



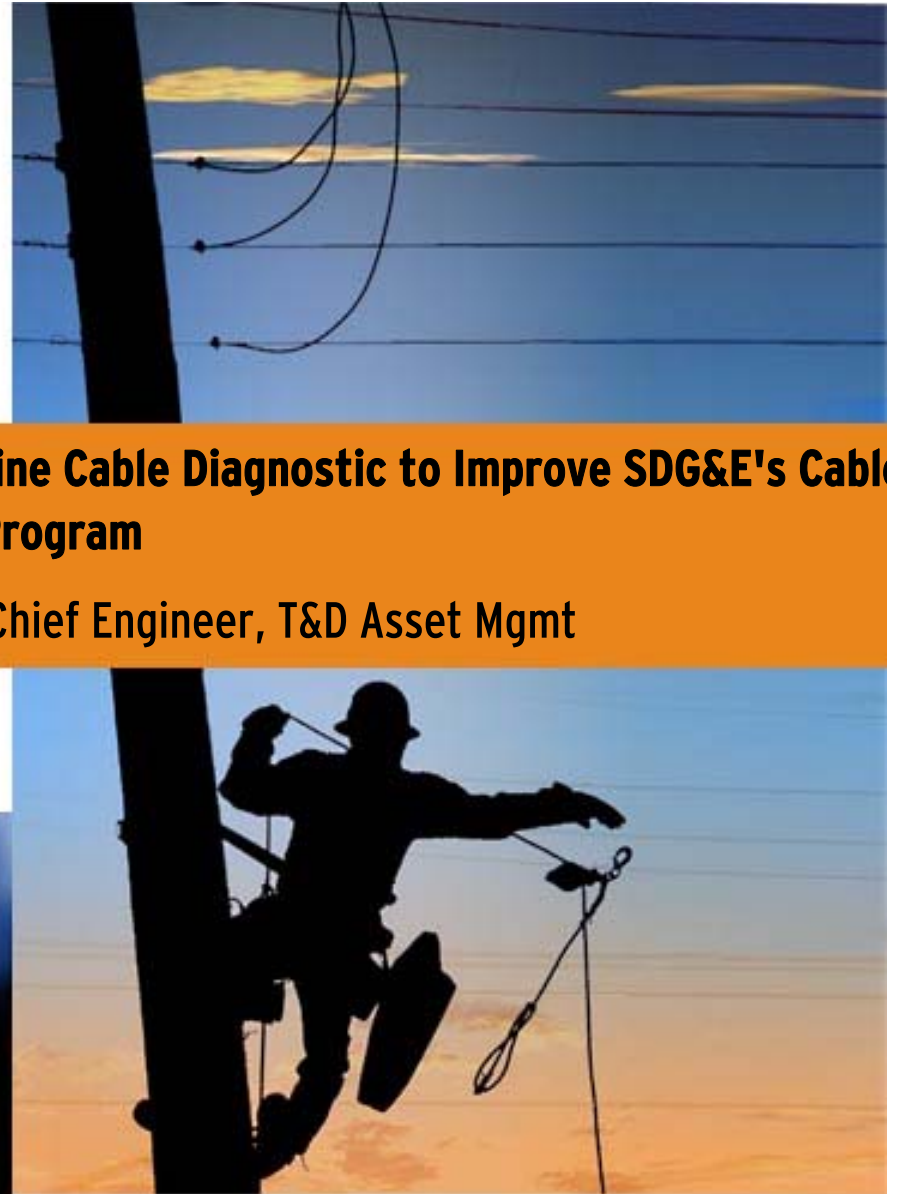
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The Need for an On-line Cable Diagnostic to Improve SDG&E's Cable Asset Management Program

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CITRIS Workshop
Feb. 25, 2008



Condition Assessment - Problem

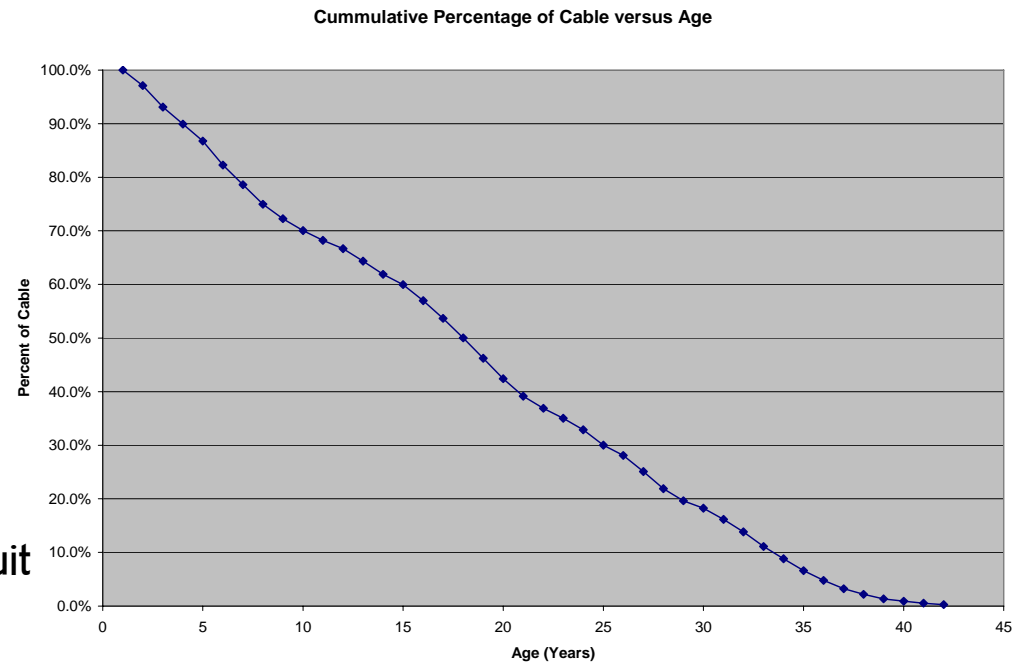


- **Aging high voltage cable infrastructure**

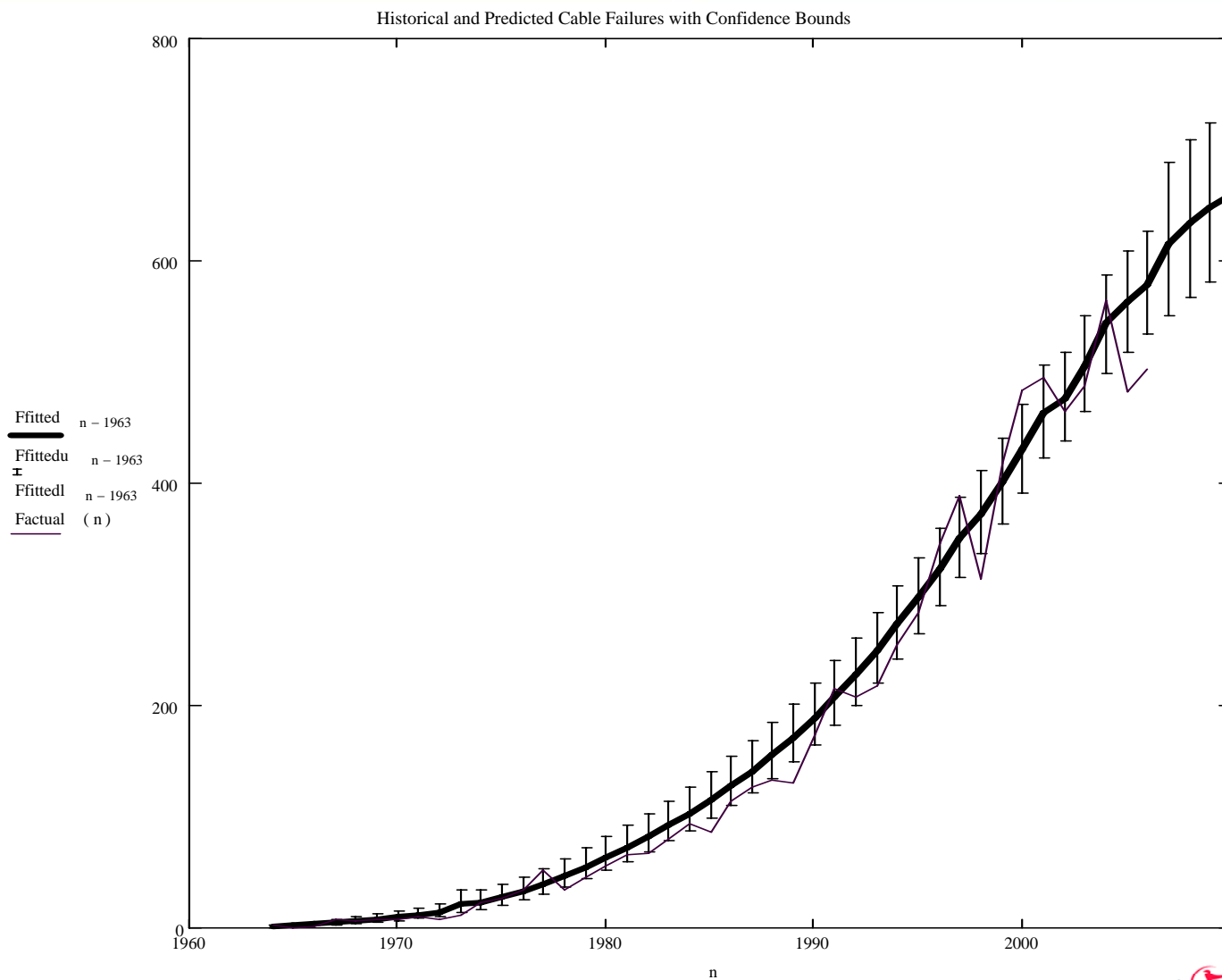
- Billion \$ asset at SDG&E
- Capital funding limited
- Replacement prioritization
- Cable insulation condition
 - Good, Fair, Bad?

- **2006 Facts**

- 60 % of system underground
- \$60-70M/year in under grounding projects
- 99+ % of cable in conduit or cable in conduit
- Cable failure replacement - all cables in conduit replaced



Asset Management - Replacement Strategies



Asset Management - Replacement Strategies



Predicted Cable Failures Derivation

Let

Installed Base Miles = B

Cummulate Miles remaining in Year n = MR(n)

Failures in Year n = F(n)

Failure Rate (as a function of remaining cable) in Year n = FR(n)

Average Miles per Failure = AMF

Proactive Replacement Miles in Year n = PM(n)

Probability that Proactive Replacement Prevents a Failure in Year n = P_n
 P_n is the expected value of a Hypergeometric distribution

Time	Cummulative Miles Remaining	Failures	Proactive
0	$MR(0) = B$	0	0
1	$MR(1) = MR(0) - (F(1) \cdot AMF) + PM(1)$	$F(1) = \frac{FR(1) \cdot B - P_1 \cdot PM(1)}{AMF}$	PM(1)
2	$MR(2) = MR(1) - (F(2) \cdot AMF) + PM(2)$	$F(2) = \frac{FR(2) \cdot MR(1) - P_2 \cdot PM(2)}{AMF}$	PM(2)
3	$MR(3) = MR(2) - (F(3) \cdot AMF) + PM(3)$	$F(3) = \frac{FR(3) \cdot MR(2) - P_3 \cdot PM(3)}{AMF}$	PM(3)
n	$MR(n) = B - \left(AMF \cdot \sum_{i=1}^n F(i) + \sum_{i=1}^n PM(i) \right)$	$F(n) = \frac{FR(n) \cdot MR(n-1) - P_n \cdot PM(n)}{AMF}$	PM(n)

Asset Management - Replacement Strategies



- **Determining Failure Rates**

- Need to know amount and type of cable (HMWPE, XLPE, TRXLPE, EPR, jacketed) installed in a certain year.
- Need to know the amount and vintage of the cable that failed.
- Need to convince your operating people of the importance of collecting cable failure information.
- Need to develop a simple method of collecting cable failure data.
- Need to be able to account for any proactive cable replacements.
- Maintain an outage database (Access database).
- Utilize statistical software (i.e. Weibull ++) to determine best fit for your data.
- Projections should include data confidence bounds (i.e. 90%).

Asset Management - Replacement Strategies



- **Cable failure tracking method**
 - Data collection
 - Outage reports
 - Map review
 - As-built
 - Equipment failure reports
 - Cable failure database
- **Cable failure rates**
 - Use of cable failure database
 - Statistical method for determining failure rates
 - Examples of cable failure rates
 - Feeder and branch circuit reliability model

Asset Management - Replacement Strategies



Microsoft Access - [1964-Present FAILURE LOG1 : Table]

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DATE	CIR	EFR #	DIST	F,L	# COND	COND SIZE	COND MATL	IIS THICK	IIS MATL	IIST TYPE	# FT	YR MFG	MFGR	IIST WO	IIST DATE	IIMF
08/31/2003	177		NE	L	3 #2		CU	220	H	C	519			5318740	8/74	
08/30/2003	42		CM	L	3 #2		CU	220	H	C	250			5380860	1975	
08/30/2003	357		EA	L	2 #2		CU	220	H	C	100			5269790	3/73	
08/30/2003	521		NE	F	3 750		AL	175	X	C	222			5746052	1/83	
08/30/2003	215		NC	L	1 #2		AL	175	X	P	431			2013200	2/84	
08/29/2003	202		NC	L	3 #2		CU	220	H	C	370			5177445	7/72	
08/29/2003	144		BC	L	3 2/0		AL	175	X	C	415			5528190	4/77	
08/29/2003	207		NC	L	3 #2		AL	175	X	P	256			5606280	5/78	
08/29/2003	463		CM	L	3 2/0		AL	175	X	C	30			5748600	8/80	
08/28/2003	EB2		NE	L	3 #2		AL	175	X	P	310			5597210	12/77	
08/28/2003	96		EA	L	1 #2		CU	220	H	P	140			5433660	3/75	
08/27/2003	502		NE	L	3 2/0		AL	175	X	C	321			5815940	12/81	
08/27/2003	383		BC	F	3 1000		AL	175	X	C	520			5710550	5/80	
08/27/2003	250		BC	F	3 750		AL	175	X	C	450			n/a	n/a	
08/26/2003	793		OC	L	1 #2		AL	175	X	P	165			5791900	12/81	
08/26/2003	323		CM	L	1 #2		CU	220	H	C	380			503572	3/70	
08/26/2003	497		NC	L	1 #2		AL	175	X	C	135			5521430	1/77	
08/26/2003	471		NE	L	3 2/0		AL	175	X	C	80	1981	Pirelli	n/a	n/a	
08/26/2003	968		BC	L	3 2/0		AL	175	X	C	110			2073800	7/84	
08/26/2003	276		BC	L	3 2/0		AL	175	X	C	562			5707120	2/80	
08/25/2003	257		CM	L	3 2/0		AL	175	X	C	554			5611990	11/78	
08/25/2003	62		NC	L	3 #2		AL	175	X	C	87			5359720	5/74	



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Asset Management - Replacement Strategies



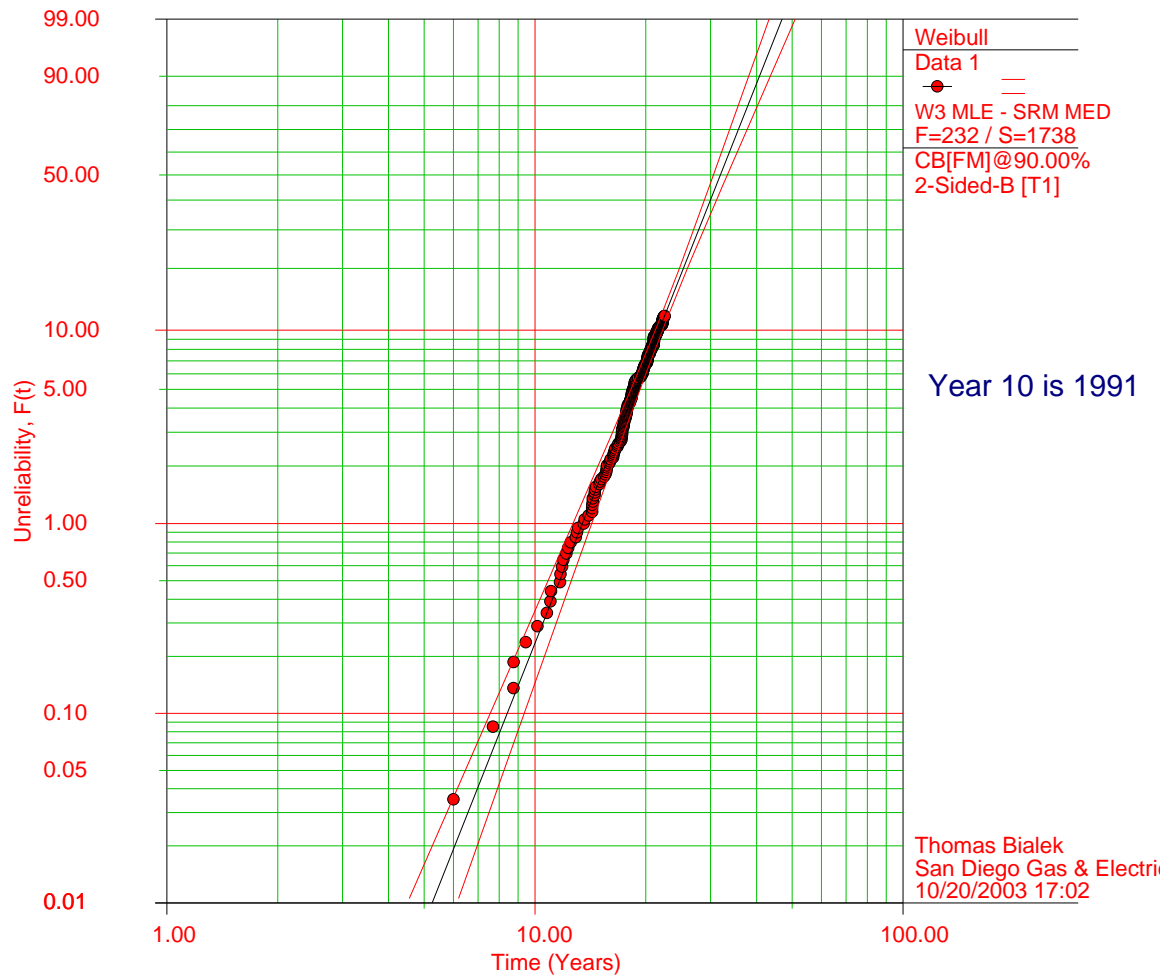
1981 XLPE			
321 Conductor Miles Installed			
Sample	Failure Time (Years)		
1	5.19		
2	6.88		
3	7.93		
4	7.94		
5	8.63		
6	9.34		
7	9.96		
8	10.21		
9	10.25		
10	10.89		
-	-		
225	21.51		
226	21.56		
227	21.61		
228	21.64		
229	21.64		
230	21.64		
231	21.64		
232	21.70		
1742	??		

Asset Management - Replacement Strategies

ReliaSoft's Weibull++ 6.0 - www.Weibull.com



Probability - Weibull 1981 XLPE



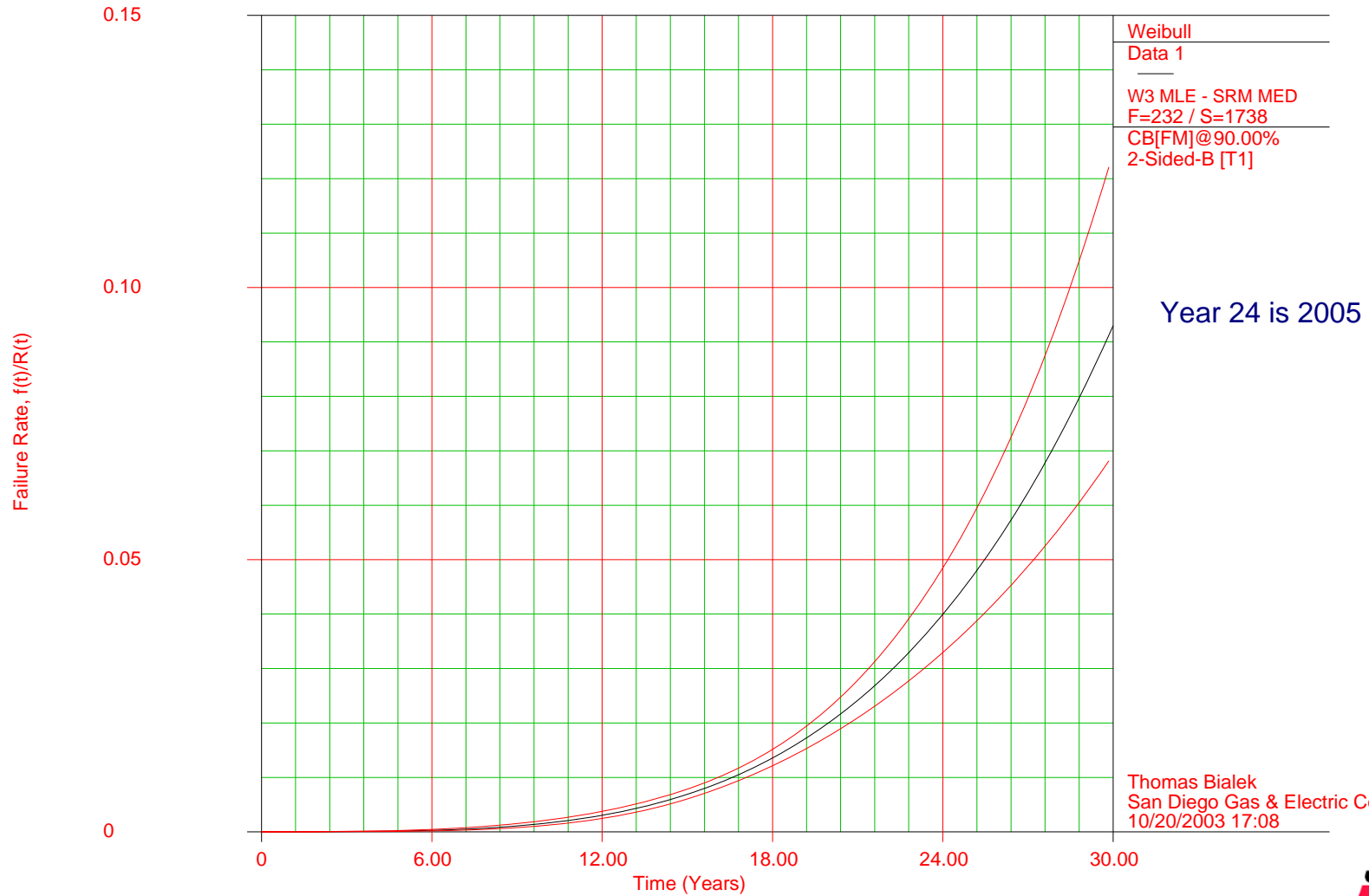
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Asset Management - Replacement Strategies



ReliaSoft's Weibull++ 6.0 - www.Weibull.com

Probability - Weibull 1981 XLPE

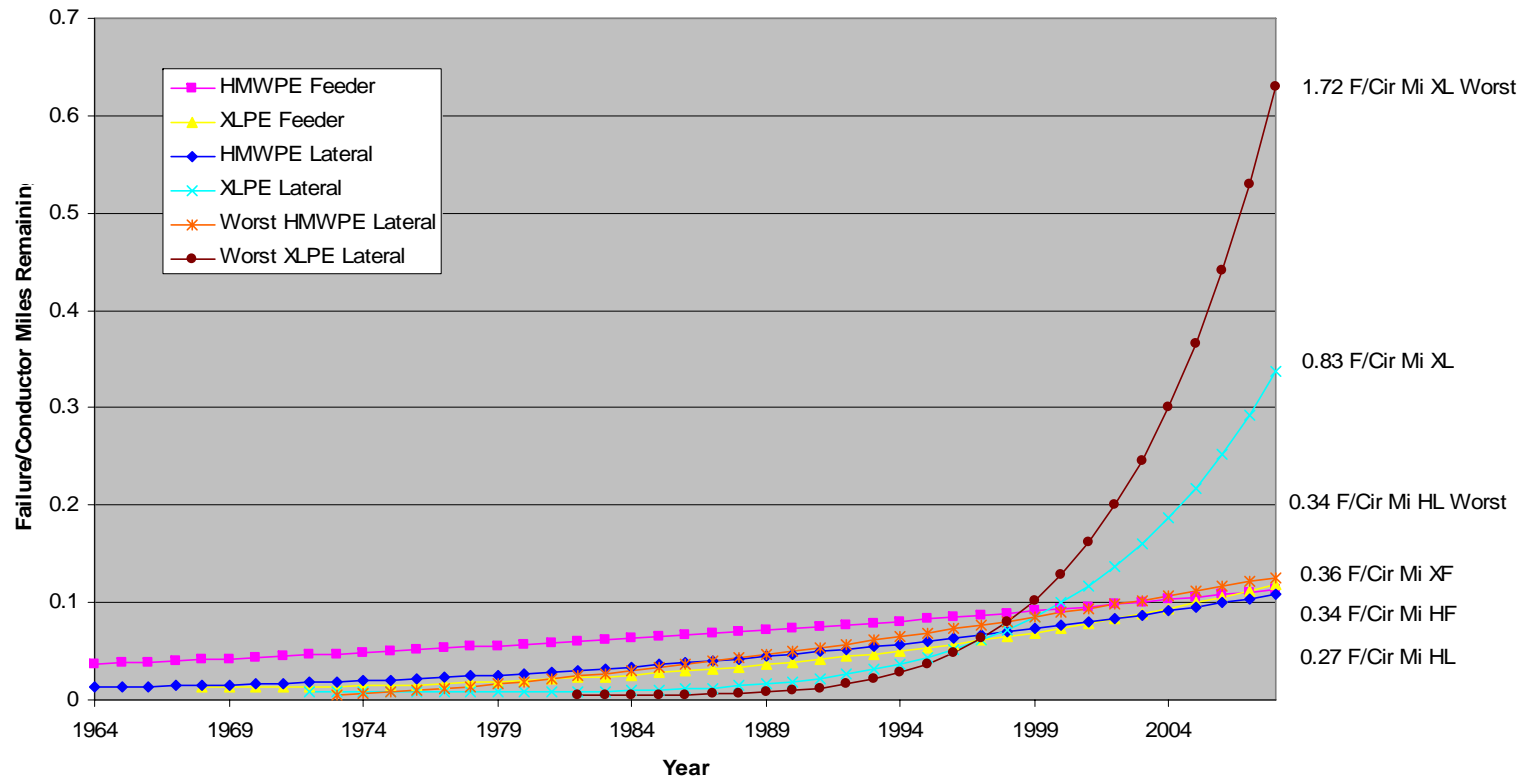


$\beta=4.9048, \eta=34.3848, \gamma=-0.8162$

Asset Management - Replacement Strategies



Summary of HMWPE, XLPE and Worst Vintage Lateral UG Cable Failure Rate (Upper 90% CL)
2003



Asset Management - Replacement Strategies



Failure rates by conductor mile in outages/year		
Cable Type	All vintages	Bad vintages
XLPE-PEJ	0.00073	N/A
XLPE	0.554	0.643
HMWPE	0.102	0.155

Options	CAIDI Gain	Units
Sub-Fusing	N/A	N/A
Looping	48	minutes
Fault Indicator Addition	20	minutes
Cable Change Out	N/A	N/A

Other Constants	
System Average CAIDI (min)	217
System Customers	1,300,000
LACC Factor	0.1211

Annualized Cost Savings per circuit foot:		
Cable Type	vintages	Bad vintages
XLPE	\$ 3.40	\$ 3.96
HMWPE	\$ 0.63	\$ 0.95

	Phase
Cable Replacement Cost	\$ 6.50 Single phase
(per foot)	\$ 9.30 2-phase
	\$ 12.00 3-phase

DO NOT CHANGE ANY DATA ABOVE THIS GRAY LINE.

Cable Change Out		
Item	Phase	Quantity
Main Branch Total Footage	Single	-
	2-phase	-
	3-phase	-
Replaced Branch Footage	Single	-
	2-phase	-
	3-phase	-
Failure Rate		0.643
Annualized Cost Savings Rate	\$	3.96
Branch Total Customers		272
Cable Replacement Cost	\$	-
Other Costs	\$	-
Project Cost	\$	-
Gain In Number of Failures		0.00000
SAIDI Gain		-
SAIFI Gain		-
PBR Gain	\$	-
Annualized Cost Savings	\$	-
RTR		0.000

Sub-Fusing		
Item	Phase	Quantity
Main Branch Total Footage	Single	-
	2-phase	-
	3-phase	-
Sub-fused Branch Footage	Single	-
	2-phase	-
	3-phase	-
Failure Rate		0.643
Branch Total Customers		272
Sub-fused Branch Customers		58
Project Cost	\$	25,000
SAIDI Gain		-
SAIFI Gain		-
PBR Gain	\$	-
RTR		0.000

Looping		
Item	Phase	Quantity
Main Branch Total Footage	Single	-
	2-phase	-
	3-phase	-
Failure Rate		0.643
Branch Total Customers		272
Project Cost		\$ 25,000
SAIDI Gain		-
PBR Gain	\$	-
RTR		0.000

Fault Indicator Addition		
Item	Phase	Quantity
Main branch total footage	Single	-
	2-phase	-
	3-phase	-
Failure Rate		0.643
Branch Total Customers		272
Project Cost		\$ 8,000
SAIDI Gain		-
PBR Gain	\$	-
RTR		0.000

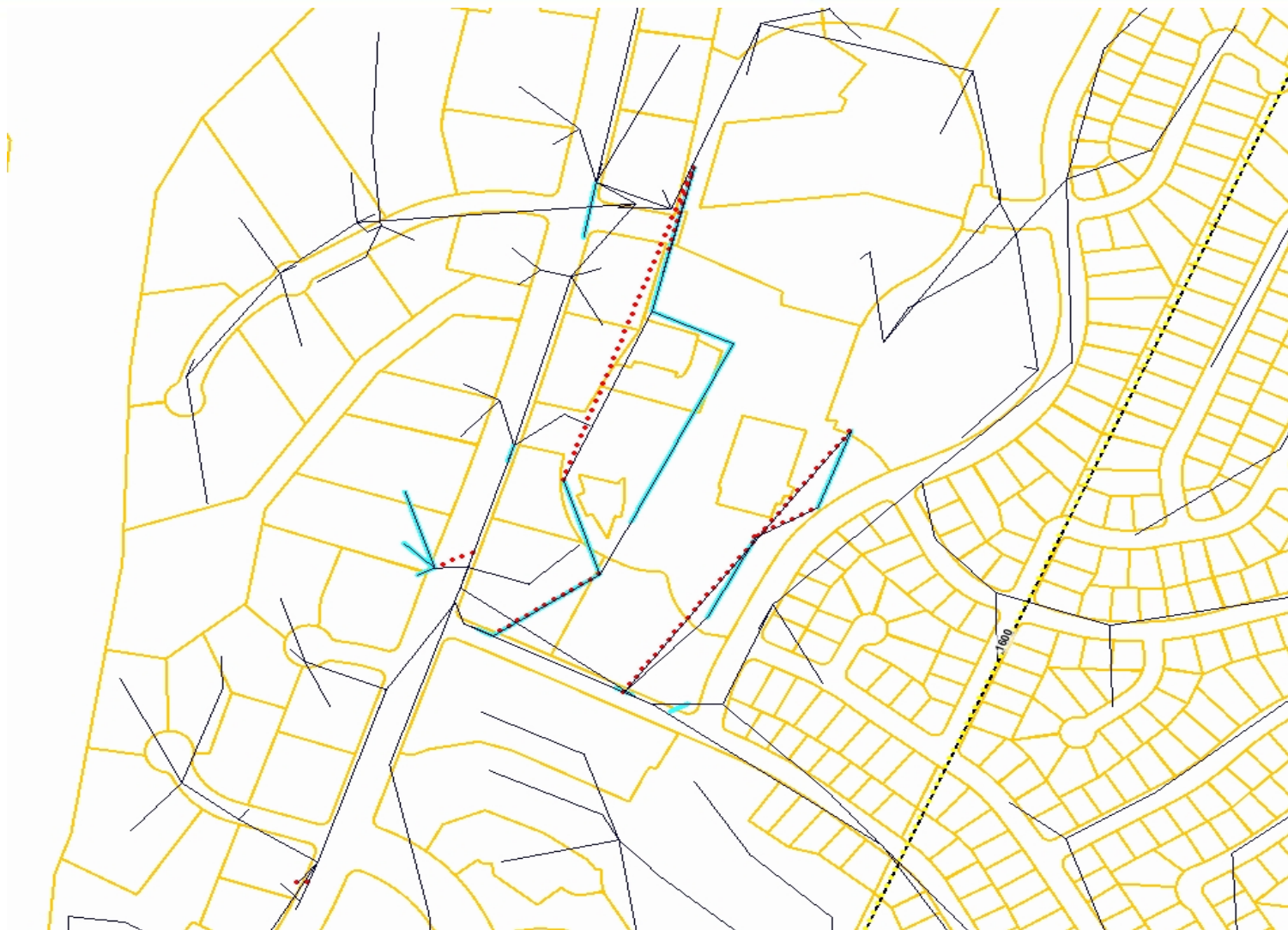
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INPUT IS ONLY REQUIRED IN THE TAN CELLS.

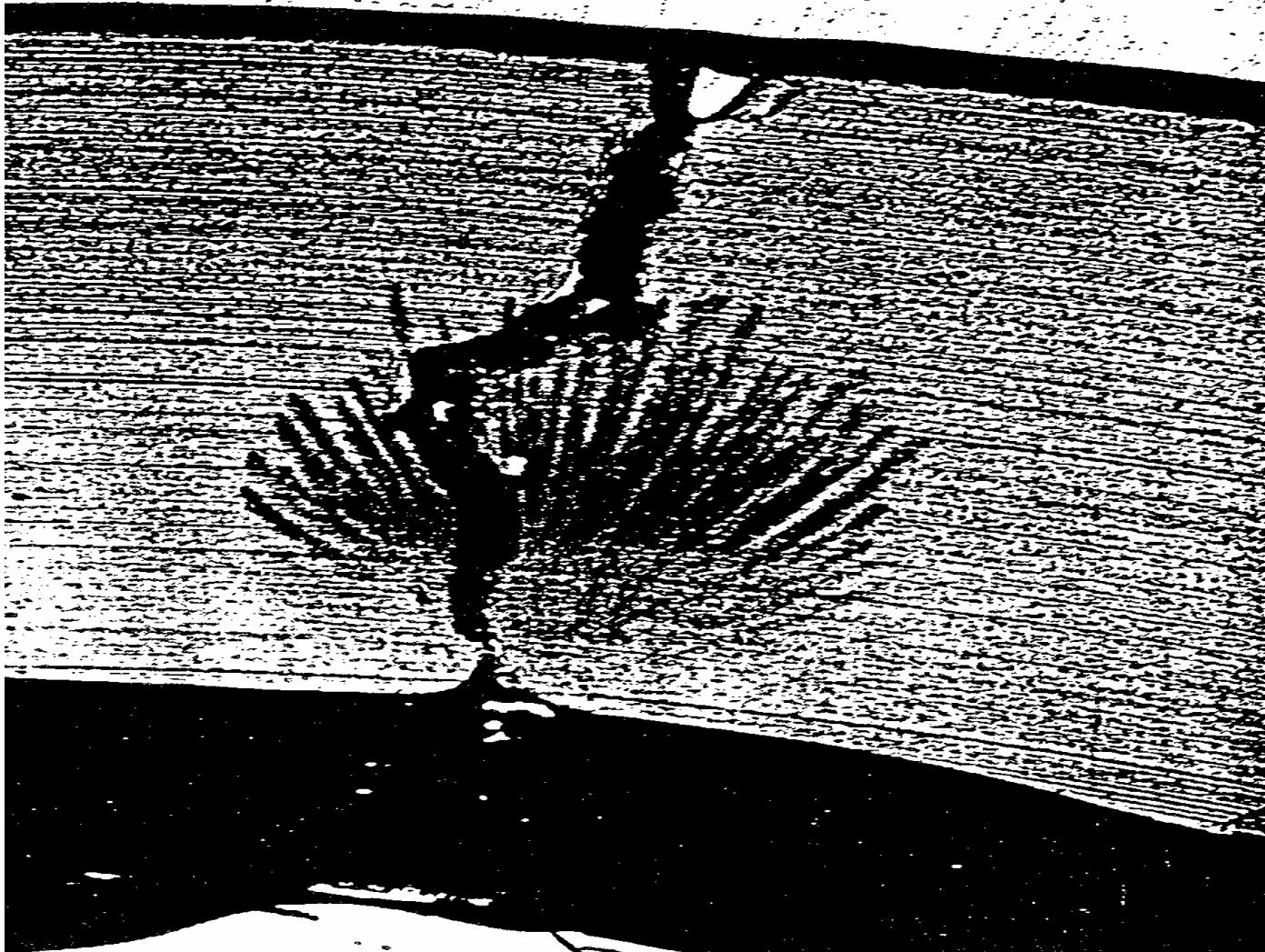


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Asset Management - Replacement Strategies



Problem



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Review Historical Information

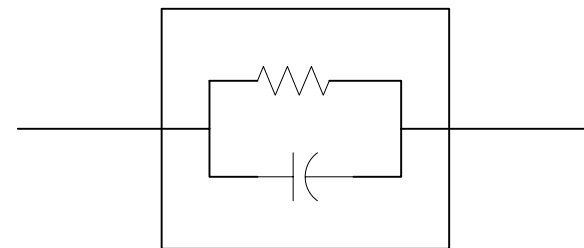
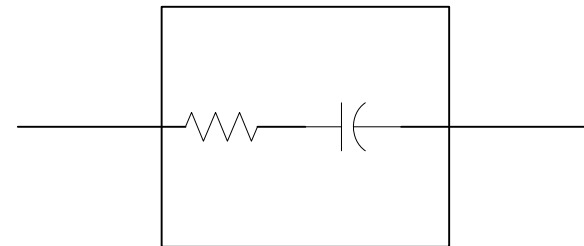


- **Limitations of existing off-line test methods**
 - Off-line tests require an outage
 - AC 60 Hz and Very Low Frequency
 - Cost and size of test equipment
 - Breakdown Tests limited correlation to cable life
 - DC
 - Voltage distribution within cable insulation
 - Partial Discharge
 - Location specific
 - 90+ % of PD in joints and terminations
- **Need robust field test**
 - Preferably on-line
 - Measures average and location specific properties

Cable Diagnostic Testing Development at SDG&E



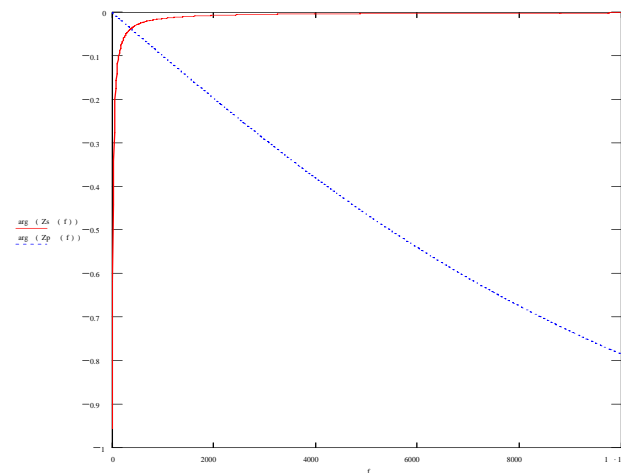
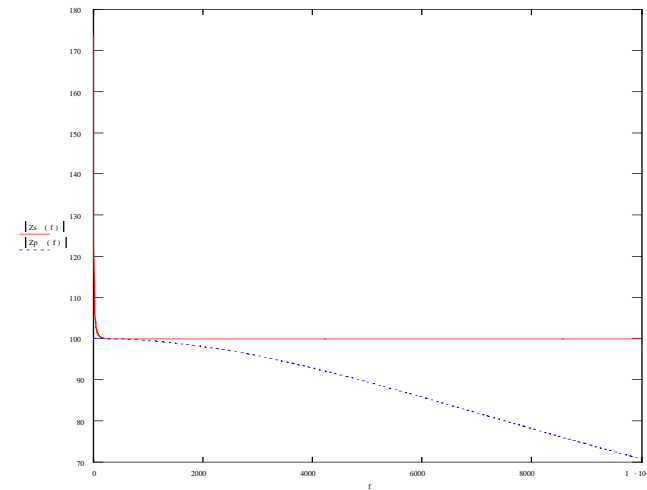
- Two black boxes
 - $Z=100 \text{ Ohms}$ at 60 Hz
- How to distinguish between them?



Cable Diagnostic Testing Development at SDG&E



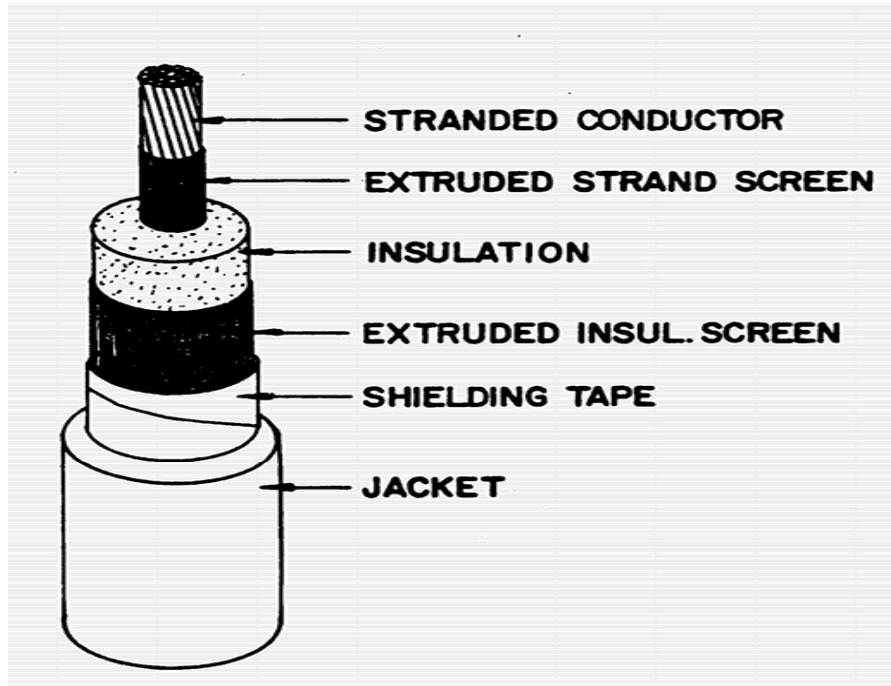
- Determine impedance magnitude and phase angle vs frequency
 - Top magnitude
 - Bottom phase angle



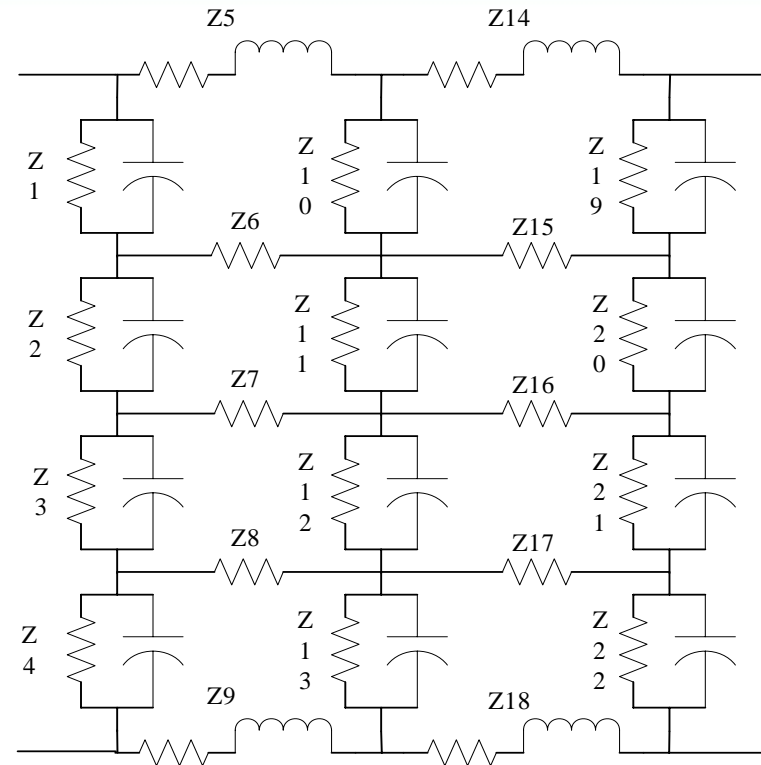
Cable Diagnostic Testing Development at SDG&E



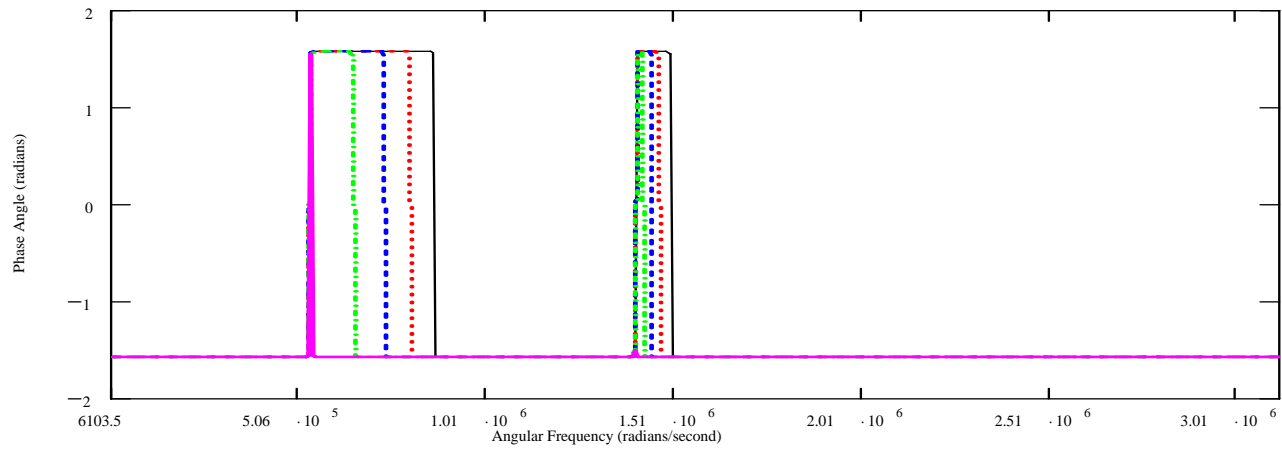
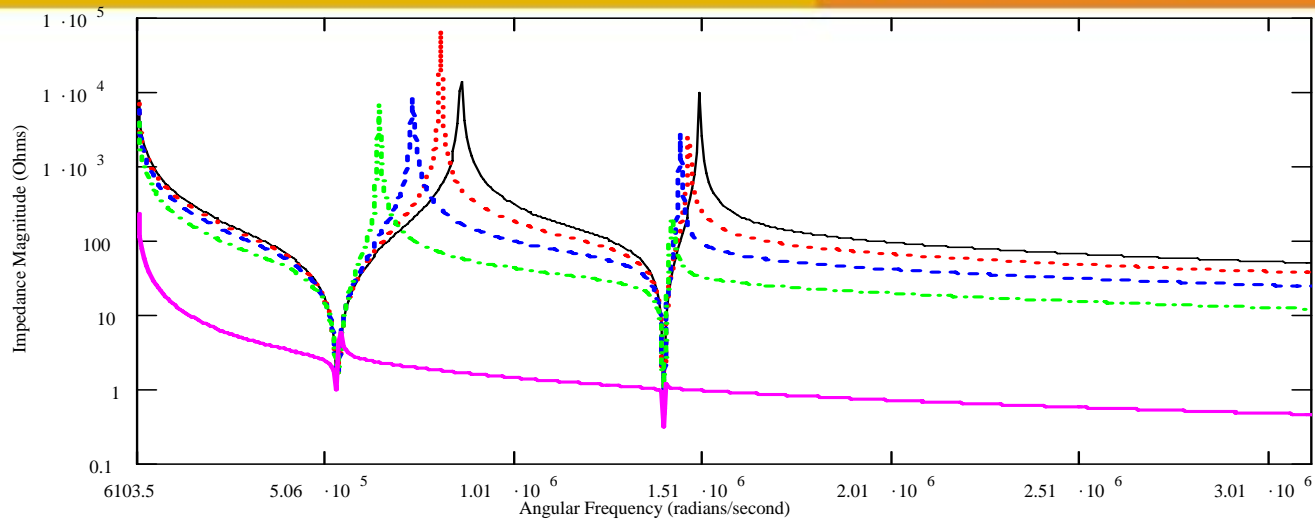
- Electric circuit view



- $L=300$ ft, 2/0 AL, 175 mils XLPE
- Insulation
 - Equivalent capacitance 32 nF
 - Equivalent resistance 3 Gigaohms
- Conductor
 - Resistance 30 milliohms
 - Inductance 0.3 mH



Theoretical Model Results

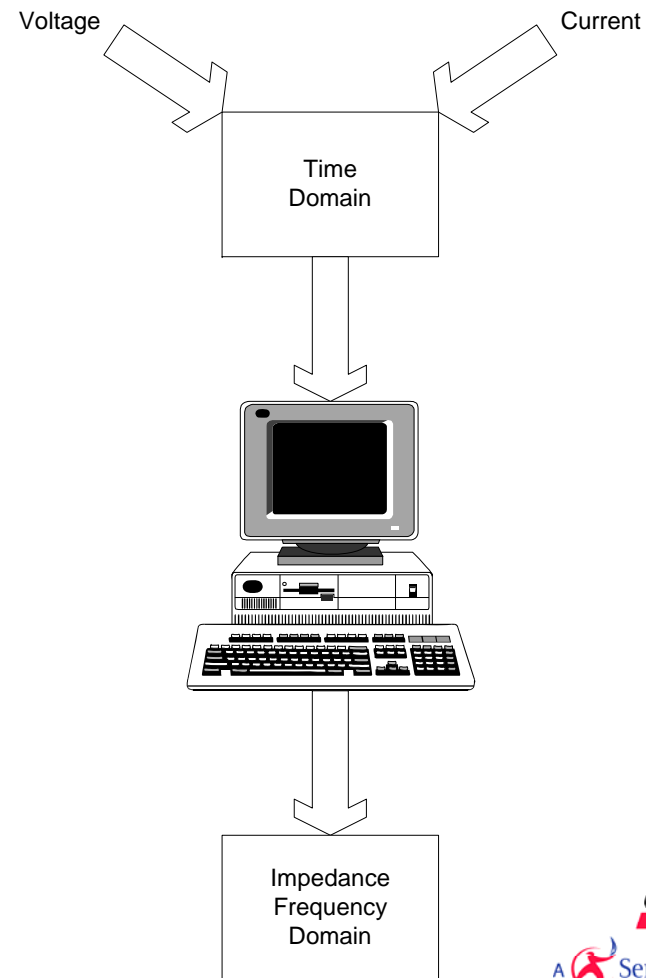


- No Water Tree
- - - Z1 Water Tree
- - - Z1-Z2 Water Tree
- - - Z1-Z3 Water Tree
- Z1-Z4 Water Tree

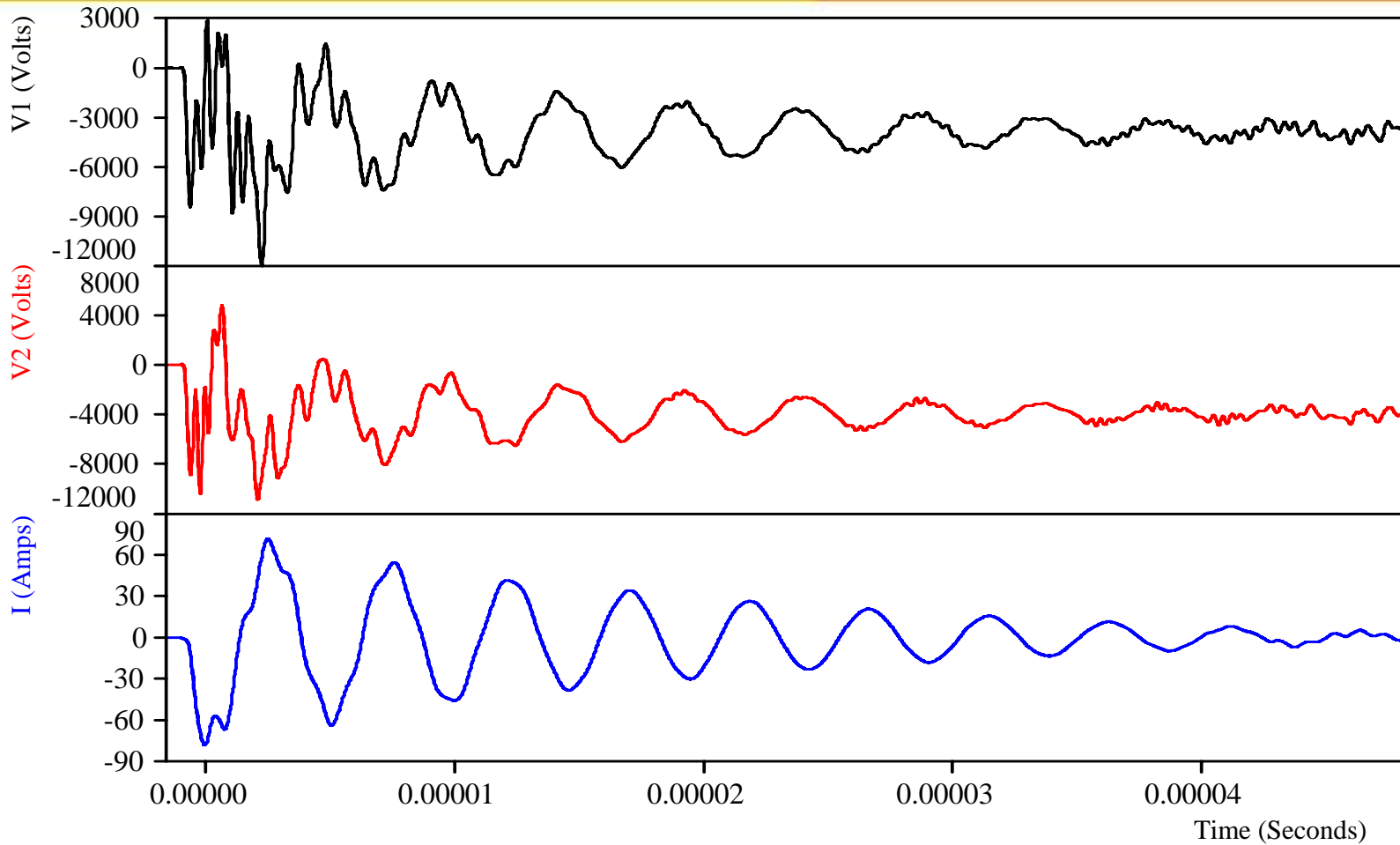
Cable Diagnostic Testing Development at SDG&E



- Two methods to determine impedance vs frequency
 - Sweep frequency spectrum
 - Apply impulse, calculate Fourier transform



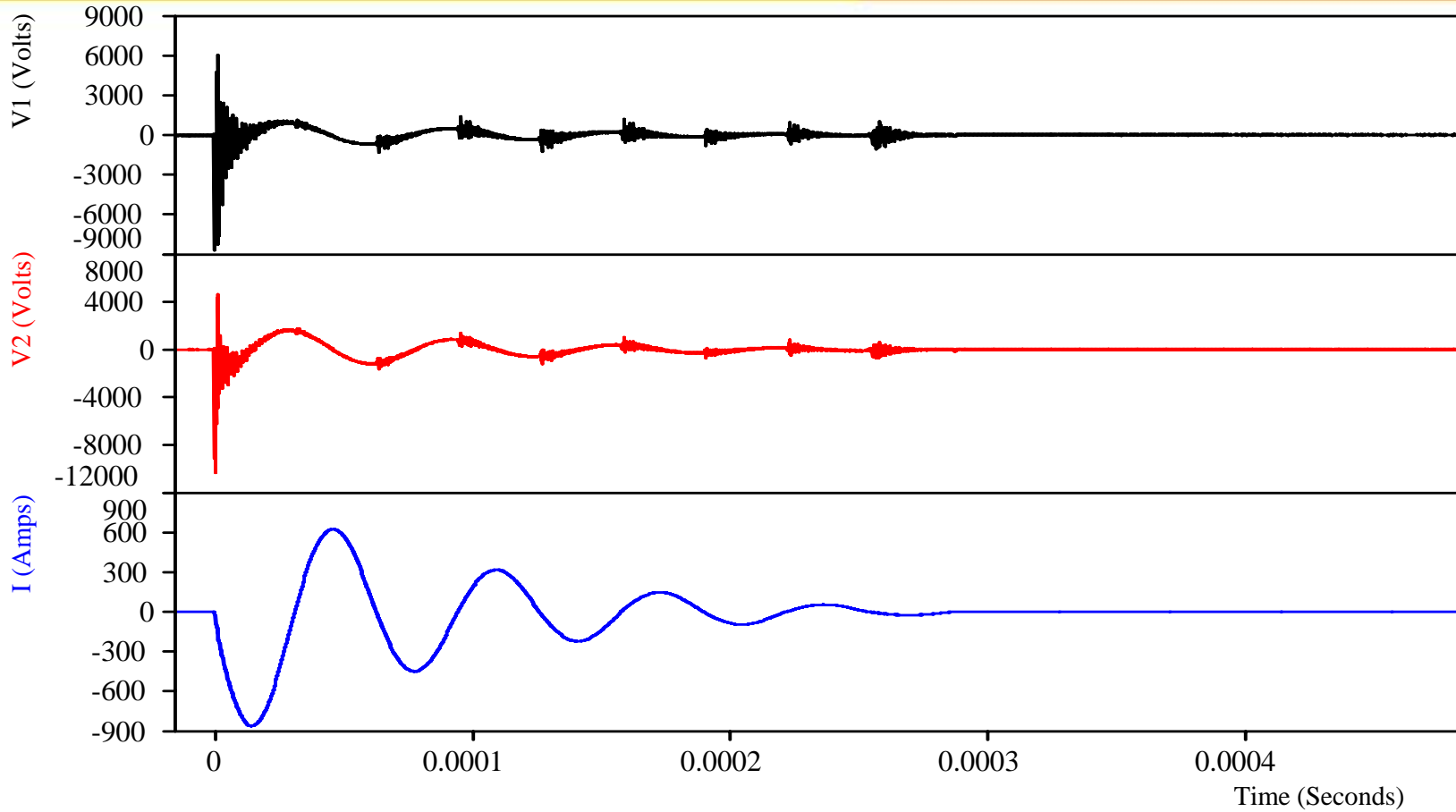
Test Results



- Test 1, Good Cable, Measured Voltages at Source, V1, and Open End, V2, and Current vs Time, L=30 ft, 1000 kcmil AL, 175 mils XLPE

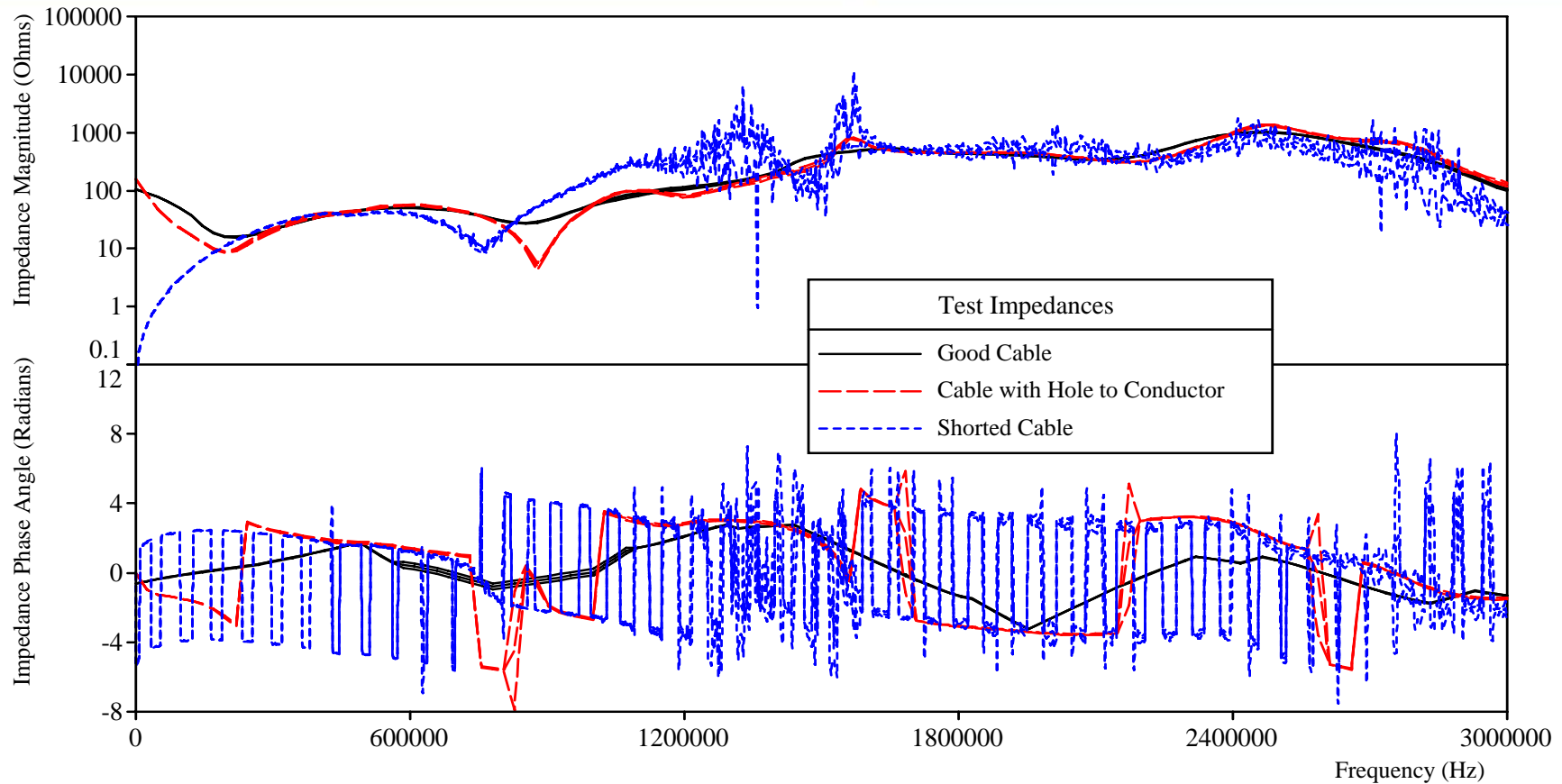


Test Results



- Test 3, Shorted Cable at 15 ft, Measured Voltages at Source, V1, and Open End, V2, and Current vs Time, L=100 ft, 1000 kcmil AL, 175 mils XLPE

Test Results



- Measured Impedance Spectra Inter-Test Comparison, L=100 ft, 1000 kcmil AL, 175 mils XLPE
 - Top Trace Average Impedance Magnitude Spectra, Upper and Lower 95% Confidence Bounds
 - Bottom Trace Average Impedance Phase Angle Spectra, Upper and Lower 95% Confidence Bounds



Conclusions



- An on-line diagnostic to prioritize replacement is needed
- Theoretical model good predictor of changes in cable condition
- New cables provide useful baseline
- Tests on field aged cable appear to distinguish cable conditions
- Combination of theoretical and tests promising and appears capable of discerning between field aged cable level of degradation