



U.S. Department of Energy
Office of Electricity Delivery & Energy Reliability

Electric Distribution



FY06 Annual Program and Peer Review Meeting

San Ramon, California
May 25-26, 2006

Cable Diagnostics Focused Initiative

Rick Hartlein

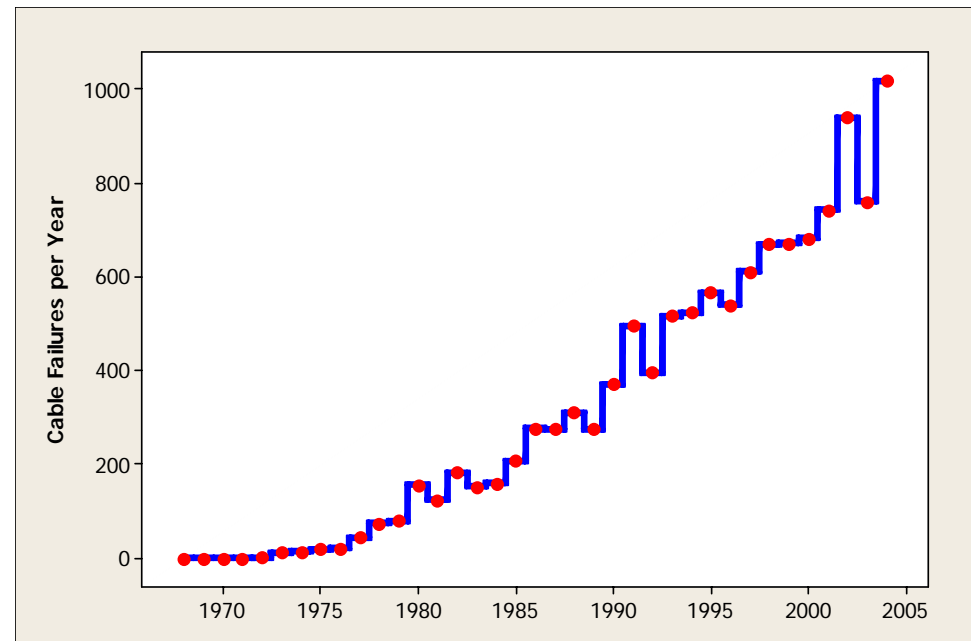
Georgia Tech NEETRAC

May 25, 2006

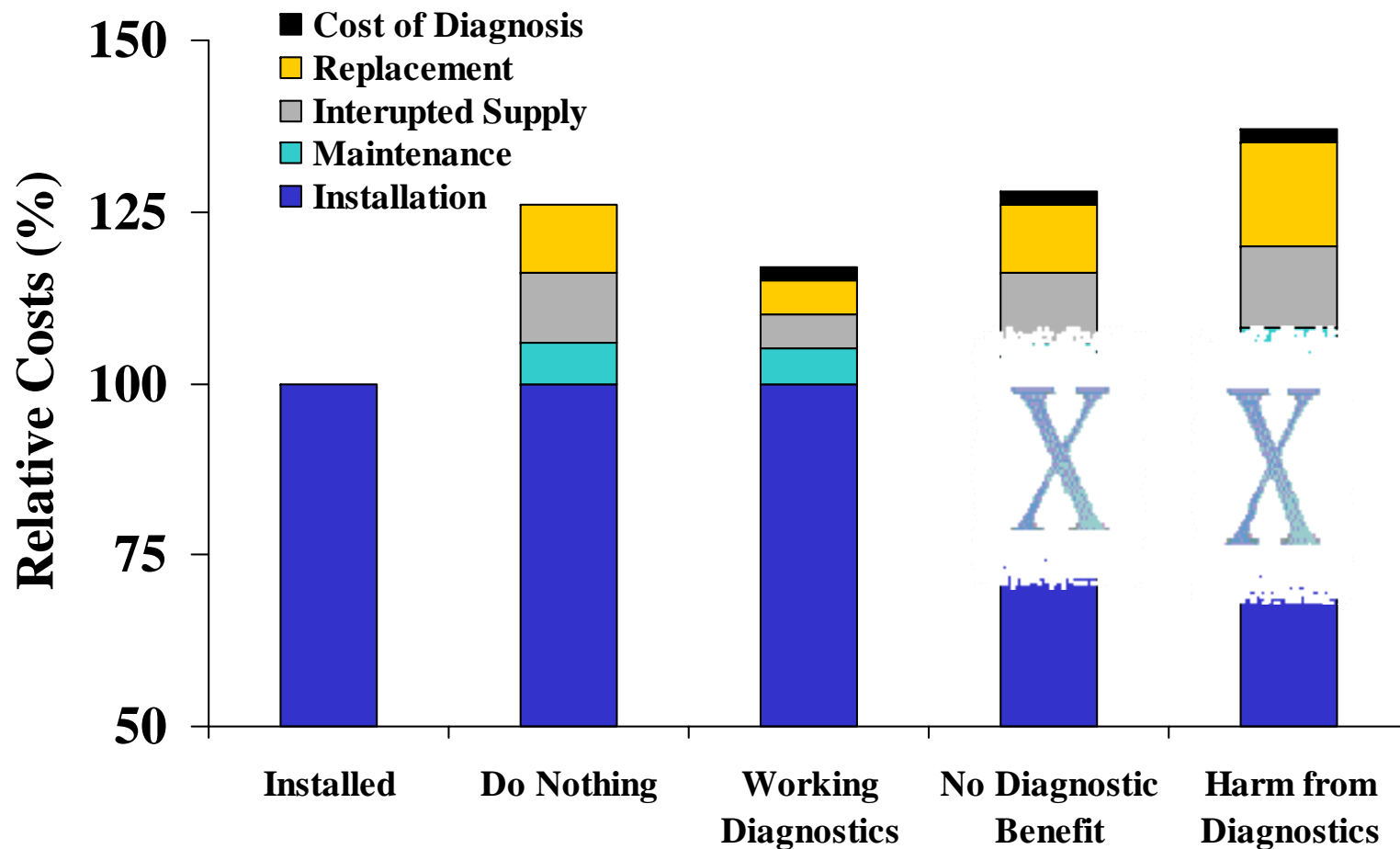
CDFI

Problem & Needs

- This country's underground cable system infrastructure is aging (and failing).
- There is no way we can simply replace all of it just because it is old (not enough money, not enough manufacturing capacity) .
- We need diagnostic tools that can help us decide which cables to replace and which can be left in service.
- Some tools are available but they are not fully utilized due to a lack of understanding of their effectiveness.



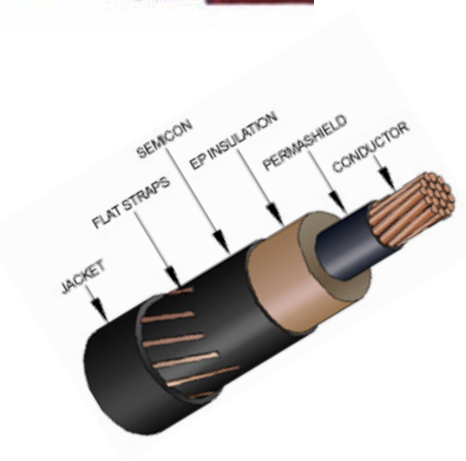
The Cable System Diagnostic Dilemma



Schematic Representation

Challenges

- Cable Circuits are Surprisingly Complex Systems
 - Different insulation types
 - Ethylene Propylene Rubber
 - Polyethylene
 - Fluid Impregnated Paper
 - Multiple splice and termination types
 - Premolded
 - Cold Shrink
 - Hot Shrink
 - Hand Taped
 - Linear and nonlinear stress relief materials
 - Circuits are often hybrid

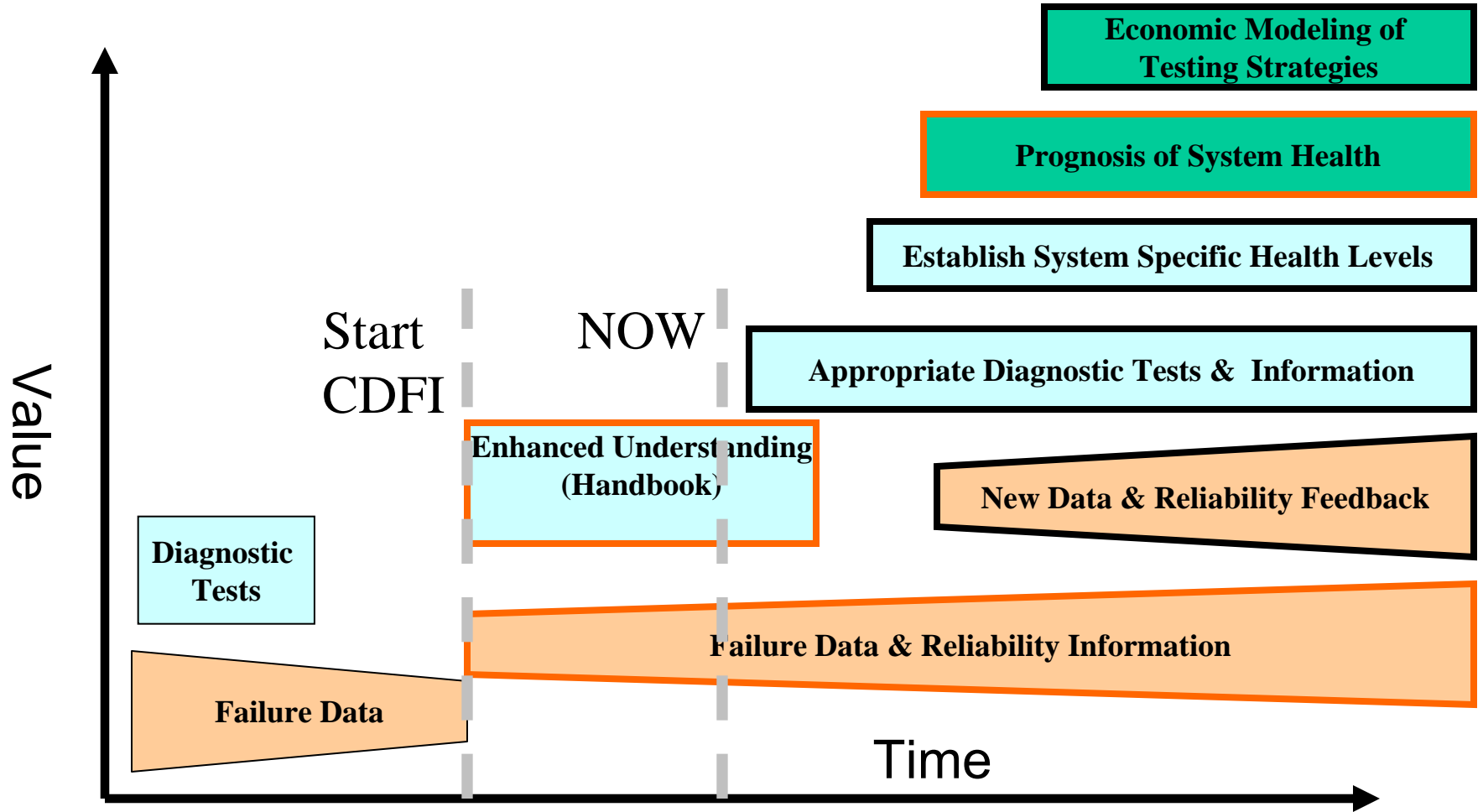


Objective: Clarify concerns and define the benefits of diagnostic testing.

CDFI - Eight Primary Activities

- 1) **Technology Review:** Review literature to understand current diagnostic testing practices and technologies.
- 2) **Journal Database:** Prepare a database to archive results of literature search.
- 3) **Analysis of Existing (Historical) Data:** Review available cable diagnostic test data in an effort to establish the effectiveness of tests conducted to date.
- 4) **Collection and Analysis of Field (New) Data:** Work with CDFI participating utilities to conduct tests on their system.
- 5) **Verification of AC/VLF Test Levels:** Establish optimal withstand V & t.
- 6) **Defect (Point & Dispersed) Classification:** Tests (PD, Tan Delta, VLF, etc.) on circuits with known problems.
- 7) **Quantification of Economic and Reliability Benefits:** Analysis and modeling to estimate the future impact of intervention strategies.
- 8) **Reports, Update Meetings and Tech Transfer Seminars:** Provide progress reports as required.

The CDFI Journey



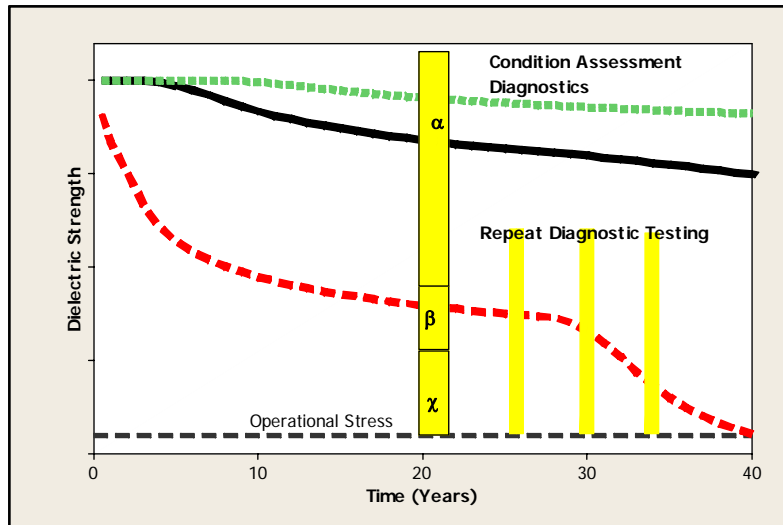
Overall Project Budget

Task	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
1-Tech. Review					
2-Journal Database					
3-Historical Data					
4-New Data					
5-Withstand Voltage					
6-Defect Classification					
7-Economics					
8-Reports/Update Mtgs.					
DOE Budget	\$279,534	\$589,535	\$821,931	0	0
Sponsor Budget	\$102,600	\$222,502	\$370,000	\$569,802	\$472,096

FY 2005 Development

- Project began building momentum/project team established
- Literature reviewed and summarized
- Journal database developed
- Diagnostic technologies identified and studied
- Historical data gathering began
- Limitations of historical data content recognized
- The need to gather/sponsor gathering of new data became apparent
- Identified equipment needed for testing in the lab

FY 06 Performance & Results-Handbook (1&2)



- Created handbook on diagnostic technologies, their application and benefits. Covers what is known today.

Table A1
Aging and Degradation Mechanisms for Extruded Cable

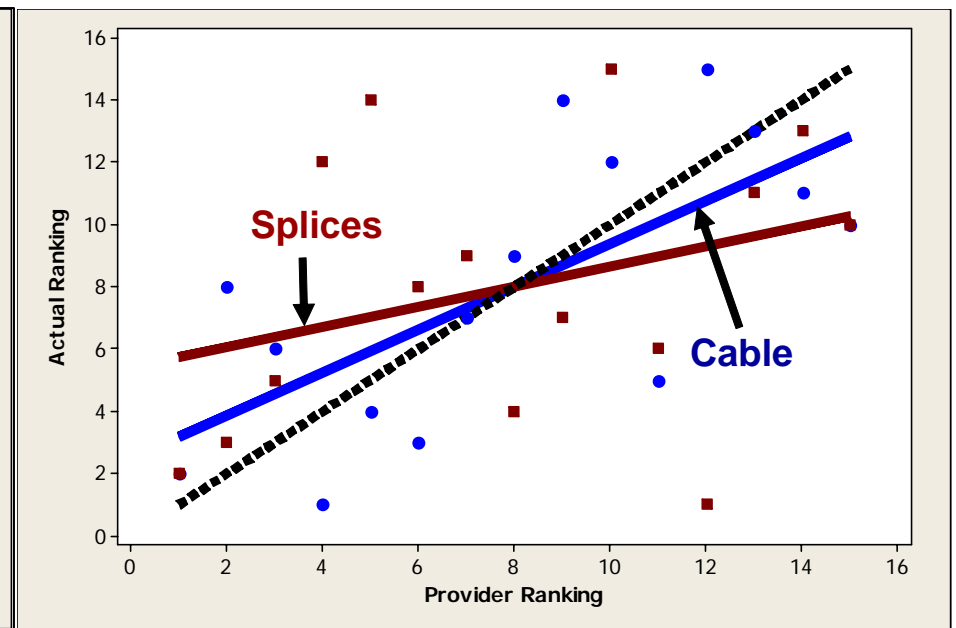
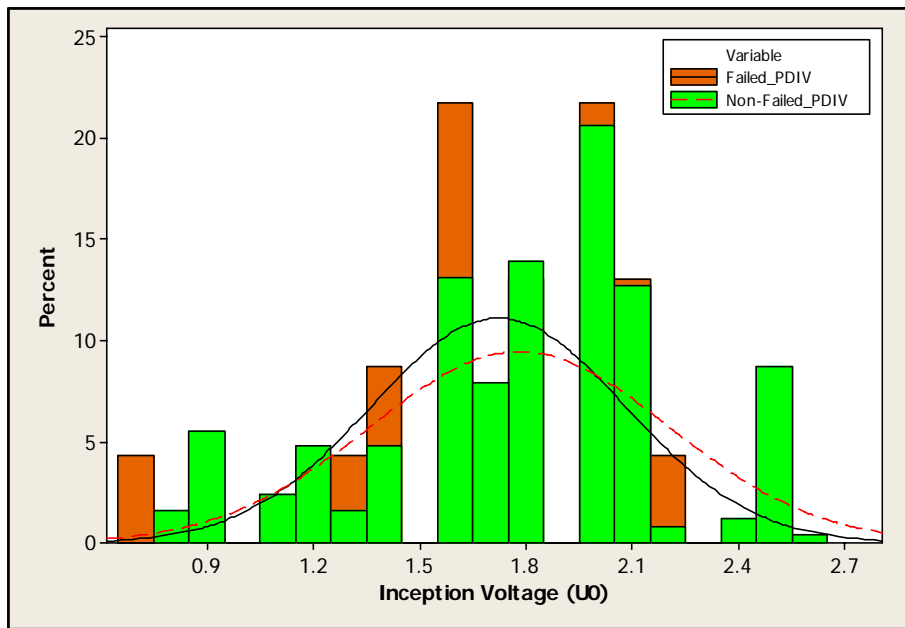
Type of Deterioration	Aging Process	Typical Causes	Example
Thermal	<pre> Operational Temperature v Oxidation v Decomposition v Evaporation </pre>	Excessive conductor current for a given environment and operating conditions	
Dry electrical	<pre> High electrical stress built up v Partial Discharge v Water Absorption v Increase in dielectric loss v Increase in dielectric strength </pre>	Manufacturing imperfections (voids, contaminants), mechanical damage	
Water tree electrical	<pre> High electrical stress built up v Partial Discharge v Water Absorption v Increase in dielectric loss v Increase in dielectric strength </pre>	Moisture ingress (external and via conductor)	
Chemical	<pre> Swelling v Cracking v Chemical Spills v Increase in dielectric strength </pre>	Petrochemical spills, transformer oil leaks, fertilizers	
Neutral corrosion	<pre> Loss of neutral v Voltage rise v Cable surface electrical damage v Corrosion v Increase in dielectric strength </pre>	Unjacketed cable in soil that enhances copper (Cu) corrosion, jacketed cable with corrosive water ingress	

Diagnostic Tests for Single Cable Insulations								
	Withstand		Partial Discharge		Dielectric			
	AC 60Hz& 0.1Hz	DC	Offline	Online	Dissipation Factor Dielectric Spec	Recovery Voltage	Polarisation Current	DC Leakage
Refer to Section for details	4.4	4.4	4.1	4.1	4.3	4.6	4.7	4.5
PILC	√	√	√	√	√	√		√
XLPE	√		√	√	√	√	√	
TR XLPE	√		√	√	√			
EPR	√		√	√	√			

FY 06 Performance & Results-*Historical Data Analysis* (3)

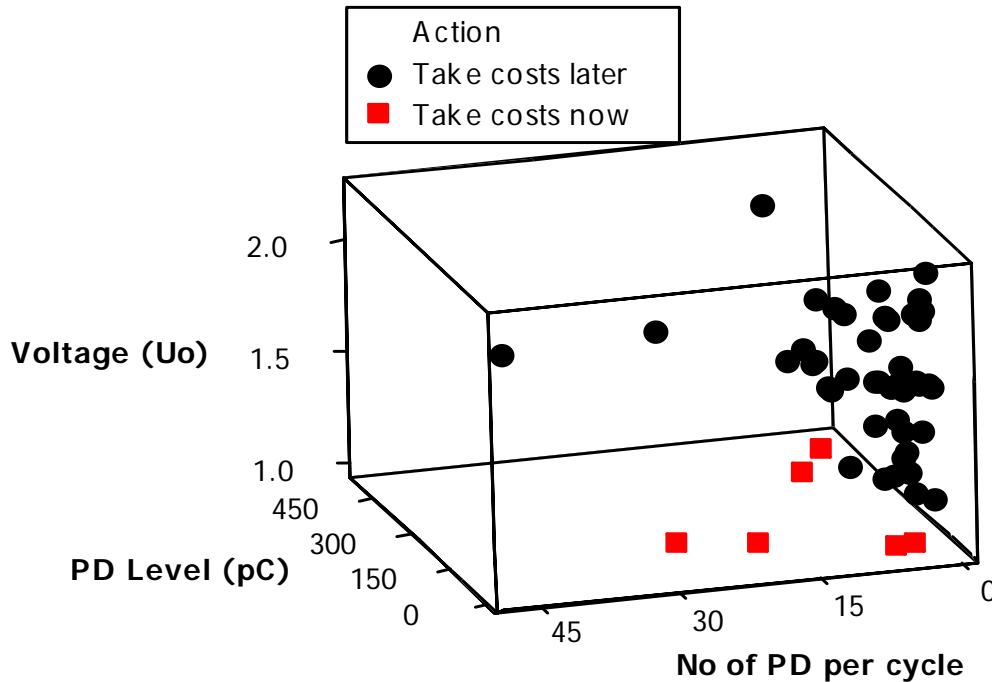
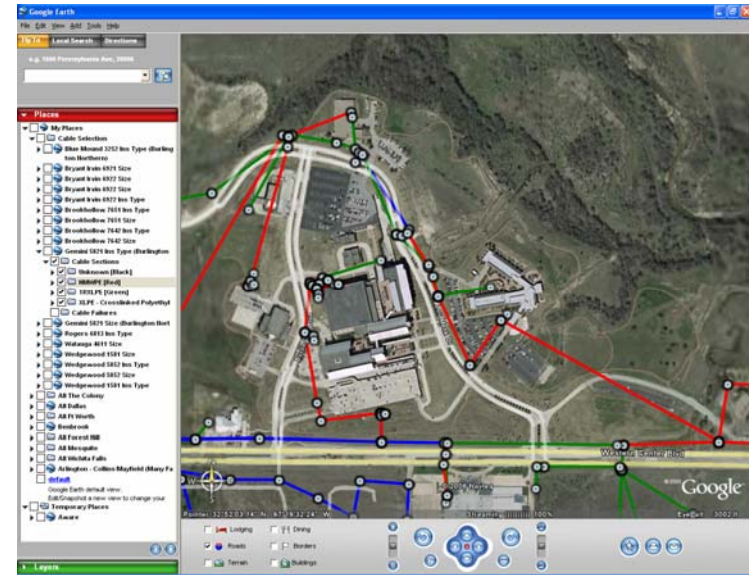
- First time various data sets analyzed in a neutral setting
- Suitable analysis techniques had to be developed
- Processing of existing data sets
 - Statistical
 - Ranking
- Limited information available

CDFI Participant	Type of Diagnostic Test	# of Records	Date of Test	Failure History Available?	Progress
Utility A	Partial Discharge	>289 lengths	2001	Yes	To Commence
	DC Withstand	3,726 lengths	2001-2005	Yes	To Commence
Utility B	Partial Discharge	176 segments	2000-2001	Yes	Complete
Utility C	Partial Discharge	<2542 lengths	2000-2005	TBD	Awaiting Full Dataset
	Tan Delta / Power Factor	2542 lengths	2000-2005	TBD	Awaiting Full Dataset
Utility D	Partial Discharge	184,000 feet	1999-2000	Yes	Complete
Utility E	Partial Discharge	212,000 feet	2001	No	Awaiting Full Dataset
Utility F	Partial Discharge	346 segments	1998-1999	Yes	Complete



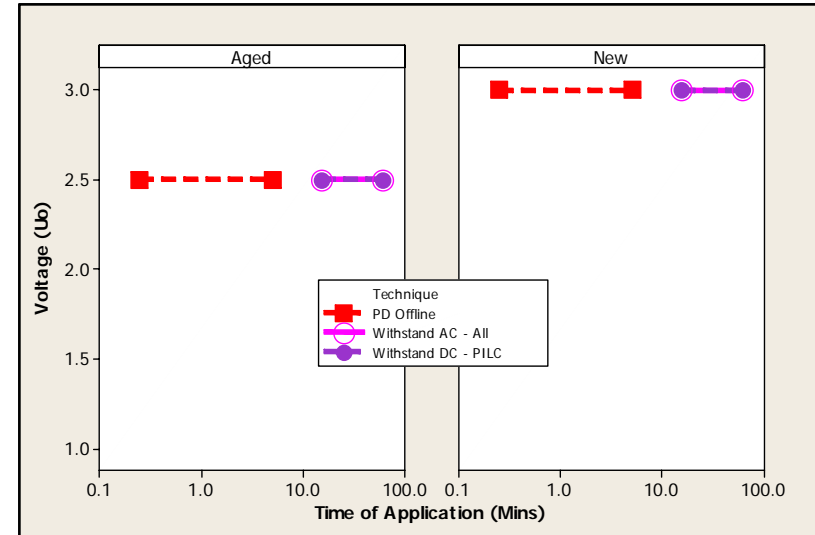
FY 06 Performance & Results – *Obtaining New Data* (4)

- Obtaining new data
 - TXU: 27 segments tested in March, 2006
 - More feature rich than historical data



FY 06 Performance & Results-*Withstand Tests (5)*

- Establish Effective Withstand Voltage Duration & Magnitude (60 Hz & VLF)



Utilize available 12 lengths of 1973 15kV XLPE cables ex Exelon

Sample Set/Tank ID	Length (ft)	Samples Tested	VLF or 60 Hz AC Test Condition				Diagnostics After 1 Year Test
			Test Voltage (Vg)	Freq (Hz)	Application Duration		
					Time (mins)	Cycles	
I / -	-	Field Aged XLPE Insulated Cable	Selected cables supplied 1968 -1974				<ul style="list-style-type: none"> •PD (conv (Biddle) & high sensitivity (TechImp) – inc location), •Tan d (60Hz & VLF) at Uo •ac Breakdown •All samples: water tree examination
II / A	280		Control – ageing only				
III / B	280		2	0.1	20	120	
IV / C	280		3	0.1	20	120	
V / A	280		3	0.1	60	360	
VI / D	280		2.5	0.1	60	360	
VII / F	280		2.5	60	0.25	900	

FY 06 Performance & Results-Lab Tests (6)

- Diagnostic Data Feature Extraction
 - PD (vlf & 60 Hz), $\tan \delta$, return voltage

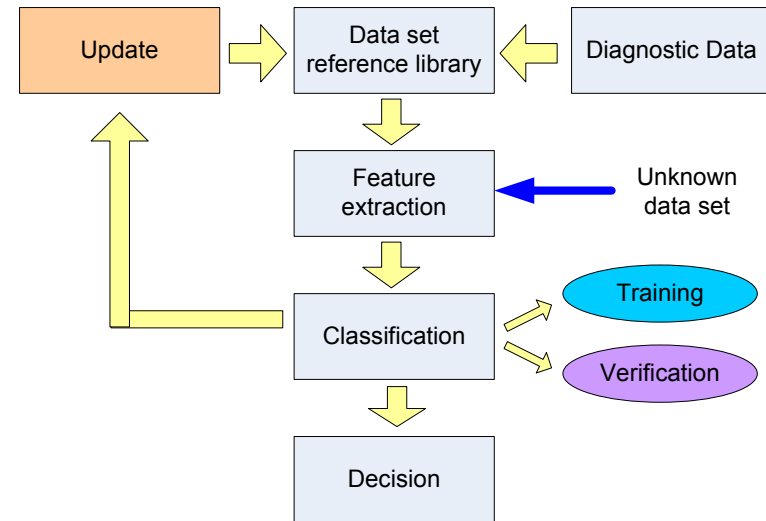
- Samples are kept under water to keep moisture in insulation



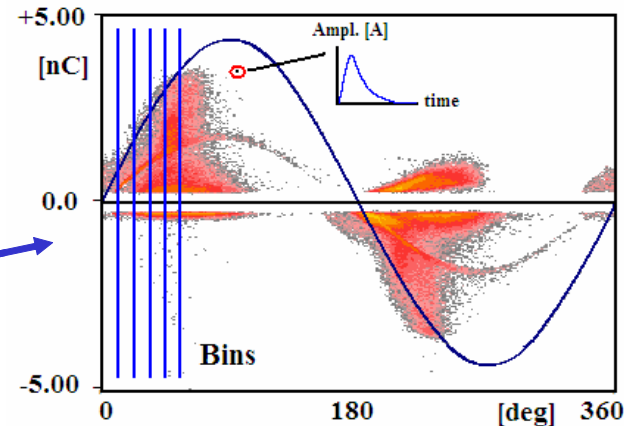
- Testing is done with the sample under water to guarantee conduction between neutral and cable insulation jacket



- Data is captured by a PC and specialized software



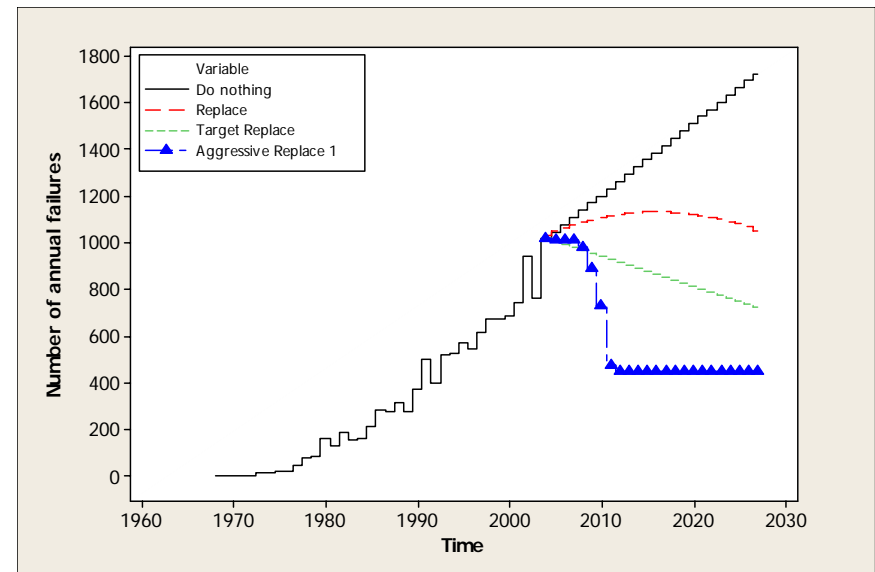
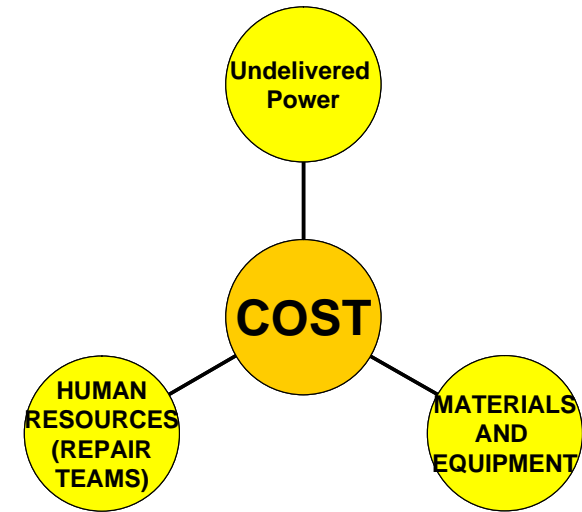
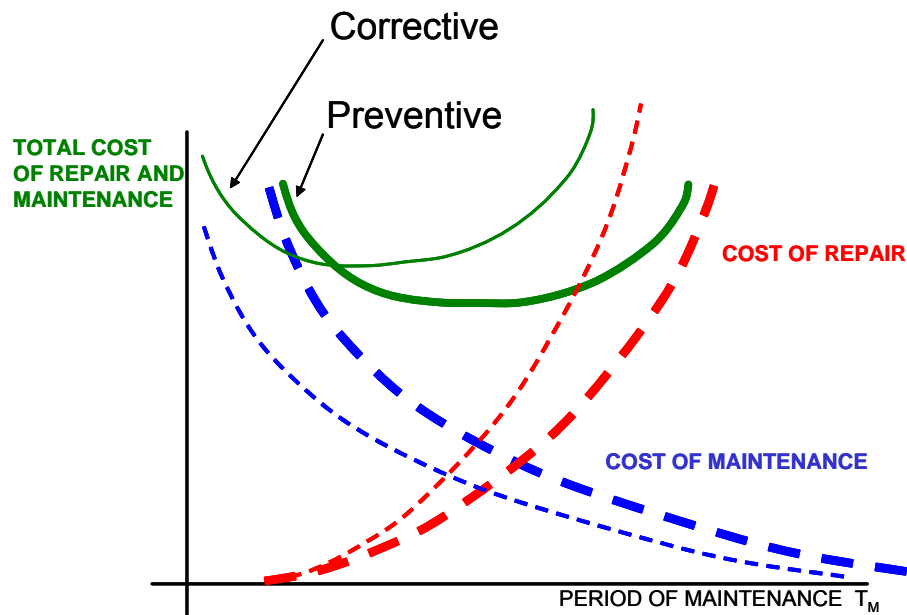
Discharge Magnitude



Phase value

FY 06 Performance & Results-Economic Analysis (7)

- Asset Management/Economic Analysis



FY 07 Plan

- Continue to gather and analyze historical data sets
- Accelerate testing of cables in service
- Conduct survey of utility cable use & testing practices
- Revise Handbook based on lucid input from participants
- Complete first phase of voltage withstand/duration lab test
- Continue feature extraction in the lab on field aged cable and cable accessory samples
- Begin construction of a success database
- Begin development of a utility useful economic model for diagnostic testing

CDFI Participants of 05/10/2006

American Electric Power	HV Technologies
Ameren	Hydro Quebec
Cablewise/DTE	IMCORP
Centerior	NRECA
Con Edison	Pacificorp (added mid 2005)
Cooper Power Systems	Pacific Gas & Electric (added Jan 06)
Duke Power Company	PEPCO
Exelon / Commonwealth Edison & PECO	TXU
First Energy	Pirelli Cable North America
Florida Power & Light	Public Service Electric & Gas
Georgia Tech	Tyco / Raychem
GRESKO	Southern California Edison
HDW Electronics	Southern Company
HV Diagnostics	Southwire

US Department of Energy

Funding

Cost Share Participants

- NEETRAC Members: \$25,000/year for 3 years = \$75,000
- Non NEETRAC Members: \$35,000/ year for 3 years = \$105,000
- Total to date: \$1,734,000

Diagnostic Providers (Small Companies)

- In kind contributions: technical expertise, test data - no cash contributions

DOE Funding

- Over three years: \$1,700,000

Project Total

- Total project cash budget: \$3,434,000

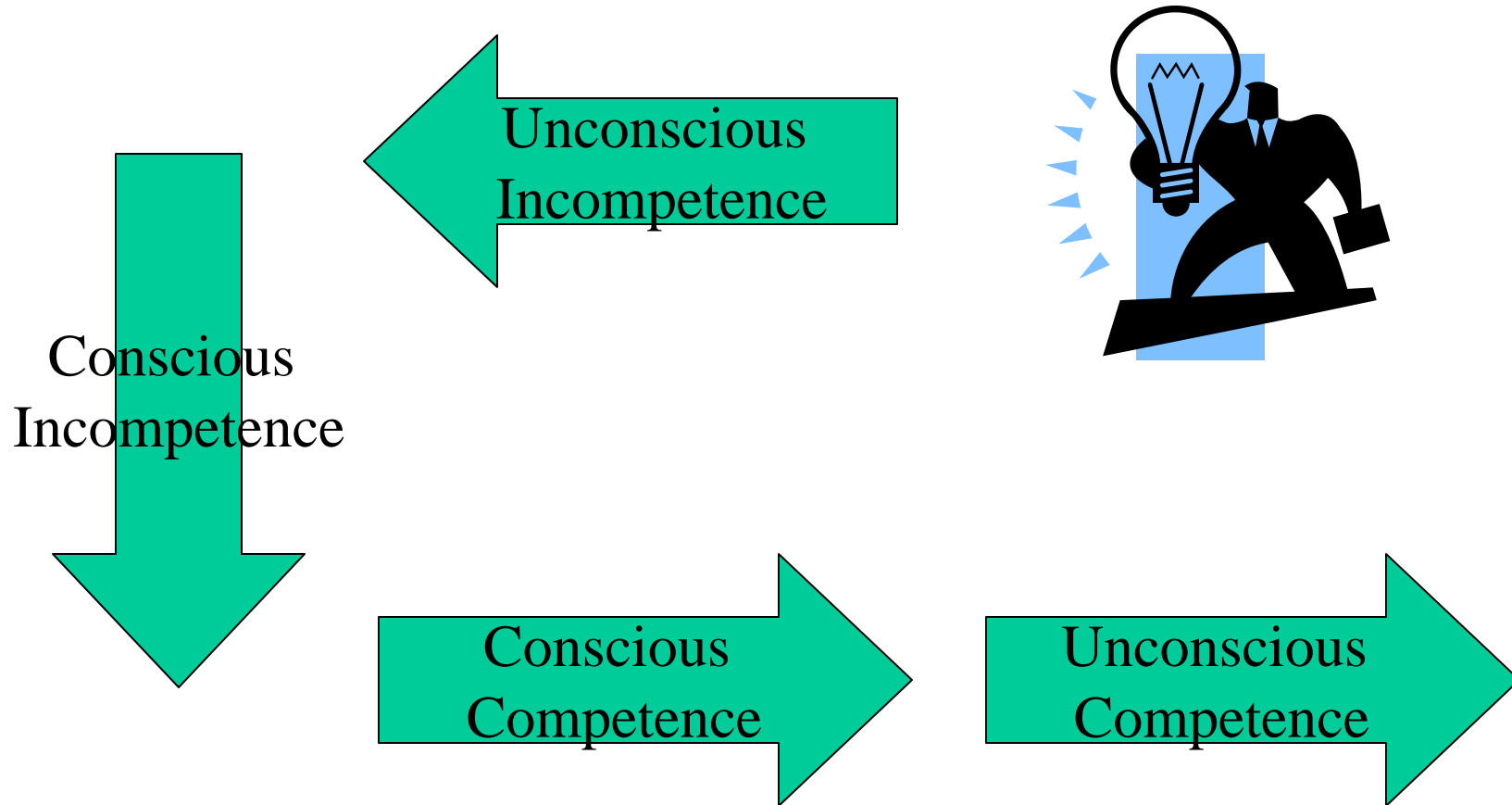
Benefits/Collaboration/Barriers/Impact

- **Benefits:** Increased understanding of how to effectively utilize cable diagnostic (condition assessment) technologies to optimally reduce failure rates and customer outages.
- **Collaboration:** Electric utilities, cable and accessory manufacturers, diagnostic technology providers, Georgia Tech, Delft University
- **Barriers:** Available data, obtaining new data, IP associated with provider technologies, time (Mitigation: Aggressively working with utilities to find circuits to test & to provide historical data)
- **Impact:** The immense size of the underground system in the United States represents a multibillion dollar critical infrastructure. If condition assessment tools can be effectively applied to allow for effective cable system repair/replacement, millions of dollars can be saved and thousands of system outages can be prevented.

Summary

- **The potential benefits of diagnostic testing are not fully utilized.**
 - Some systems are far too complex.
 - The meaning of many measured cable characteristics still needs to be established.
 - Expectations must be set properly.
 - Implications for system performance must be quantified.
- **Diagnostic testing is all about feature extraction & analysis.**
 - There are many different features to observe
 - tan delta, pd magnitude, etc.
 - Measured as a function of voltage, frequency, time
 - Features have to be analyzed many different ways (statistical, pattern recognition, ranking, etc.)
 - Extracted features must be associated with specific types of problems
 - Different features must be extracted and analyzed for different cable systems.
- **Economic benefits are potentially significant**

The CDFI is a journey in learning



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