. EPRI will work with network utilities to develop a desired features list, including attributes such as graphical displays, ability to perform primary feeder fault analysis, ability to perform networked secondary load flows, ability to perform PQ analyses, and interfaces with mapping systems, GIS data, AMI data, CIS data, and SCADA/remotely monitored data to create accurate network models. EPRI will produce a matrix of vendor product offerings with available features that support network planning, design, and operations.

Value

- Research will summarize features that are important to members.
- The research will enable utilities to understand what functionality is available in the marketplace and ascertain whether the features of commercially available products will meet their needs, including secondary modeling and analysis.
- Analysis will result in a matrix that shows features of commercially available products, which will help utilities evaluate vendors and select products.

How to Apply Results

Utility engineers and network system operators will be able to compare the functionality of commercially available products to their specific network analysis and modeling needs. This comparison will help them develop a practical technology implementation strategy and prepare a justification for the investment in a vendor modeling and analysis software implementation and integration. Ultimately, the implementation of network modeling and analysis software will help engineers develop optimum system reinforcement plans to meet capacity and reliability expectations. It will also aid operators in optimally configuring the system based on real-time conditions.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Urban Network Simulation Tools	12/31/2009	Technical Update

PS30C Underground Distribution Technology Transfer and Knowledge Development (067419)

Project Set Description: The EPRI Underground Distribution Technology Transfer and Knowledge Development project set is new in 2009. The goal is to leverage high-impact resources in covering a range of topics relevant to underground distribution systems planners, designers, and operators.

This project set includes Bronze Book development. This project continues the tradition of providing distribution engineers and planners with a reference to underground cable design and construction theory and practical application knowledge. This multiyear project provides new information in a comprehensive reference book that covers all issues of an underground distribution system, from the substation to the service box.

Project Number	Project Title	Value
P30.007	Underground Distribution Reference Guidebook - The Bronze Book	Provides distribution engineers and planners with comprehensive reference to underground cable design and construction theory and practical application knowledge. Benefits include <ul style="list-style-type: none"> comprehensive information on underground distribution systems, and training support for utility personnel.
P30.008	UG Distribution Tech Transfer and Knowledge Development	Utility managers and staff can immediately use the knowledge provided by this project to improve underground distribution system design, maintenance, and troubleshooting practices. The service is provided through a standards exchange and member forum, which allows for easy access to knowledge, discussions, and expert staff.

Project Descriptions

P30.007 Underground Distribution Reference Guidebook – The Bronze Book (062127)

Issue

There has not been an updated reference guide on the topic of underground distribution systems published in the past 20 years. Important topics to include are underground system components and system design, cable designs, cable materials, cable electrical characteristics, lightning effects and arcing, ampacity, diagnostics, component aging phenomena, accessories, corrosion, installation, testing, operation, and maintenance. EPRI is in a unique position to develop and publish such a resource for the industry.

Description

EPRI's Underground Distribution Systems Program has provided a wealth of knowledge in the underground distribution area, from early work on premature failure mechanisms, to the effect of

transients on cables, to advanced diagnostic techniques for determining the condition of underground assets. This project continues the history of providing distribution engineers and planners with a ready reference to underground cable design and construction theory and practical application knowledge.

This multiyear project provides new information in a comprehensive reference book that covers all issues of an underground distribution system from the substation to the service box. The project began in 2006 and is planned to be completed in 2009, covering the topics approved by the Project Advisory Team in the order of priority agreed by the team. The guidebook may include the following features:

- Industry style similar to previous editions
- Presentation of science and technology in the same depth as similar editions
- Expanded coverage of international practices, technology, sources of information such as CIGRE, and use of SI and imperial units
- Oriented to designers and engineers with a training level of at least two years of university training in mathematics and physics
- Presentation style that utilizes advances in electronic media, including integration of software routines and incorporation of video and tutorial material

Value

- Provide comprehensive current information on underground distribution systems
- Support training of utility personnel

How to Apply Results

Covering all aspects of underground distribution from the substation to the service box, this manual will be a reference for practicing engineers and a training tool for new engineers or those transitioning to underground distribution.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
First Edition Underground Distribution Reference Book	12/31/2009	Technical Report

P30.008 UG Distribution Tech Transfer and Knowledge Development (067436)

Issue

Distribution companies face a variety of pressures and technical challenges. Personnel such as utility planners, engineers, and operators must stay familiar with the latest technologies, software tools, standards, and procedures for optimizing distribution system performance.

Description

EPRI's Distribution Knowledge-Based Services cost-effectively supports utility distribution engineering managers and staff with exclusive technical resources, training, and standards information. Subscribers gain access to the best distribution engineering expertise in the industry to deal with specific challenges in a timely manner and stay informed on key technical developments. The project includes the following:

- Standards exchange: A web-based repository of utility design, operations, and maintenance standards in a default PDF format. Members can submit standards and access standards submitted by other utilities. All documents are accessible through a full-text search based on customized queries.

- Member forum: A web-based forum for utilities, with topics covering any issue related to distribution system design and operations, such as equipment problems, maintenance strategies, application of equipment, reliability problems, and more. Members access the forum via a website or email. All messages can be queried with a search engine.
- Updates on important new developments in the industry standards community. Updates on activities in IEEE standards development affecting distribution systems, including reliability standards, distribution equipment standards, and distribution operations standards.

Value

- Increases productivity and technical expertise of utility staff
- Represents utility interests with respect to standards development
- Provides cost- and time-effective updates on industry developments

How to Apply Results

Utility managers and staff can immediately use the knowledge provided by this program to improve distribution system design, maintenance, and troubleshooting practices. The service is provided through a standards exchange and member forum, which allows for easy access to knowledge, discussions, and expert staff.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Subscription to EPRI's Distribution Knowledge-Transfer Electronic Publications And Resources	12/31/2009	Technical Update
