ELECTRIC POWER RESEARCH INSTITUTE

Distribution Cable Fleet Management: Catalog and Assessment of Industry Practices

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Technical Update, December 2010

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Electric Power Research Institute (EPRI)

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NOTE

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ABSTRACT

Utilities are faced with the ever-increasing challenge of providing high reliability from an aging infrastructure of underground distribution cables. Management of this critical asset in the utility system begins with the specification and purchasing of high-quality products and continues with installation, maintenance, operation, diagnostics, and repair or replacement at end of life.

The Electric Power Research Institute (EPRI) is conducting research to identify practices currently being used at utilities for life cycle management of the distribution cable system. This work will identify trends and commonalities across the industry. Industry leading practices will be identified and shared with program funders.

This report describes the results of a survey conducted across the industry, including EPRI program funders as well as other key industry leaders. Participant companies ranged from small rural cooperatives to investor-owned utilities in large metropolitan areas with dense network systems. Results of this research project will be leveraged to develop recommendations for utility cable fleet management programs to help prioritize cable replacement and support proactive asset management.

Keywords
Asset management
Diagnostics
Distribution cable

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1 INTRODUCTION

Background

The underground medium-voltage distribution cable system can be one of the more challenging components of the utility system to maintain and operate at very high levels of reliability. Utilities in large metropolitan areas can easily have tens of thousands of miles of underground cable spread over hundreds of square miles of service territory. Add to this a changing mixture of cable types, often poor records on location and service history, and many assets over 40 years of age.

Diagnostic testing of aging cable systems has the potential to identify problems prior to failure and allow repairs or replacements without service interruption to customers. However, questions remain as to the effectiveness of different test methods applied to one cable type versus another. The equipment or outside service providers can be expensive. These factors make economic justification of systemwide implementation of such programs difficult. In addition, systemwide replacement of cables based solely on age is not economically viable. This raises the question of how to identify those assets in need of repair. Should cable systems be operated in a “run-to-failure” mode as has traditionally been the case?

Strong asset management plans for the underground cable fleet must start with specifying and purchasing high-quality cable products. Incoming inspections can ensure that standards are met. The cables and accessories must be properly installed and, if possible, tested prior to service to avoid early failures resulting from defects or poor workmanship. Following this, an understanding of local and industrywide failure rates and failure mechanisms for various cable types, combined with effective diagnostics, will enable prioritization of repair and/or replacement programs within available budgets.

The Electric Power Research Institute (EPRI) is conducting research to develop guidelines and identify outstanding industry practices for the overall management of this system asset. The first step in this process is an industry survey to better understand current practices in the overall life cycle management of underground distribution cable systems. EPRI is looking for outstanding and notable programs and processes that may be shared or highlighted.

This report describes Phase One in a multiyear project to develop cable asset management guidelines. An industry survey was conducted to gather information related to current industry practices for total life cycle management of underground cable systems. Results of the survey are discussed.

Survey Structure

The survey is divided into six parts: 1) general, 2) procurement, 3) installation and maintenance, 4) diagnostics, 5) planning, analysis, and costing, and 6) case studies. The intent is to understand the cable system management and implementation process at each utility. This covers all aspects of planning, purchasing, installing, operating, and maintaining underground medium-voltage cables.

The response format is a mixture of buttons, drop-down lists, and free text. This allows participants to elaborate as appropriate on key topics such as rejuvenation, diagnostics, and costing.

In many cases, personal follow ups were made with respondents for elaboration of key points.

The survey was conducted using the online tool www.surveymonkey.com.

Survey Responses

Fourteen “complete” responses to the survey were received. “Complete” responses are considered those with a majority of the questions completed. In a few cases, survey responses included answers to only three or four questions. These responses were also included in the statistics reported here.

In questions 1 and 2, the free responses are paraphrased and tabulated to determine the number of repetitions for similar responses.

Any responses that included the utility’s name were edited to remove the identity of the respondent in order to provide an anonymous data set.

Acronyms and Abbreviations Used in This Report

ac	alternating current
AEIC	Association of Edison Illuminating Companies
Al	aluminum
BU	business unit
CBM	condition-based maintenance
CDFI	Cable Diagnostics Focused Initiative
CEC	Cable Engineering Committee (of AEIC)
CIC	cable-in-conduit
CN	concentric neutrals
CPUC	California Public Utilities Commission
CSA	Canadian Standards Association
Cu	copper
CU	construction units
dc	direct current
DCA	detailed condition assessment

EPR	ethylene propylene rubber
HIPOT	high-potential
HMW	high molecular weight
HMWPE	high-molecular-weight polyethylene
ICEA	Insulated Cable Engineers Association
LCT	longitudinal corrugated tape
LLDPE	linear low-density polyethylene
MH	manhole
MOV	metal-oxide varistor
MU	macro units
NEETRAC	National Electric Energy Testing Research and Applications Center
NESC	National Electric Safety Code
O&M	operations and maintenance
OH	overhead
PD	partial discharge
PILC	paper-insulated lead-covered
PUC	Public Utilities Commission
RUS	Rural Utilities Service
TDR	time domain reflectometry
TRXLPE	tree-resistant cross-linked polyethylene
UD	underground distribution
UG	underground
URD	underground residential distribution
VLF	very low frequency
XLPE	cross-linked polyethylene

2
SURVEY RESULTS

Section 1: General

Question 1

What are the three (3) questions you would like answered in this peer comparison survey? Put it another way: If I were to come back to you in six (6) months with a completed peer comparison survey, what would be the three areas that would be most beneficial for you to read? What would you pay for? (See Table 2-1.)

Table 2-1
Desired Outcomes from Survey

Response	Number of Responses
Cable replacement strategy—criteria and prioritization	7
Type and design of cables used; criteria for selection	6
Diagnostic testing techniques and technologies	5
Cable injection/rejuvenation—effectiveness	5
PILC replacement implementation	3
Failure rates by cable type	2
Protection measures for cable (MOV arresters, sacrificial anodes, and so on)	2
Economic justification of replacement programs	1
Cable injection/rejuvenation—economic justification of program	1
How to determine effective cable age without system data	1
How purchasing decisions on designs and suppliers are made	1
How to locate a shared trench	1
Transition joints—PILC to solid dielectric	1
Grounding methods	1
Best practice for fleet management	1
Fault location	1

Question 2

If we were to conduct an industrywide data-gathering survey on cable failures, what variables would you be interested in? (See Table 2-2.)

Table 2-2
Variables of Interest

Response	Number of Responses
Cable type	12
Average age (age at time of failure)	11
Environment/conditions for installation (direct bury, duct)	8
Root cause of failure	7
Loading	4
Manufacturer	4
Cost per failure	1
Length of outage	1
Failures after injection	1
Lightning protection	1
Water treeing	1
Neutral condition at time of failure	1
Splice-cable combinations used	1

Question 3

Is there a "set aside" mandated by your local commission for underground projects? What is the amount/percentage of revenues? (California: CPUC 1–2% of revenues). Are there other ways of funding this?

- 100% = no PUC mandate
- 1 response = city mandate for new construction

Question 4

How many miles of primary distribution class underground cables do you currently have system wide? Could you provide a breakdown by voltage? Break down by cable type (HMWPE, XLPE, TRXLPE, EPR, PILC)? (See Table 2-3 and Figures 2-1 and 2-2.)

Table 2-3
Total Quantity of Cable Covered by Survey

Metric	Miles
Total miles reported	2,099,760
Average per utility	161,520
Median value	6,111

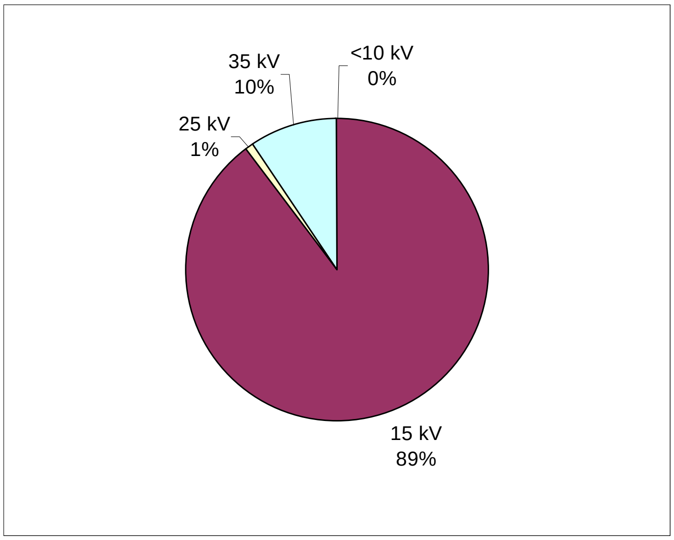

Figure 2-1
Cable Breakdown by Voltage

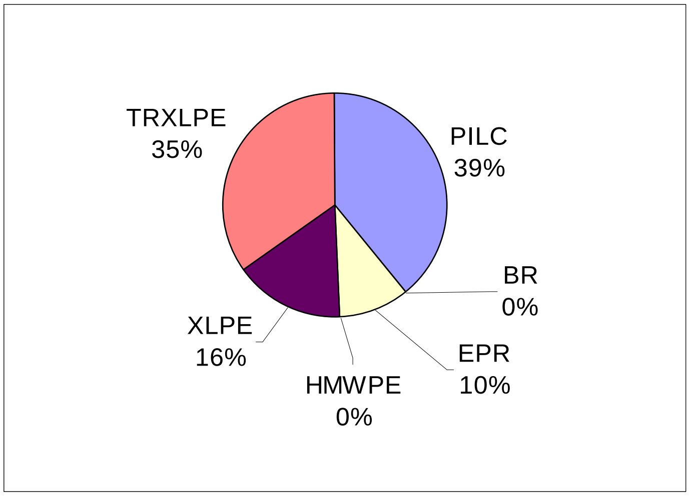

Figure 2-2
Cable Breakdown by Insulation Type

Question 5

What is the size of your underground distribution business unit? What is your annual budget? Number of employees? Number of contractors? (See Table 2-4.)

Table 2-4
Size and Makeup of Distribution Business Unit

Response Number	Size of Underground Distribution Business Unit	Annual Budget	Number of Employees	Number of Contractors
1		$15–20 million	40	0
2	We are a cooperative and not split up in OH and URD business units.			
3	Not sure what you are asking.	$286 million	450	0
4	No separate business unit.	Included in electric distribution improvement budget	6 dedicated to work with UD power cables	None for underground distribution
5	Business unit is split between other areas of company.	?	Underground crew only: 60	20 in addition to 60 crew
6			54	0
7	Not divided by OH and UG; numbers reflect total distribution BU.	$500 million	3500	400
8	No separation in business units.			
9	Medium.	$31 million	54	15
10	Not a separate unit.			

Table 2-4 (continued)
Size and Makeup of Distribution Business Unit

Response Number	Size of Underground Distribution Business Unit	Annual Budget	Number of Employees	Number of Contractors
11	Only one in company.	Unknown	8 engineering; 40 line	Varies
12	The following supports the UG Cable Asset Management Program.	$9 million	15	
13	We have two field groups: one dedicated for PILC and manholes with mixed PILC and XLPE. The other group can only do manholes containing only XLPE cables.	For maintenance (O&M and capital) $20 million	Approximately 50 people doing underground distribution work	18
14	Construction and Maintenance Department is the business unit.	$15,790,000 for corrective and preventive maintenance	27	None

Question 6

What is your estimate of OH versus UG primary distribution on your system (historical, not planned new construction)? (See Figure 2-3.)

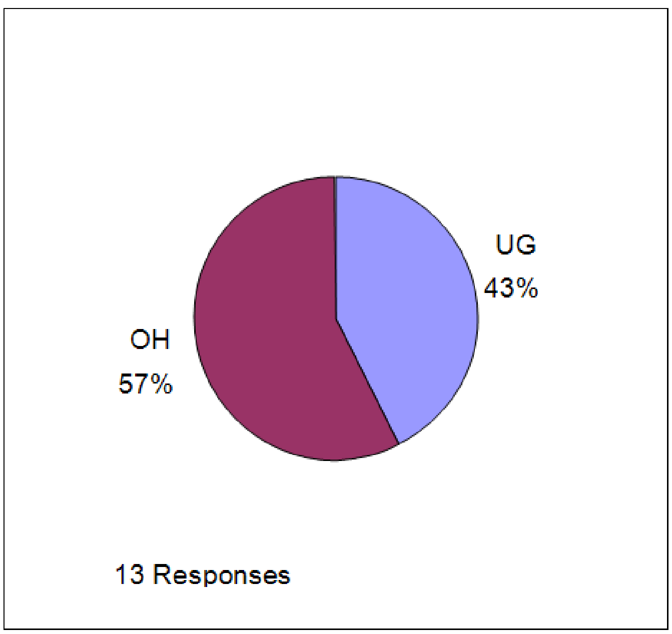

Figure 2-3
Breakdown of Historical Overhead Versus Underground Distribution

Question 7

Do you face the challenge of PILC replacement—reduced diameter ducts that dictate special cable designs for replacement of aging infrastructure? (See Figure 2-4.)

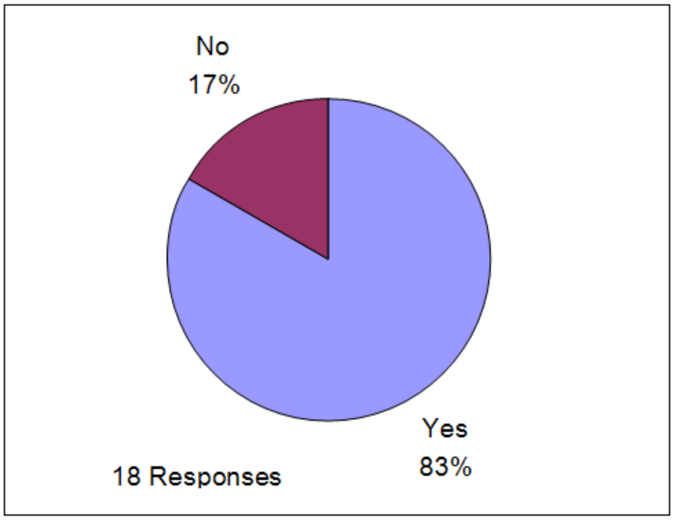

Figure 2-4
Percentage Facing Paper-Insulated Lead-Covered Replacement Challenges

Section 2: Procurement

Question 8

Do you work with other infrastructure providers (cable/telephone/gas, and so on) to co-locate UG cable and minimize the cost of installing this infrastructure? What is the division in costs? (See Figure 2-5.)

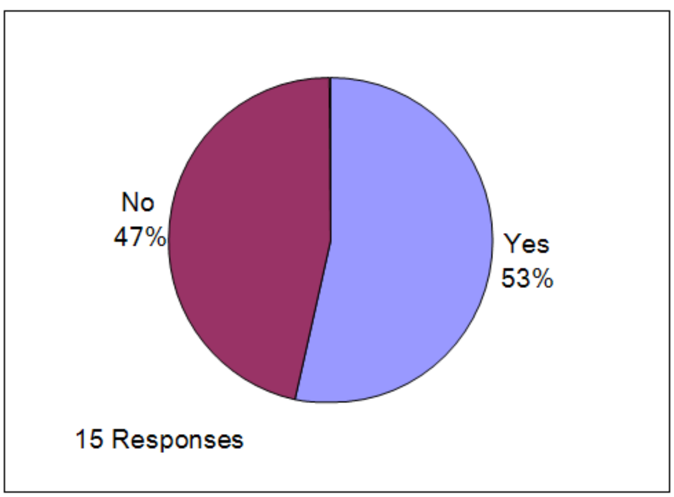

Figure 2-5
Percentage Working with Other Infrastructure Providers for Co-Location

Question 9

What industry specifications do you use and follow? AEIC CEC? ICEA? Other? (See Figure 2-6 and Table 2-5.)

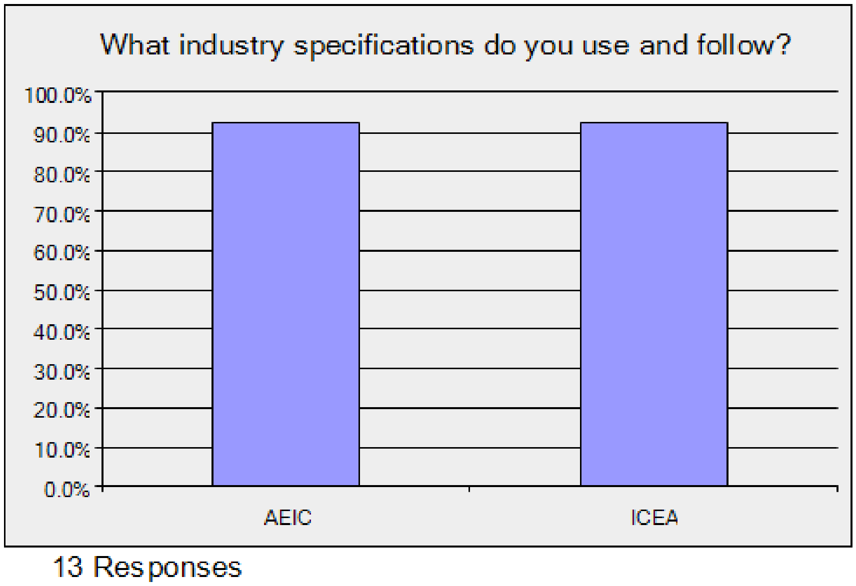

Figure 2-6
Industry Specifications

Table 2-5
Comments on Cable Specifications

Additional Comments
Utility spec supersedes both in certain areas.
IEEE.
We have our own Material Standards Specs as well.
IEEE, CSA.

Question 10

Explain your design and planning criteria in the selection of new underground cables and accessories. (See Table 2-6.)

Table 2-6
Design and Planning Criteria for New Underground Cables and Accessories

Response Number	Response
1	For 15 kV we use 750 and #2. For 25 kV we use 1000 and 1/0 and for 35 kV we use 750/1000 and #2/1/0.
2	TRXLP on #2 and 1/0, EPR on 500 and 750 mcm we use #2 in all residential developments and 1/0 three phase in all commercial development. No 4/0 URD is used. 750 mcm on main feeders and 500 mcm on branches.
3	We install 750 kcmil Cu with 220 mil EPR insulation and jacketed concentric neutrals between the substation transformer and 12 kV breakers. We install 1/0, 3/0, 750 kcmil and 1000 kcmil Al, 220 mil TRXLPE, concentric neutral, jacketed cable with no moisture blocker in the conductor or under the jacket. We generally use cold shrink splices and terminators with premolded elbows. All padmounted switchgear is live front.
4	Compatibility with existing equipment/materials, adequate to meet current/future needs, economy of installation, cost evaluations, field evaluations, and environmental issues.
5	Load capabilities of the cables' conductors and the voltage of the circuit.
6	We have developed material standards specs for this material and as long as a manufacturer meets our specs, they are allowed to quote the material.
7	We have a set specification for our URD and feeder cables. URD cables are all the same size, and there are several sizes to choose from on feeder cables.
8	Voltage and amperage and materials.
9	Based on application and expected load of the circuit.
10	Must be suitable for placement in conduit in a wet environment. Rated for 200 A for tap circuits and 600 A for feeder circuits.
11	For new installation (that is, subdivisions), use UG. Downtown is currently reconfigured (underground) for 100% PILC feeders: - If a segment (MH to MH) is recommended for replacement, the segment is replaced with PILC. Mixed PILC and XLPE cables: - If segments of PILCs are assessed to be defective, we replace those defective portions with XLPE as long as there is space for transition splice (not congested) and duct size is not a constraint. - If the defective segments are located on a slope, use XLPE as long as there is enough space for transition splice (not congested) and duct size is not a constraint.

Table 2-6 (continued)
Design and Planning Criteria for New Underground Cables and Accessories

Response Number	Response
12	New cables must meet internal cable specifications and ampacity requirements. Accessories are chosen based on manufacturer's technical specs, references and recommendation from other users, and conformance to national standards.
13	TRXLPE insulated cables are used for all direct-buried cable installations. Premolded splices are used with these cables. Both EPR and TRXLPE insulated cables are used in our manhole and duct system. The EPR insulated cables are used to replace PILC cables. The TRXLPE insulated cables are used for the remaining applications. Cold shrink splices are used to join solid dielectric to solid dielectric cables. Heat shrink splices are used to join solid dielectric cables to PILC cables.

Question 11

Please complete the table for standard cable products purchased for your system. (See Tables 2-7 and 2-8.)

Table 2-7
Standard Cable Products

Conductor	Moisture Block	Insulation Type/Level	Voltage Class	Shield Type	Configuration	Neutral Size	Neutral Configuration	Number of Hits
Cu	Yes	EPR: 133%	15	Regular	3/c parallel	1/3	Concentric wires	1
Al	Yes	EPR: 133%	25	Regular	3/c parallel	1/3	Concentric wires	1
Cu	Yes	PILC	15	Regular	3/c parallel	Other	Lead sheath	1
Al	Yes	TRXLPE: 133%	15	Super smooth	1/c	Full	Concentric wires	1
Al	Yes	EPR: 133%	15	Super smooth	1/c	Full	Concentric wires	1
Cu	No	EPR: 133%	15	Regular	1/c	1/6	Concentric wires	1
Al	No	TRXLPE: 133%	15	Super smooth	1/c	1/6	Concentric wires	1
Al	No	TRXLPE: 133%	15	Super smooth	1/c	Full	Concentric wires	1
Al	No	TRXLPE: 133%	15	Regular	1/c	Full	Concentric wires	1
Cu	No	EPR: 100%	15	Regular	3/c parallel	Full	Flat straps	1
Cu	No	EPR: 133%	15	Super smooth	3/c plexed	Other	Tape	1
Al	No	EPR: 133%	15	Super smooth	3/c parallel	Other	Tape	1

Table 2-7 (continued)
Standard Cable Products

Conductor	Moisture Block	Insulation Type/Level	Voltage Class	Shield Type	Configuration	Neutral Size	Neutral Configuration	Number of Hits
Al	Yes	TRXLPE: 100%	15	Super smooth	1/c	Full	Concentric wires	4
Al	Yes	TRXLPE: 100%	25	Super smooth	1/c	Full	Concentric wires	1
Al	Yes	TRXLPE: 100%	25	Super smooth	1/c	1/6	Concentric wires	1
Cu	Yes	TRXLPE: 100%	25	Super smooth	1/c	Other	Concentric wires	1
Cu	Yes	TRXLPE: 100%	15	Regular	1/c	Other	Flat straps	1
Cu	Yes	TRXLPE: 100%	25	Regular	1/c	1/6	Flat straps	1
Cu	No	EPR: 133%	15	Regular	1/c	1/3	Concentric wires	1
Cu	No	PILC	15	Regular	3/c with jacket	Other	Lead sheath	1
Al	No	EPR: 133%	25	Regular	3/c parallel	1/3	Concentric wires	1
Cu	No	EPR: 133%	35	Regular	3/c parallel	1/3	Concentric wires	1
Al	Yes	EPR: 100%	15	Regular	1/c	Full	Concentric wires	2
Al	Yes	EPR: 100%	15	Regular	3/c plexed	1/3	Concentric wires	1
Cu	No	EPR: 100%	15	Regular	3/c plexed	1/3	Concentric wires	1
Cu	No	EPR: 100%	15	Regular	3/c plexed	1/3	LCT	1
Cu	No	EPR: 100%	35	Regular	3/c plexed	1/3	LCT	1
Al	Yes	EPR: 100%	15	Regular	3/c parallel	1/3	Concentric wires	1
Cu	Yes	EPR: 100%	15	Regular	3/c parallel	Full	Flat straps	1
Al	Yes	EPR: 100%	35	Regular	3/c parallel	1/3	Concentric wires	1
Cu	Yes	EPR: 100%	35	Regular	3/c parallel	Full	Flat straps	1
Al	Yes	TRXLPE: 100%	15	Regular	3/c with jacket	1/3	Concentric wires	1
Al	Yes	TRXLPE: 100%	35	Regular	3/c with jacket	1/3	Concentric wires	1
Al	Yes	TRXLPE: 100%	15	Regular	3/c plexed	1/6	Concentric wires	1

Table 2-7 (continued)
Standard Cable Products

Conductor	Moisture Block	Insulation Type/Level	Voltage Class	Shield Type	Configuration	Neutral Size	Neutral Configuration	Number of Hits
Al	Yes	TRXLPE: 133%	15	Regular	3/c plexed	1/6	Concentric wires	1
Cu	Yes	EPR: 100%	15	Regular	3/c plexed	1/6	Flat straps	1
Al	Yes	TRXLPE: 100%	25	Regular	3/c parallel	1/6	Concentric wires	1
Al	Yes	TRXLPE: 100%	15	Super smooth	3/c plexed	1/3	Concentric wires	1
Cu	No	EPR (reduced)	15	Super smooth	3/c plexed	1/6	Flat straps	1
Al	Yes	TRXLPE: 100%	35	Super smooth	3/c plexed	1/3	Concentric wires	1
Cu	Yes	TRXLPE: 100%	15	Super smooth	3/c plexed	1/3	Concentric wires	1

Table 2-8
Cable Design Option Response Percentages

Parameter	Option	Response Percentage
Conductor material	Al	58%
	Cu	42%
Moisture block	Yes	67%
	No	33%
Insulation	EPR	49%
	PILC	4%
	TRXLP	47%
Insulation level (solid dielectric)	100%	67%
	133%	33%
Voltage	15 kV	71%
	25 kV	16%
	35 kV	13%
Conductor shield	Regular	62%
	Super smooth	38%

Table 2-8 (continued)
Cable Design Option Response Percentages

Parameter	Option	Response Percentage
Configuration	1/c	40%
	3/c parallel	27%
	3/c plexed	27%
	3/c with jacket	7%
Neutral size	1/3	36%
	1/6	20%
	Full	31%
	Other	13%
Neutral configuration	Concentric wires	71%
	Flat straps	16%
	LCT	4%
	Lead	4%
	Tape	4%

Question 12

What is the reel type for the cable products purchased for your system (wood: non-returnable; steel: returnable)? (See Figure 2-7.)

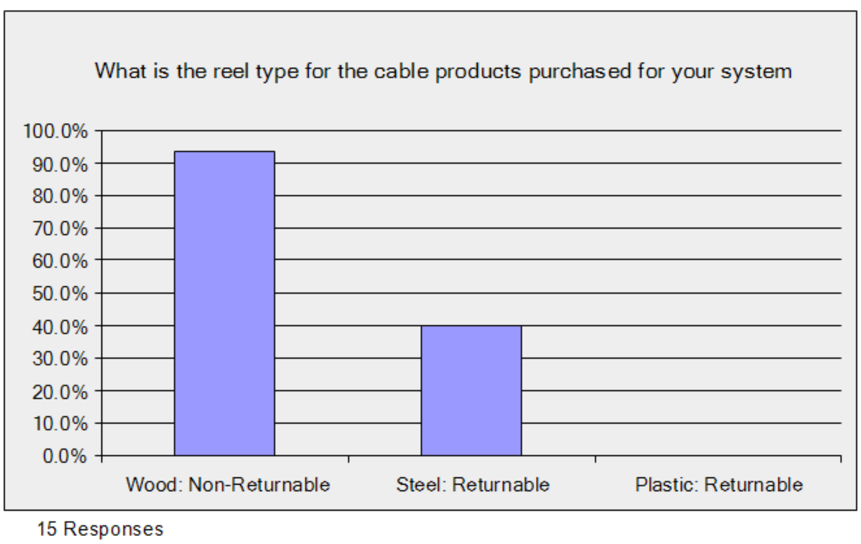

Figure 2-7
Reel Type Usage

Question 13

What has been the trend in your utility regarding the types of cable you are purchasing over the last decade? (See Table 2-9.)

Table 2-9
Trends in Cable Purchases

Response Number	Response
1	We have predominately purchased EPR with some PILC on the system.
2	We have been purchasing the same design cables for the last 20 years. We have approved insulation suppliers other than Dow Chemical in the past couple of years.
3	Al, no moisture block, 133% TRXLPE, supersmooth shields, encapsulated round concentric neutral wires, LLDPE insulating jacket.
4	The majority of the purchases are jacketed concentric neutral direct-bury 15 kV cables with XLP insulation.
5	TRXLPE insulation only. Added reduced diameter cables for PILC cable replacement. Just began to reduce the amount of PILC being purchased.
6	Use TR-XPLE for everything except 500 mcm; then we go to EPR strictly for the flexibility.
7	The specification has remained the same for the last decade and some time before. We use only one vendor. During the last decade, we began installing larger feeder cables: 500 mil and 750 instead of 250 and 500.
8	All cables are EPR jacketed. CN wires are encapsulated, and aluminum conductors have water blocking.
9	Reducing types and streamlining purchases.
10	For the last 10 years, the standard was TRXLPE for #2, 1/0, 350 kcmil and 1000 kcmil. In January of 2007, we started using EPR for 1000 kcmil feeder cables.
11	TRXLPE.
12	The majority is TRXLPE. EPR is reduced diameter design for PILC replacement.
13	Purchases of cables have stabilized over the last decade. EPR insulated cables are used for PILC cable replacements, and TRXLPE cables are used for all other primary cable applications.

Question 14

What is the approval process for qualifying new vendors (plant inspections, qualification test report review, samples, and so on)? (See Table 2-10.)

Table 2-10
Vendor Approval Process

Response Number	Response
1	We review the manufacturing and supply capabilities. We require a local distributor and stocking. We visit the factory and review production (this step has eliminated a couple of vendors). We talk with other users of the cable. We review qualification test reports and talk with the manufacturer's engineering department.
2	Must meet internal cable spec, plant inspections, and qualification report.
3	Samples, references, test reports.
4	Plant inspection, qualification test report review, certified test report review, analysis of samples similar to cable to be purchased, trial installation period of six months.
5	Sometimes we do plant inspections; otherwise we depend on test reports, and we send samples into an independent testing lab.
6	Qualification test report review, samples, and asking other utilities.
7	We have a detailed approval procedure that includes product evaluation, plant evaluation, user input, manufacturing records, and test data.
8	Check user references and review their certified test reports as well as obtain and evaluate samples.
9	Plant inspections, qualification test report review, and ability to supply the required lengths and specifications.
10	Samples, design drawings, conformance to internal spec, list of other utility users, reference letters, test installation on local system.
11	1. Plant inspections. 2. Approvals by other utilities. 3. All cables are bought from U.S. companies.

Question 15

Does your utility have set guidelines on the application of EPR versus TRXLPE cables on feeder or branch circuits? (For examples, 1) all feeders are EPR and branches are TRXLPE, 2) 100% TRXLPE, 3) 100% EPR, or 4) geographical—preference of operating company.) (See Table 2-11.)

Table 2-11
EPR Versus TRXLPE Usage Guidelines

Response Number	Response
1	No guidelines; we use only EPR or PILC on all URD and feeder applications.
2	Developments have TRXLPE #2 (residential) and 1/0 commercial. All mainlines have EPR 500 and 750 mcm.
3	Substation transformer to 12 kV substation breakers is EPR. All other cables are 133% TRXLPE.
4	No.
5	100% TRXLPE on the system.
6	100% EPR.
7	We use only EPR cables.
8	We have a mix of all of those listed. Typical installations are EPR exits to a riser pole then OH. Subdivisions are typically TR-XPLE; networks vary depending on location.
9	Feeders are EPR, and branches (taps) are TRXLPE.
10	We only use TRXLPE.
11	No.
12	No. EPR is used for all PILC replacements, and TRXLPE is used for all other primary cable applications.

Question 16

What is the revision date of your company's cable purchasing specification? (See Figure 2-8.)

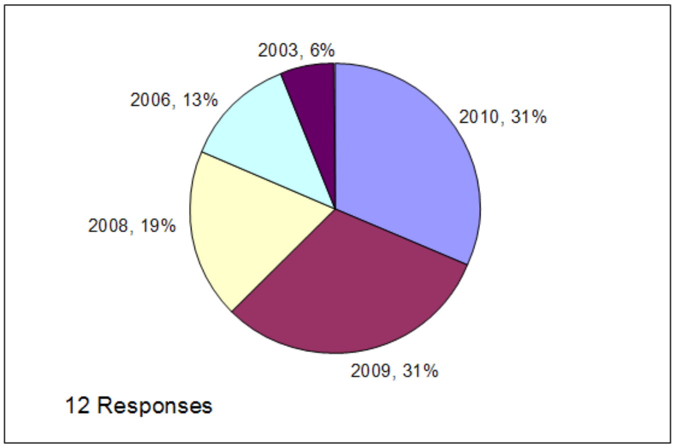

Figure 2-8
Purchasing Specification Revision Date

Section 3: Installation and Maintenance

Question 17

What percentage of cable installation is performed by in-house crews versus contracted? (See Figure 2-9.)

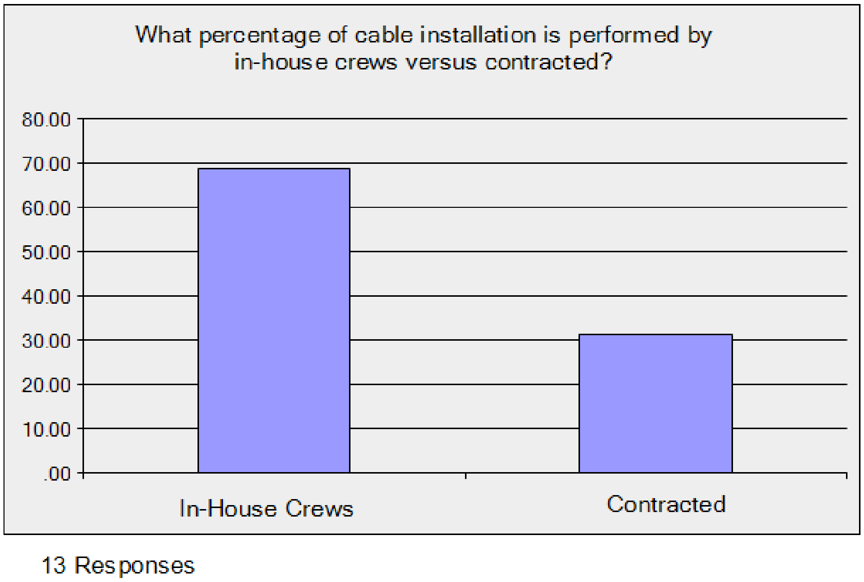

Figure 2-9
In-House Versus Contracted Crews for Installation

Question 18

Do you install primary cable in conduit or direct-bury? What has been the trend over the past decade? (See Figure 2-10 and Table 2-12.)

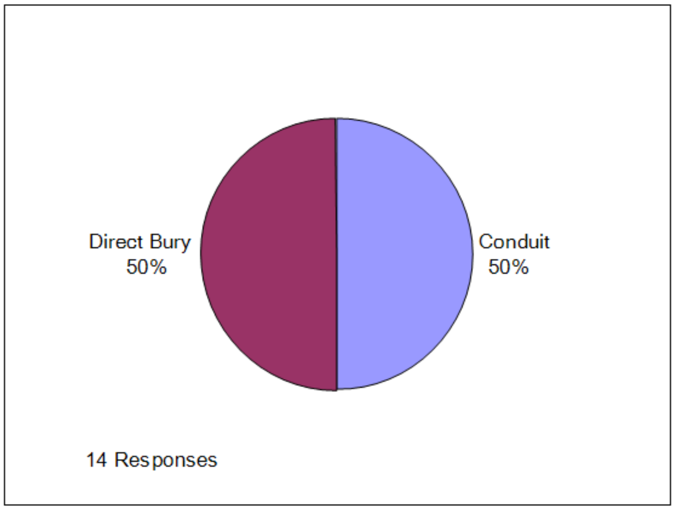

Figure 2-10
Conduit Versus Direct Bury

Table 2-12
Installation Trends

Response Number	Response
1	We now install all residential in conduit (last 3 years). The rest is still direct buried.
2	In URDs we direct bury the cable with a spare polyethylene smoothwall conduit. We like to have the ability to dig up and repair the direct-buried cable. The spare conduit is for future circuit replacement.
3	The majority is direct bury.
4	Both. Only direct-bury residential and small commercial development. Everything else in conduit.
5	All conduit, no direct buried.
6	100% direct bury.
7	We have installed cable in conduit consistently for the last decade and before.
8	We still direct bury in some locations, but the trend is toward using conduit.
9	This depends on whether you are talking about exit cable or subdivisions. Exits are almost always duct; subdivisions are almost always direct bury.
10	Installed direct-buried unjacketed cable until 1988, then switched to jacketed cable in conduit. Between 1988 and 1993, there was still a small amount of unjacketed cable used as well as direct-buried jacketed cable. By 1993, all cable was jacketed and installed in conduit.
11	Direct buried has not been allowed since 1975.
12	Cable is installed in conduit and direct buried, depending on the location. The survey would not allow both choices.

Question 19

Do you utilize cable-in-conduit (CIC) product offerings? (See Figure 2-11.)

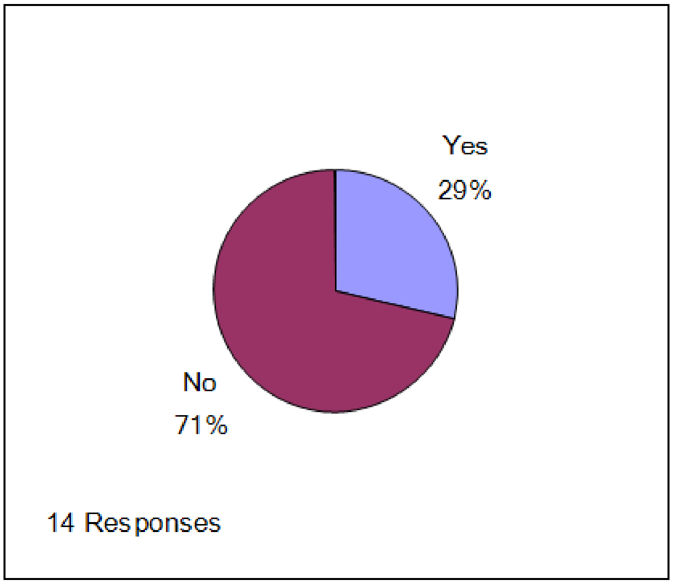

Figure 2-11
Use of Cable-in-Conduit

Question 20

Do you undertake trenchless digging? What percentage is trenchless currently? Do you own your own equipment for trenchless work? (See Table 2-13.)

Table 2-13
Use of Trenchless Digging

Question	Yes	No	Response Count
Do you undertake trenchless digging?	10	5	15
Do you own your own equipment?	4	8	12
What percentage is trenchless?			10
		Answered question	**15**

Average percentage trenchless of 10 responses = 44%

Question 21

What kind of cable joint technology do you use (bitumen, heat shrink, tape resin, premolded/slipover, cold shrink resin, cold shrink hybrid, and so on)? (See Table 2-14.)

Table 2-14
Cable Joint Technology Implemented

Answer Options	Response Percent	Response Count
Bitumen	0.0%	0
Heat shrink	69.2%	9
Tape resin	7.7%	1
Premolded/slipover	61.5%	8
Cold shrink resin	23.1%	3
Cold shrink hybrid	46.2%	6
Other (please specify): • Heat shrink and tape resin for PILC cables only • Prysmian Elaspeed cold shrink • Disconnectable • 3M cold shrink		4

Question 22

Do you have an “incoming” cable inspection program? What is it? What does it involve? In-house or third party? (See Table 2-15.)

Table 2-15
Incoming Cable Inspection Program Responses

Response Number	What Is Your “Incoming” Cable Inspection Program?	What Does It Involve?	In-House or Third Party?
1	We send samples to NEETRAC; the number depends on amount of cable in the batch.		
2	Remove end caps and visually inspect all reels. Dissect 20% of reels.	Dissect, slinky, strip test, and dimensional analysis.	In-house
3	No.		
4	Inspect 100% of medium-voltage cable shipping reels.	Physical inspection and measurements and microscopic inspection of wafers.	In-house

Table 2-15 (continued)
Incoming Cable Inspection Program Responses

Response Number	What Is Your "Incoming" Cable Inspection Program?	What Does It Involve?	In-House or Third Party?
5	Visual—have samples sent to a testing facility.	Test samples to make sure they meet specifications.	Both
6	Visual only.	Look for damage, and verify that product is correct.	
7	Barely; it is something we are looking at changing.	Cutting off a few feet of cable; send it to the lab—not all reels, only a sampling.	In-house
8	Integrated approach of detailed condition assessment (DCA).	Leakage current, TDR, partial discharge.	In-house and utilize our subsidiary company
9	No formal inspection program.	Visual inspection by Receiving.	In-house

Question 23

When you undertake rejuvenation of cable, what methods do you use? What method have you learned from experience to avoid? (See Table 2-16.)

Table 2-16
Rejuvenation Experiences

Response Number	Methods Used	Methods to Avoid
1	Cable injection for URD.	N/A
2	All of our cable is strand filled for the last 40 years so can't do this.	
3	Don't use.	
4	Analyze cables before injection. Minimum percentage of concentric neutral required. Maximum number of joints per foot of run before injection.	
5	No rejuvenation done.	
6	"Low pressure" cable injection with a soak period (that is, UtilX CableCURE, Novinium, and so on).	None
7	UtilX.	All
8	Cable injection (UtilX was low bid, so we are using CableCURE).	
9	We only inject submarine cables; we use Novinium.	
10	No rejuvenation since 2002.	
11	None currently.	

Question 24

Do you mark your cables in some fashion to distinguish them from telecommunication cables? What marking method do you use? (See Table 2-17.)

Table 2-17
Cable Marking Techniques

Response Number	Marking Method Used
1	Most of our cables are installed in conduit. Depending on the type of conduit used (flex pipe, for example), this would have to have a black with red stripe down the length. In cases where the cable is direct buried, the outer jacket would have a lightning bolt embedded into the jacket of the cable.
2	NESC required mark on the cable. Tape over the cable trench.
3	Center strand indentation. Jacket has three red stripes and has indented hot foil transfer tape markings per ICEA.
4	NESC lightning bolt symbol only.
5	RUS requires three red strips on the cable.
6	Red stripes.
7	ICEA S-94-649. Power cable symbol.
8	NESC requirement of marking the primary cable with a lightning bolt.

Question 25

Do you perform commissioning tests after installation to verify proper workmanship and performance? (See Figure 2-12.)

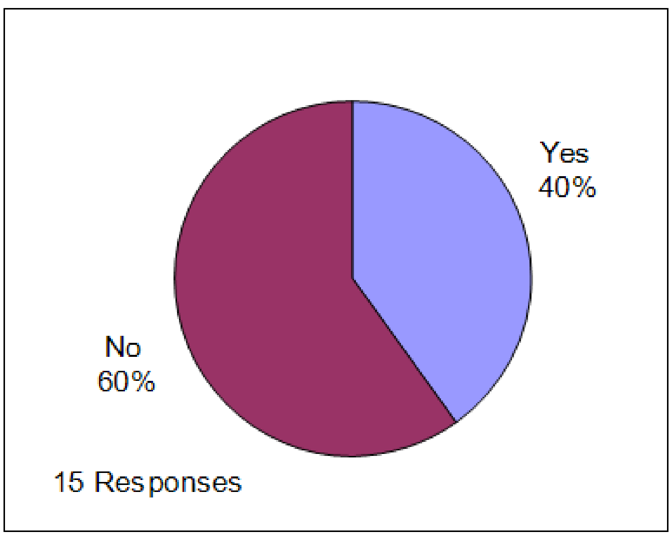

Figure 2-12
Use of Commissioning Tests

Section 4: Diagnostics

Question 26

What is the primary cause of cable failure that you have seen? What is the secondary? (See Tables 2-18 and 2-19.)

Table 2-18
Primary and Secondary Causes of Failure

Response Number	Primary	Secondary
1	Splice	Splice/connector issues
2	Insulation failure	Damage during installation
3	Insulation treeing associated with age and wear	Loss of insulation shield bond
4	Age and environment	Third party and environment
5	Insulation degradation due to water trees	Corroded concentric neutrals
6	Insulation failure probably due to lightning	Damage during installation
7	For feeder cable, splice failure; for URD, water treeing or unknown	Unknown
8	Mechanical damage	Workmanship
9	Workmanship	Accessory failure
10	Treeing	Neutral corrosion
11	Deterioration due to age	Deterioration due to age
12	Service condition (slope or MH is always full of water)	Workmanship or manufacturer's defect
13	Age (fatigue, corrosion)	Mechanical damage

Table 2-19
Consolidated Failure Mode Responses

Failure Mode Response	Percentage
Age (general)	18.5%
Installation/workmanship	18.5%
Splices/joints	14.8%
Water treeing	14.8%
Third-party damage (mechanical)	11.1%
Neutral corrosion	7.4%
Lightning	3.7%
Shield debonding	3.7%
Service conditions (water)	3.7%
Unknown	3.7%

Question 27

Can you assign percentages to the following causes: weather and environment, third party, age and wear, no fault found, other? Do you have these kinds of criteria when you analyze UG faults? (See Table 2-20.)

Table 2-20
Cause of Failures

Response Number	Joint Failure	Water Ingress	Treeing	Workmanship	Weather and Environment	Third Party	Age and Wear	No Fault Found	Other
1	65	10	5	10				10	
2	35						65		
3	5	10	35	25	5	5	5	10	
4	2	2	46	2	46	2			
5	60	10	10			10	10		
6	19				11	3	63		6
7	45	45	25	30	50	10	40		
8					4		15	3	78

Question 28

For locating cable faults, what method do you use? Do you distinguish between conduit and direct buried? (See Table 2-21.)

Table 2-21
Fault Location Methods

Response Number	Method Used	Distinguish Between Conduit and Direct Buried
1	Thumper/radar/fault wizard	
2	Radar and thumping for final location	If in total conduit, we have not had failure other than dig-ins
3	Time domain reflectometer; then pinpoint with low energy thumper	Direct buried
4	HIPOT and thumper	
5	Thumper with TDR	System maps
6	Radar/thumper: try thumping at the lowest voltage possible	
7	Electronic fault locators, thumper (mostly on feeders)	Cable in conduit is replaced

Table 2-21 (continued)
Fault Location Methods

Response Number	Method Used	Distinguish Between Conduit and Direct Buried
8	Thumper	
9	VLF, tan delta, thumper	No
10	TDR/thumper	
11	dc HIPOT and thumper	No
12	Thumping	No
13	Biddle, Mega Beast, TDR or radar, others	N/A

Question 29

If you use a thumper on solid dielectric cables, how do you limit any damage to the cable? Explain. (See Table 2-22.)

Table 2-22
Use of Thumper

Response Number	Response
1	They gradually increase voltage on the cable.
2	Use radar to find the location, and typically only need one or possibly two thumps to pinpoint the failure.
3	Try to minimize energy and the number of thumps.
4	Keep applied voltage low.
5	Use TDR to limit the number of thumps. Keep voltage at a minimum to still get the cable to thump.
6	Start at the lowest setting and move up (often it's only used to determine if the cable has faulted or not).
7	Limit test voltage.
8	Don't; we are usually trying to fail the cable at that point.
9	Limit voltage to 10 kV.
10	For commissioning, using VLF following IEEE standards.
11	There are no specific procedures to limit cable damage.

Question 30

What kind of degradation analysis do you undertake on your cable fleet? (See Figure 2-13 and Table 2-23.)

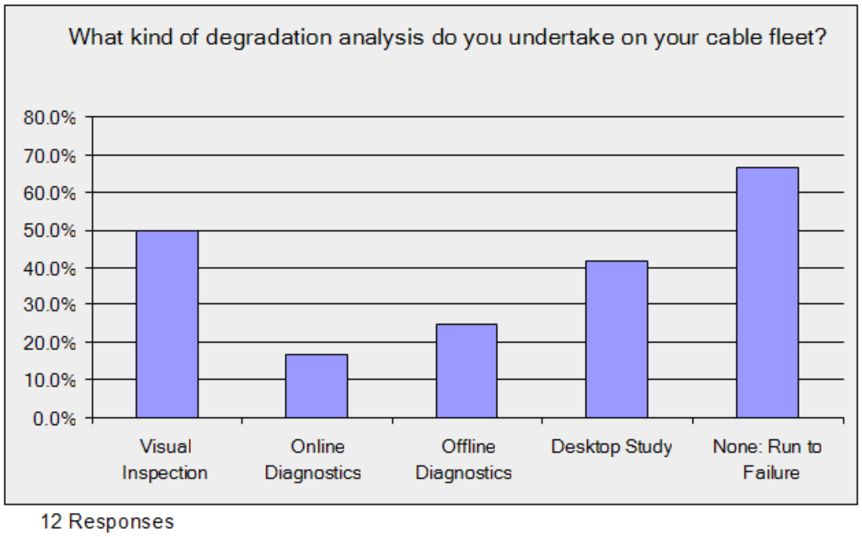

Figure 2-13
Degradation Analysis Used on Cable Fleet

Table 2-23
Comments on Degradation Analysis

Response Number	Response
1	We look at the number of faults for the area/section. Tried physical testing many times; have not found one system that works.
2	We analyze many but not all cable failures to determine the condition of cables before replacement of the cables. We use this data for system analysis. We have tried pilot programs for off-line diagnostics, but never implemented a full program.
3	Only do visual when cable is excavated; otherwise, we run to failure.
4	We are trying to develop a more scientific method to make predictions.
5	We have done some limited off-line diagnostics.
6	Mostly it is run to failure; we are looking into doing life-cycle testing.
7	Periodic VLF ac testing on solid dielectric (off line).
8	Integrated approach.

Question 31

What kind of testing do you undertake on your cable fleet (partial discharge, very low frequency, infrared, and so on)? (See Figure 2-14 and Table 2-24.)

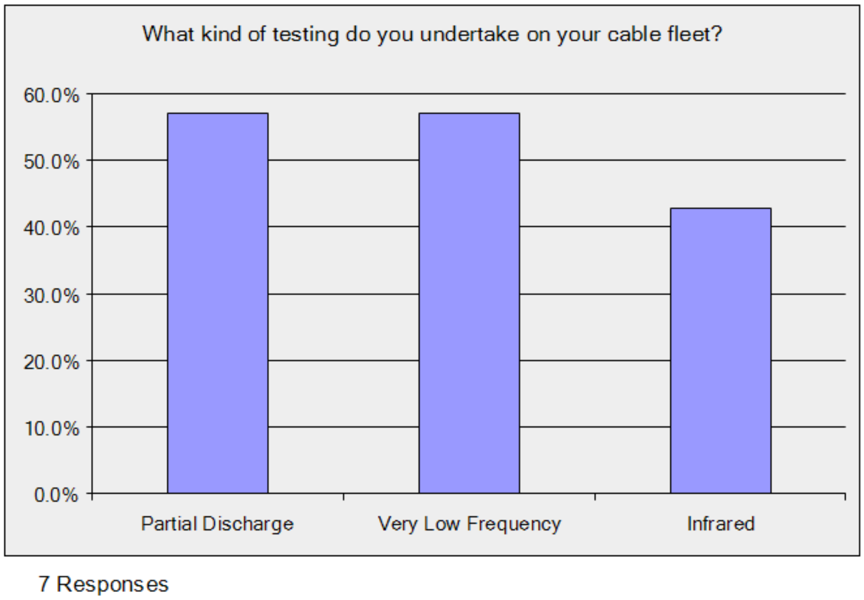

Figure 2-14
Types of Testing Employed on Cables

Table 2-24
Comments on Types of Testing Employed in Field

Response Number	Response
1	Tried partial discharge; did not work at all
2	N/A
3	No regular testing
4	Tan delta
5	Infrared scan for solid dielectric splices only
6	Leakage current for insulation integrity
7	None

Question 32

Do you use a proprietary or off-the-shelf analysis tool to conduct your failure analysis modeling? What off-the-shelf package do you use? (See Table 2-25.)

Table 2-25
Statistical Analysis Tools Employed

Response Number	Response
1	Proprietary analysis tool.
2	Database statistical analysis. We do not have complete data.
3	In-house Microsoft Access database of failures.
4	In house.
5	None.

Question 33

Do you use only your own data on failures or industrywide (external) data? (See Table 2-26.)

Table 2-26
Use of Internal or Industrywide Failure Data

Answer Options	Response Percent	Response Count
Own data	100.0%	11
Industrywide (external) data	9.1%	1
	Answered Question	**11**

Question 34

What additional diagnostic equipment are you most in need of? (See Table 2-27.)

Table 2-27
Desired Diagnostic Equipment

Response Number	Response
1	Something that doesn't give false positives and false negatives. We do not have confidence in any equipment currently available.
2	Company-owned and -operated diagnostic equipment—VLF probably.
3	A technology which could successfully detect that a cable is close to failure.
4	Accurate fault locating.
5	On-line monitoring.
6	Accurate and practical PD tool.
7	Equipment that can safely and accurately detect failures before they occur without deenergizing.

Section 5: Planning, Analysis, and Costing

Question 35

Do you have a cable replacement program? Please explain. (See Table 2-28.)

Table 2-28
Cable Replacement Programs

Response Number	Response
1	Only for URD applications. Third failure and cable segment is replaced.
2	Yes, we are replacing based on the number of customers affected and the number of faults for the area. We budget a fixed dollar amount for the year, and the cable replacement team decides which areas to spend the dollars on. We watch the number of URD cable faults on the system and raise or lower the dollars to keep the annual number of faults level.
3	At this point we have not experienced escalating, wide-scale failures. We do not have a replacement program, but we do have a well-developed replacement guideline.
4	Yes, our cable program is based on performance (failure rates), condition of the infrastructure, and loading (current and expected).
5	Yes, but only for cable that has failed. We sometimes will replace an entire subdivision if warranted.
6	Yes. If a section of cable fails more than three times in two years, it gets replaced.
7	Yes. For residential distribution (laterals), we have both a reactive and proactive cable replacement program budgeted each year. Reactive replacement replaces cable segments after two or more failures based on systemwide prioritization. Proactive replacement replaces entire laterals or groups of cables that are high risk.
8	Replaced based on the number of failures during a period of time.

Table 2-28 (continued)
Cable Replacement Programs

Response Number	Response
9	Yes, for URD. When budgets permit, we do exit cable.
10	We have approximately 1000 miles of direct-buried unjacketed cable that we are replacing and injecting at a rate of 20 miles per year for replacement and 40 miles per year for injection.
11	Yes. Asset Management sets cable replacement goals. 2011 is 10 miles/year.
12	Yes, we have a condition assessment to identify the cables to replace. The cables are prioritized based on service condition, loading number of faults, and customer importance. The assessment technique is an integrated approach of electrical, visual, and mechanical tests.
13	Replace feeder main sections within 24 months after two faults due to insulation failure. Replace 350 kcmil XLP after one fault. Replace tap sections within 24 months after three faults. Replace #2 HMW after two faults. Replace cables with missing concentric neutrals.

Question 36

Do you have a rule of thumb when it comes to cable replacement? When do you rejuvenate, and when do you replace? What are the criteria? What factors do you use? (See Table 2-29.)

Table 2-29
Replacement and Rejuvenation Issues

Response Number	Rule of Thumb	When Do You Rejuvenate and Replace	Criteria	Factors
1	Third failure on URD only.	Rejuvenate if stranded and has low failure numbers. Replace third failure and beyond.		
2	Three faults in the last 5 years.	Always replace.	Three faults in the last 5 years tend to trigger replacement.	Number of customers affected.
3	Replace cable between two pieces of equipment if the failed sample has trees or other serious flaws. Also replace if it is the second failure between the same two pieces of equipment.	We never rejuvenate; we always replace (based on test installations and analysis conducted several years ago).	If there have been three or more years between the first and second failure, the cable is not replaced. Cable is generally not replaced due to splice failures.	
4	Replace.	N/A.		

Table 2-29 (continued)
Replacement and Rejuvenation Issues

Response Number	Rule of Thumb	When Do You Rejuvenate and Replace	Criteria	Factors
5		Rejuvenate a span of cable if possible after a failure; otherwise replace the cable span.	Whether the cable is injectable or not.	Concentric neutral condition, maximum number of joints in a span of cable, whether the conductor is too corroded.
6	No rejuvenation.			
7	Replace when practical after the first two failures.	We rejuvenate whenever possible and when it is practical to rejuvenate a group of cables all at once. Obviously, cable with solid conductor or strandfill must be replaced.	Number of failures, number of failures on a particular lateral, number of customers affected, radial or looped, age of cable, type of insulation.	We do not rejuvenate cables if the neutral conductors are extensively corroded or if the injection fluid will not flow and there are more than one or two splices that would have to be replaced.
8		We never rejuvenate; we always replace.		
9	Three failures in a loop.	Moving away from rejuvenating.	Money.	Customer complaints.
10	Replace all cable in plant if installed prior to 1975 (35 years old). Test and inject if installed after 1975; then replace the cables that were rejected during the cable injection testing process.	Inject if neutral corrosion is less than 50%.		
11	Unjacketed concentric neutrals: three or more breaker trips per year.	No rejuvenation done since 2002.	Location, residential versus commercial customers, number of customers affected.	
12	We don’t rejuvenate feeder cables—only submarine cables.	A submarine cable can be rejuvenated if it passed our condition assessment.		

Question 37

What is the split of underground to overhead distribution in new construction spending for your utility? Can you place a dollar value and/or percentage? (See Figure 2-15.)

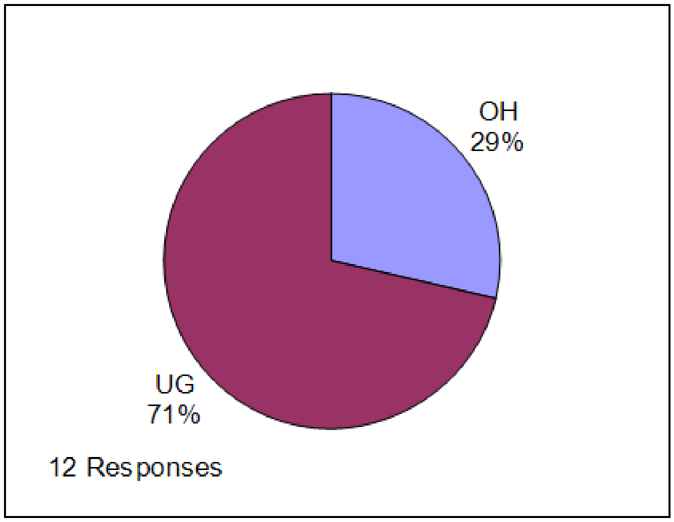

Figure 2-15
New Construction Spending: Overhead Versus Underground

Question 38

Can you provide some statistics about outages that have occurred in your UG systems? (See Table 2-30.)

Table 2-30
Outage Statistics

Response Number	Response
1	Typically the outages/failures have occurred on older XLPE cables along with some PILC failures of about 60+ year old cable. Very few if any failures experienced on EPR cable (assuming just cable failure).
2	We are typically around 0.05–0.06 URD faults per primary mile of URD. Mostly depends on lightning activity during the year.
3	In 2009, we experienced 32 cable failures, 17 splice failures, 5 elbow failures, and no terminator failures. We do have detailed outage information available regarding length of outage and so on.
4	About 12 failures per 100 miles per year.
5	Of the 700 miles of cable, aging from 1968 to present, we have experienced 14 cable failures this year. By far, the majority was manufactured by Reynolds in 1976, 1977, and 1978.
6	40–50 feeder failures occur per year. Over the last 5 years, we’ve averaged about 335 URD faults per year. That’s 0.0607 faults per mile of cable per year.

Table 2-30 (continued)
Outage Statistics

Response Number	Response
7	We have approximately 1950 extended outages per year due to underground equipment/cable failures. Customer interruptions due to underground equipment/cable failures are approximately 78,500 per year.
8	Not really. We track outages but don't really trend them.
9	2000: 39, 2001: 22, 2002: 42, 2003: 37, 2004: 82, 2005: 72, 2006: 70, 2007: 53, 2008: 60, 2009: 63, 2010: 50 to date. This is the number of primary underground cable failures on approximately 1000 miles of unjacketed direct-buried cable.
10	2010 year-to-date total cable system outages are 461. YTD 2010 total for all outages including scheduled/planned is 1897.
11	55% splices and 45% cables.
12	Approximately 1700 underground primary cable faults and 3500 underground secondary cable faults in 2009.

Question 39

What do you use as the cost per mile to replace overhead with underground distribution? What is the calculated maintenance cost? Over what period? What components go into that cost (right of way, vaults, manpower, disposal, and so on)? (See Table 2-31.)

Table 2-31
Costs for Underground Installation

Response Number	Response
1	$1 million is our rule of thumb for UG cost.
2	Depends on main line versus development. For development, we are replacing at around $20–30 per foot. This includes all costs such as replacing transformers if necessary. For main line, the cost is variable. Urban versus rural. Size of wire, number of boxes, and so on. City permit fees. (One city is now charging a $1-per-foot permit fee!) Costs are from $125,000 to $350,000 per mile.
3	We only replace OH with UG when requested and when the customer pays the difference in cost, including estimated maintenance over the life of the new system. The cost-per-mile value ranges widely based on whether it is a feeder circuit or residential single phase.
4	Replacement costs are virtually the same as new installation costs. New installations cost about $49,000 per mile for single-phase 1/0 and are as high as $141,000 per mile for three-phase 500 mcm.
5	For feeders, about $800,000 per mile. Maintenance cost unknown. We don't do inspections or other regular maintenance on our underground feeders.
6	$1 million per mile.

Table 2-31 (continued)
Costs for Underground Installation

Response Number	Response
7	We don’t have a rule of thumb on this because each project differs greatly. Each one is estimated individually. We are seeing more of these projects coming up, though.
8	Current cost-per-mile figures are unavailable. The 2010 UG maintenance cost is $4,905,000 per year, which includes manpower, materials, and dewatering.
9	It costs approximately $1 million per mile to convert overhead to underground. There are no wholesale conversions of overhead to underground.

Question 40

Do you have a costing model you could share? (See Table 2-32.)

Table 2-32
Costing Models

Response Number	Response
1	We have standard costs for construction units (CU) and macro units (MU) in our work management system. Some of these are adjustable based on the length of a span or other factors and are used by our designers to create a cost estimate for each job. The costs are also offset against revenue and new business when appropriate.
2	None. Budgets are based on historical data or Asset Management goals.

Section 6: Case Studies

Question 41

Is there a particular case study you could highlight regarding UG systems where you installed, replaced, rejuvenated, or maintained an UG system? (See Table 2-33.)

Table 2-33
Case Studies

Response Number	Response
1	Perhaps.
2	We have many examples that we could relate. All too lengthy to report here, that is, circuits that lost insulation shield bond and started failing faster than we could replace it, entire circuits that were eventually replaced after replacing some individual segments, replacement of a significantly bad year of feeder cable from the same manufacturer, experimentation with rejuvenation, old cable designs from the 1960s that are still in service and saving our utility thousands of dollars in deferred costs, extended cable life due to the installation of MOV arresters and neutral protection at road crossings, use of 220 mil cable, and so on.
3	As briefly mentioned in a previous response, we have a second responder program that has worked fairly well for us. After a URD cable has failed and been switched in order to get the customer's lights back on, a contractor crew comes out to determine if the cable can be injected or replaced. They are then responsible for getting the cable back in service using either cable injection, directional boring, or open-trench cable replacement.
4	We are just beginning a project to revitalize our downtown network, so we have nothing to share at this time.
5	I have several, but since I am not sure what you are looking for...I leave this one.
6	Our utility has identified 25 kV disconnectable 600 A splices as a problem. The cable system was only 10 years old, and the number of outages due to these splice failures was unacceptable. We just completed a splice replacement project using a combination of splices—one-for-one 600 A tee, Elastimold vault-stretcher for straight splices, Richards Y-joints.

Question 42

Is there some kind of innovation that your utility is undertaking in the UG distribution system that you could share with your peers? (See Table 2-34.)

Table 2-34
Innovations That Have Been Implemented

Response Number	Response
1	We believe our internal cable specification, early identification of the benefit of MOV arresters, road crossing methods that extended the life of non-jacketed concentric neutrals, and acceptance testing have provided us with superior cable performance.
2	Probably not much different than what other utilities are already using.
3	We plow in counterpoise grounding at all risers to make sure we have good grounding for our lightning protection. We purchase all padmount transformers with under-oil arresters. We have been doing this since about 1992.
4	We have aggressively used reduced diameter cables to replace PILC cables. We are moving toward cold-shrinkable splices with shear head connectors.
5	I am not sure if it is all that innovative, but we are using tan delta testing on our cables to test life, and it is saving huge amounts of money: $900,000 versus $48,000. Much better to replace cable that truly needs it than reacting in a knee-jerk fashion.
6	1.) We are refining our diagnostic tests by using PD with sensors. 2.) We will be using a robot to inspect restricted manholes because of defective splices and cables that have been identified as safety risks.

3
DISCUSSION OF SURVEY RESPONSES

The opening questions of the survey ask what information is of most interest to the utility engineer. Based on the common responses received, the areas of greatest commonality deal with what cables are being used, criteria and prioritization of replacement programs, and diagnostic testing. The responses throughout the remainder of the survey provide interesting data in each of these areas.

Cable Products

Based on the wide variations in cable designs specified (see Question 11), there seems to be little commonality from one utility to another. Of the 43 designs entered into the responses, there were 41 unique cable designs. Because of the high degree of customization and flexibility in cable parameters, there might be opportunity for a degree of standardization or consolidation that would lead to more economical cables across the industry.

It is interesting to note that there is approximately the same number of EPR and TRXLPE cable designs specified in Question 11. However, the breakdown of installed cable miles by insulation type in Question 3 indicates the usage of TRXLPE as three times that of EPR on a volume basis.

Of the utilities performing incoming quality control testing on their cables, most engage random sampling with checks of physical dimensions only. Few respondents do more detailed evaluations or testing.

A high percentage (83%) of respondents indicated that they are facing the challenge of PILC replacement. However, only 1 of the 43 cable designs entered in Question 11 was a reduced-wall design. The common challenge for PILC replacement projects is the reduced diameter ducts in older PILC circuits. This might indicate a general lack of confidence in reduced-wall designs for EPR and TRXLPE.

Replacement Programs

The most common response to questions regarding cable replacement yield a run-to-failure with three-strikes-and-out rule. In most cases, little if any true condition assessment diagnostic testing is performed on the installed cable fleet across the industry. It seems quite common for cables to be evaluated only after a failure has occurred. After the third failure on a given length of cable, repairs are no longer attempted, and the segment is replaced.

Reported failure rates in this survey were in the range of 0.02 to 0.12 failures per mile per year.

Utilities with active replacement programs prioritize their work based on previous failure occurrences, number of customers affected, age, and budget.

Diagnostics

Very few utilities today are performing monitored diagnostic testing for condition-based assessment of their cable fleet. Monitored diagnostic tests are evaluation techniques that provide information on the health of the cable and accessories beyond a simple withstand test. A withstand test such as the very low frequency (VLF) withstand (also called *ac HIPOT*) gives a pass/fail result based on whether the cable faults during the allotted testing time. Monitored tests such as tan delta or partial discharge provide additional information on the health or condition of the cable segment.

The one utility indicating internal implementation of tan-delta measurements (see Question 42) believes that it has significant positive economic impacts due to the use of the technology.

Personal follow-ups by the EPRI project manager with many respondents have resulted in several cases of trials for partial discharge testing by outside service providers. These experiences have generally been negative: the consensus is that results are not reliable. Engineers believe that they get false positive and false negative results from partial discharge test reports.

Existing industry references for field testing of distribution cables include IEEE P400 [1] and its associated point documents P400.1 [2], P400.2 [3], and P400.3 [4]. In addition, the National Electric Energy Testing Research and Applications Center (NEETRAC) is engaged in a multiyear program funded by the U.S. Department of Energy called the *Cable Diagnostics Focused Initiative*, or *CDFI*. The Phase 1 report from this program, *Reference Guide to Diagnostic Testing of Underground Cable Systems* (also referred to as the *Cable Diagnostic Handbook*), is due to be published at the end of 2010 [5]. In addition, Chapter 10 of the 2011 revision of the *EPRI Underground Distribution Systems Reference Book* (known as the *Bronze Book*) [6] discusses diagnostic testing techniques and their applicability to different types of cables.

4
CONCLUSIONS AND FUTURE WORK

Conclusions

This survey has demonstrated that there is considerable diversity across the industry in what cable products are specified and used (Question 11), installation techniques, size and scope of underground systems, and approaches to maintenance and/or replacement. However, at the same time, there is considerable commonality with regard to a need for additional capability and confidence in diagnostics and evaluation of aged cables.

A small percentage of utilities are implementing advanced diagnostic techniques that provide information on the health of cables. In order to develop a comprehensive life cycle management approach to cables, an effective condition-based maintenance plan is critical. Test methodologies and techniques must be available with high levels of confidence and reliability to enable engineers to prioritize cables for repair or replacement. Simply replacing cables based on age is not practical or economical. Run-to-failure methods risk outages to customers.

A considerable body of knowledge exists, and publications are available in the public domain related to diagnostic testing techniques (for example, the references in Chapter 10 of the *EPRI Underground Distribution System Reference Book* [the Bronze Book]) [6]. References are also cited for some of the pilot CBM programs that have been implemented at several utilities around the world.

Future Work

Phase 2 of the Cable Fleet Management project will use the data gathered in this survey and discussions with members to determine where EPRI can bring value to the development of life cycle management approaches for cables. Clearly, diagnostic testing, health evaluation, and replacement prioritization are opportunities. Analysis is needed to determine whether existing testing techniques provide the desired levels of accuracy and ease of use for the utility engineer. If these techniques require industry experts and third-party vendors to successfully implement, there is little chance for widespread adoption for everyday use in CBM programs. This might point to the need for additional technology development that EPRI might lead on behalf of its members.

EPRI is participating in Phase 2 of the CDFI project and will provide input and guidance to this work. Participation will also bring feedback on advanced diagnostic techniques to program funders.

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REFERENCES

1. IEEE P400. Shielded Power Cable Systems.
2. IEEE P400.1. IEEE Guide for Field Testing of Laminated Dielectric, Shielded Power Cable Systems Rated 5 kV and Above with High Direct Current Voltage. 2007.
3. IEEE P400.2. IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF). 2004.
4. IEEE P400.3. IEEE Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment. 2007.
5. Cable Diagnostic Focused Initiative (CDFI). Reference Guide to Diagnostic Testing of Underground Cable Systems. December 2010 (scheduled).
6. *EPRI Underground Distribution System Reference Book.* EPRI, Palo Alto, CA: 2010 (scheduled). 1019937.

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