Assuring Critical Cable System Reliability with Effective Diagnostics

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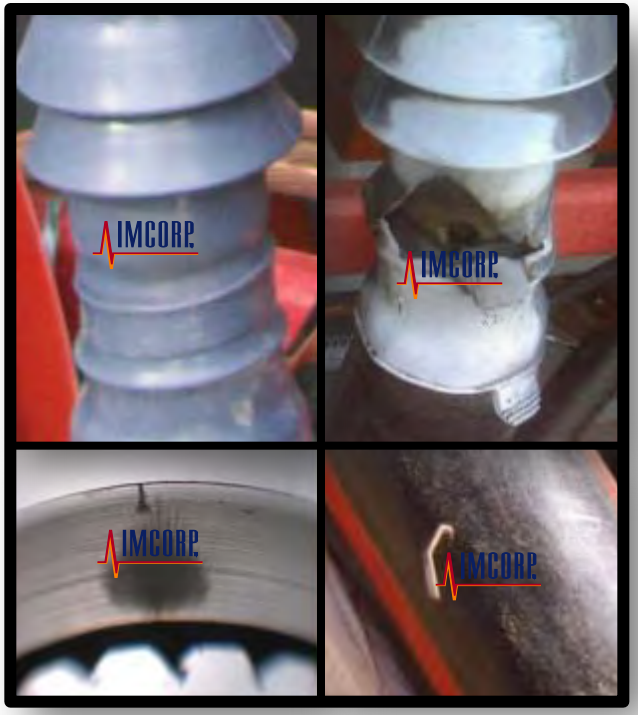

Executive Summary

- Critical industries have lost 100's of millions of dollars due to defective cable systems (mostly workmanship) & ineffective tests
- New extruded cable systems predominately fail by a process of erosion associated with PD, not conduction (leakage detectable by HIPOT)
- High Potential (HIPOT) (AC & DC) tests are intentionally destructive & do not assure reliability
- Repeating the manufacturers' off-line 50/60Hz PD QC test in the field is only effective way to assure insulation system meet design life.
- Over the last decade, one diagnostic technology has been demonstrated to effectively reproduce factory test comparable result in the field. (DSD technology)

What is a critical cable system?

Example Categories

- Life support
- 24x7 facilities
- Power generation
- Government facilities
- Military facilities
- Manufacturing facilities
- Transportation facilities
- Large public venues

Example Facilities

- Hospitals, elder care facilities
- Large IT, bio tech
- Nuclear, fossil, renewable
- Gov. buildings, DOE, DOD
- Army, Air force, Navy
- Injection mold, steel, IC chip
- Air & rail support facilities
- Stadiums, arenas

Question

Which cable system test would you consider best practice to assure the reliability of critical cable systems?

- DC withstand
- VLF AC withstand
- Tangent delta
- On-line PD
- Off-line 50/60Hz PD

What
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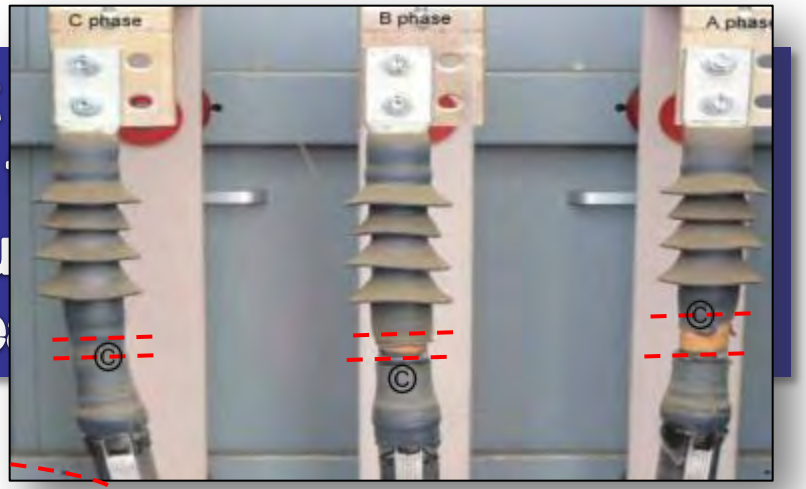

Question:

What is the typical economic impact of a critical cable system failure?

- $100k+
- $10k to $99k
- $5k to $9k
- <$5k

Critical Power Plant Case Study

Excerpt from client's internal report

- All systems pass VLF AC HIPOT acceptance test
- Failure occurs during the first year of operation
- Estimated production lost = $156,212.00
- Emergency fault location labor cost = $44,670.00
- Emergency repair cost = $13,285.00
- **Total Loss = $214,167.00**
- DSD 50/60Hz off-line PD test performed, several additional cable insulation & accessory defects pinpointed

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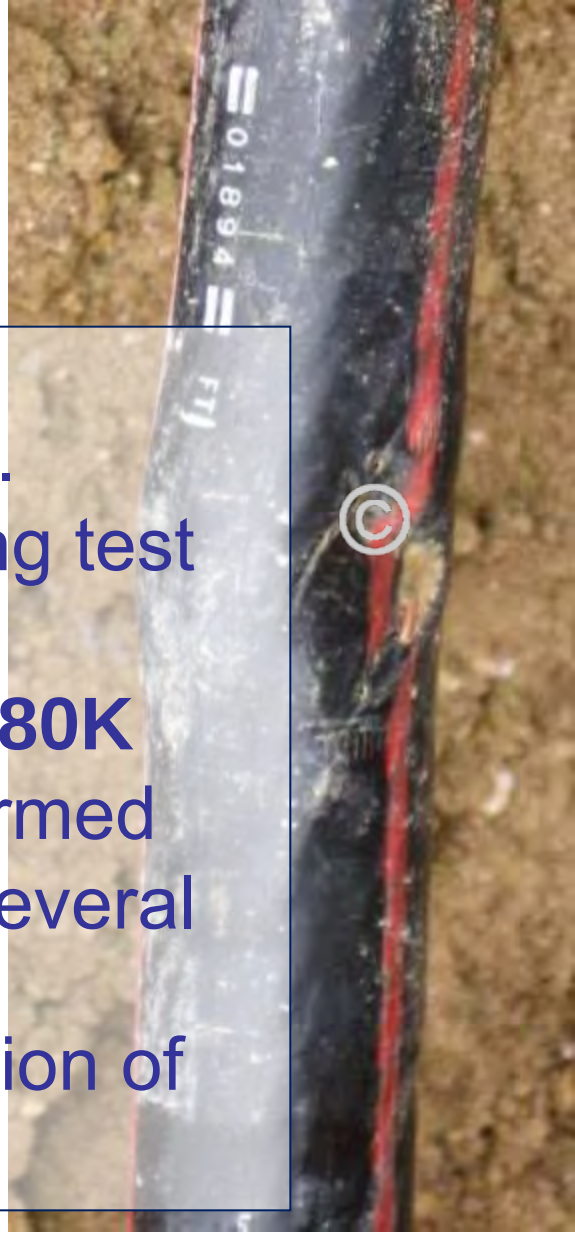
Critical Plant Case Study

- Client opted not to perform DSD test.
- All cables pass HIPOT commissioning test
- Experienced fault after five months
- **Production loss & failure cost =$480K**
- DSD 50/60Hz off-line PD tests performed
- Pinpoints additional cable defect & several termination defects
- No failures for 4 years since completion of repairs and successful retests



Insulation Defect Defined by IEEE, ICEA, IEC & VDE Standards

Standards

Standard	Joints	Terminations	Separable Connectors	MV Cable	HV Cable
IEEE/ICEA	404_2006	48_1996	386_2006	S_97_682_2007	S-108-702-2009
VDE DIN	0278_629_1	0278_629_1	0278_629_1	0276_620	-
IEC	60502_4	60502_4	60502_4	60502_2	62067

Thresholds

IEEE/ICEA	<3 pC@ ≥ 1.5Uo	<5 pC@≥ 1.5xUo	<3 pC @≥ 1.3xUo	<5 pC @≥ 4.0xUo*	<5 pC @≥ 2.0xUo
VDE DIN	<10pC@≥ 2.0Uo	<10 pC@≥ 2.0xUo	<10 pC @≥ 2.0xUo	<2 pC @≥ 2.0xUo	-
IEC	<10pC@ ≥1.7Uo	<10 pC@≥ 1.7xUo	<10 pC @≥ 1.7xUo	<10 pC@≥2.0/1.7xUo	<10pC@≥1.5Uo

- Uo is cable system's voltage at 50/60Hz
- All pC values are in apparent charge

* actually 200V/mil (7.87kV/mm)

Question:

Which test can fail (detect) a higher percentage of cable system defects, a DC HIPOT or an AC HIPOT? (e.g. VLF HIPOT)

Question:

What percent of cable defects can an VLF AC HIPOT fail (detect)?

- >95%
- >70%
- < 40%
- < 5%

What percent can a DC HIPOT fail?

Critical Power Plant Cable System Case Study

- All systems pass VLF AC HIPOT
- 1st failure on energization
- 2nd failure within one year
- DSD PD Test performed
- Defects pinpointed: 1 cable, 1 splice & 10 terminations

In service failure 1
Termination contamination

In service failure 2
Cable damage

How long will massive workmanship defects last under an AC HIPOT?

Cable Accessory Damage
IEEE 48, IEEE 404, and IEEE 386 Noncompliant

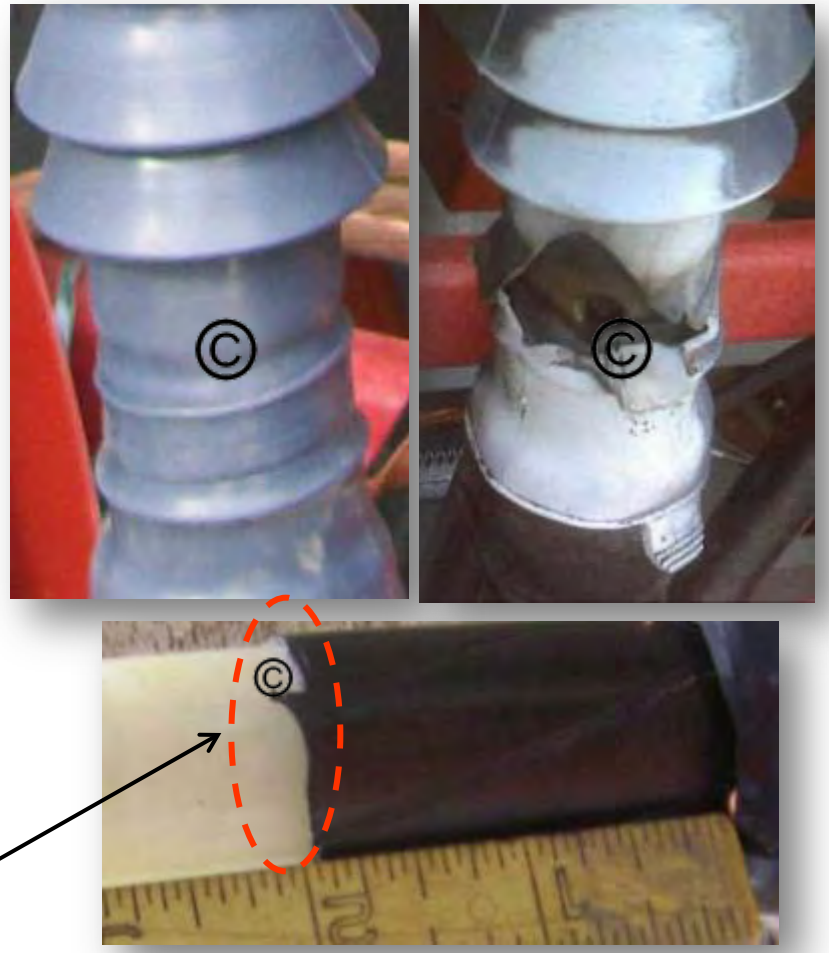
Knife Cut 1/3rd of Insulation Wall

Poor Cleaning -Semicon Residue

Stress Control Misplaced

Critical Cable System Case Study

- All 12 terminations at substation determined to be defective by DSD
- E. contractor disagreed
- VLF HIPOT performed
- All cable systems passed
- Termination fails in 3 weeks time
- All repaired & retested
- Some terminations still did not pass IEEE standards



Question:

What is the likelihood of an on-cab

Cable System 731

- 567 -NO PD in cable
- 164 -with PD in cable

< 5% of cable defects w/PDIV ≤ 1 Uo

- >70%
- < 40%
- < 5%

Critical Power Plant Cable System Case Study

- All systems pass DC HIPOT
- 9 failures in 3yrs, >$300k
- All systems pass on-line PD test -3 failures next yr.
- Total losses >$400k
- DSD PD Test performed
- Defects pinpointed 6 cable, 4 splice & 5 terminations
- After repairs & retests -no failures in 5 yrs.

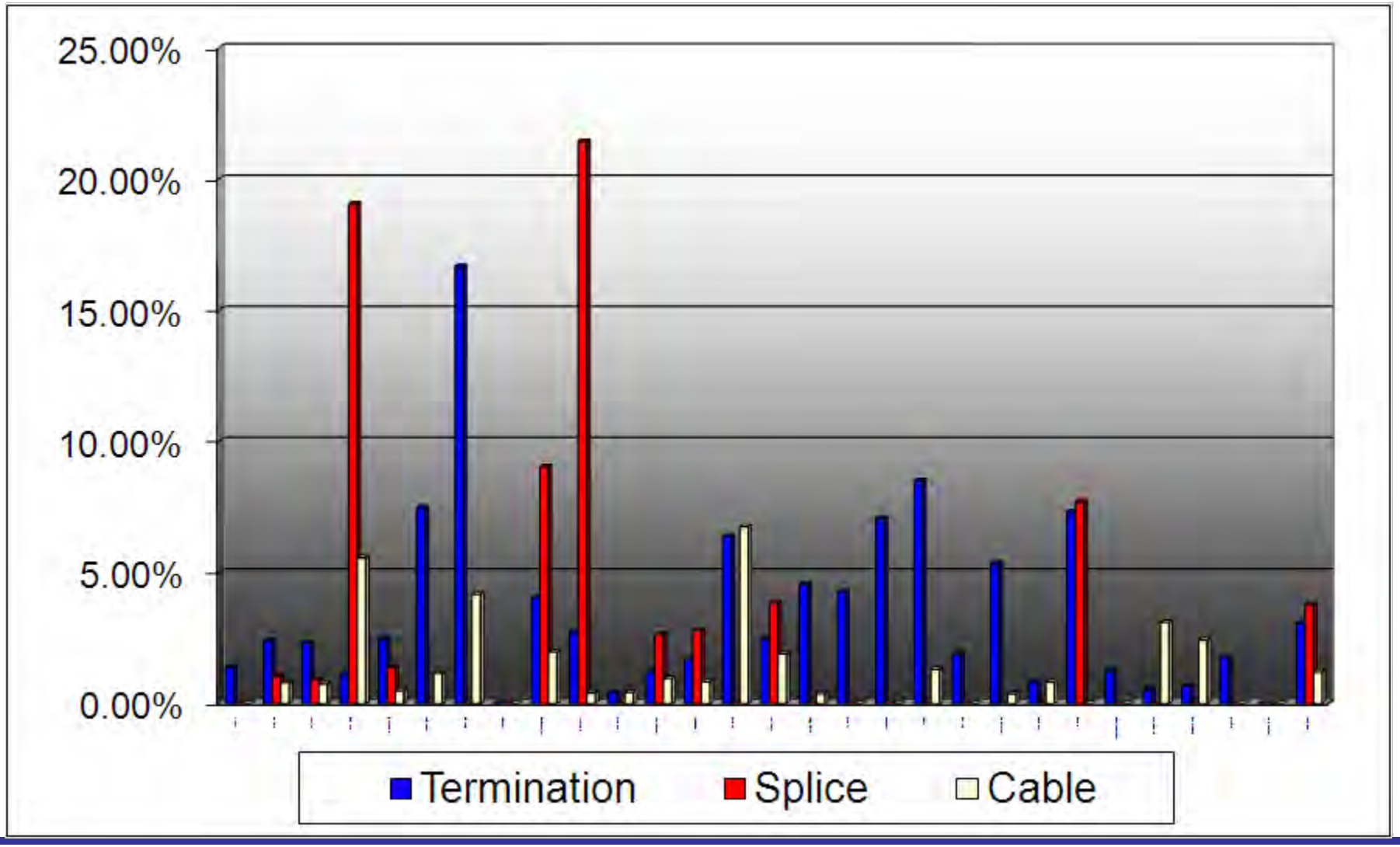
Case Study
Critical Industrial Plant

- Cable systems routinely pass DC maintenance test
- **Plant historical avg. 1 cable failure/ 3 years**
- Fault records indicates mostly termination issues
- Off-line PD diagnostic test performed in 2000
- 40 repairs recommended
- **No failures since diagnostic & repairs 2000 (8 yrs)**
- Historical failure rate predicted 2 more failures

Plant A: Pareto Analysis

Cables Diagnosed (3 phase)	44
Termination Defects	40
Splice (joint) Defects	9
Cable segments recommended for replacement	3

2009 Selected Project Performance

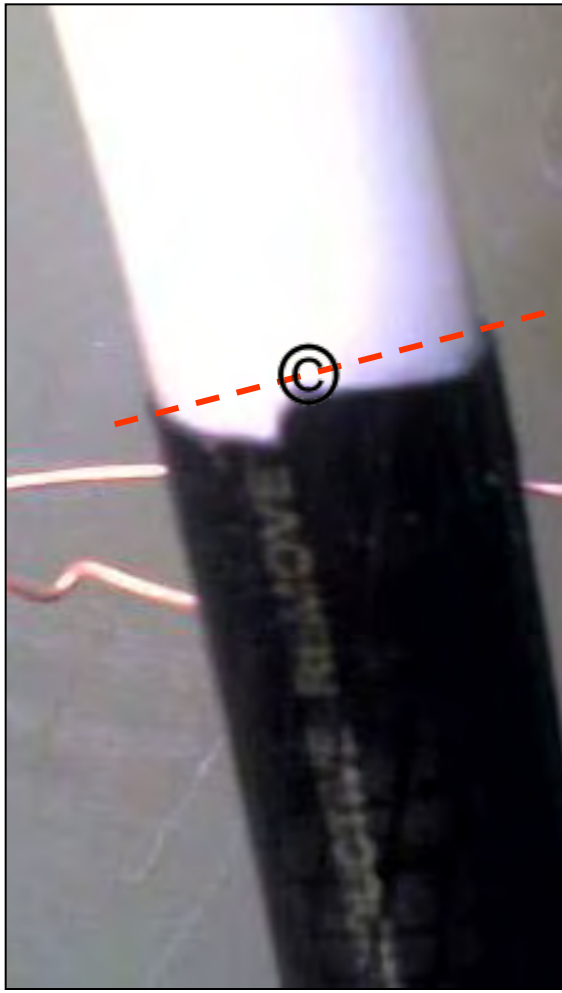


Percentage of components **NOT** passing manufacturers' standards

Critical Client Experience 2003-2009

- Failures after (no DSD)
  - DC HIPOT
  - VLF HIPOT
  - VLF Tangent Delta
  - On-line PD

  >150
- Defects pinpointed by DSD after other tests ‘pass’ cable >403
- Failures after DSD 1*



*Based on over 20,000 tests; excluding post test damage such as dig-ins, thermal design issues

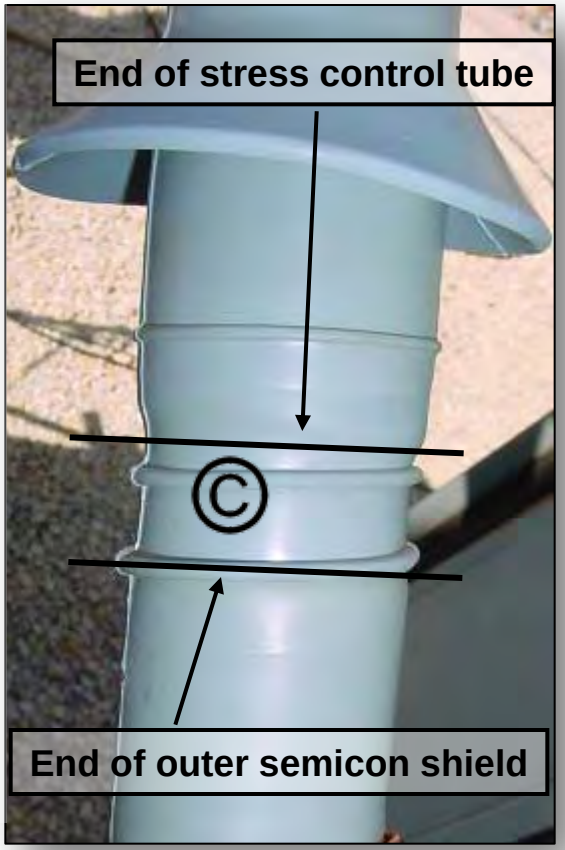
Summary

- 100's of millions of dollars have been lost due to inept tests and cable system defects –primarily workmanship
- Modern cable systems fail by a process of erosion associated with PD (not conduction detected by a HIPOT)
- High Potential (HIPOT) (AC & DC) tests are destructive & do not assure reliability
- Repeating the manufacturers' PD diagnostic test in the field is only way to assure insulation system design life
- The off-line 50/60Hz PD diagnostics (Defect Specific Diagnostics -DSD) is the only technology which can repeat the manufacturer's QC test in the field
- Where:
  - financial risk is significant
  - contractor warranties are involved
  - reliability is critical
  - significant assets need to be prioritized for replacement

DSD technology can assure cable system reliability at the lowest cost.

Case Study
Critical Industrial Plant

- 12 new 15kV cables installed
- DC HIPOT –all cable systems pass
- DSD 50/60Hz Off-line PD diagnostic
- Termination defect pinpointed per IEEE 48
- Stress control material accidentally misplaced
- Repair proven after successful retest
- Client says an outage > USD1million

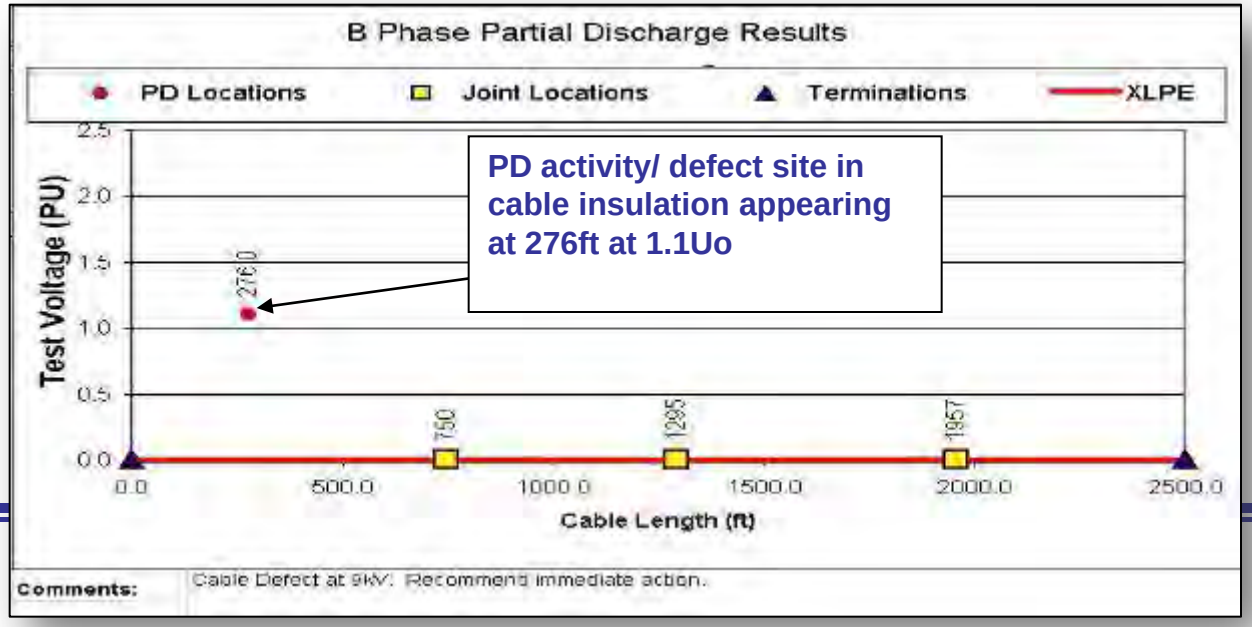


Example of misplaced stress material

Case Study

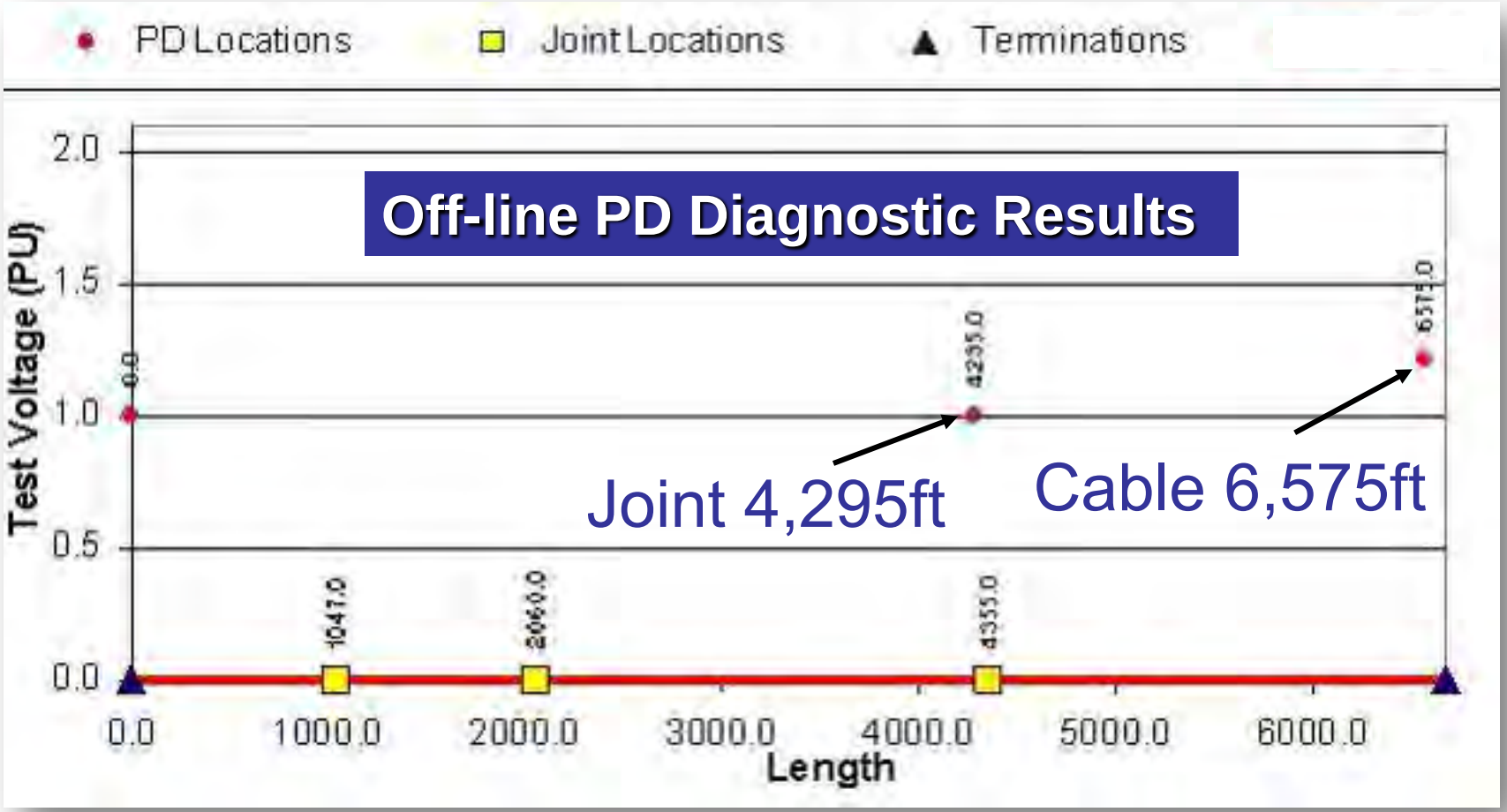
Critical Industrial Plant

- Off-line PD diagnostic survey performed
- Only one defect identified in cable insulation
- Immediate action was recommended due to severity
- Operating constraints force re-energization
- Cable fails within 24 hrs at the indicated defect site

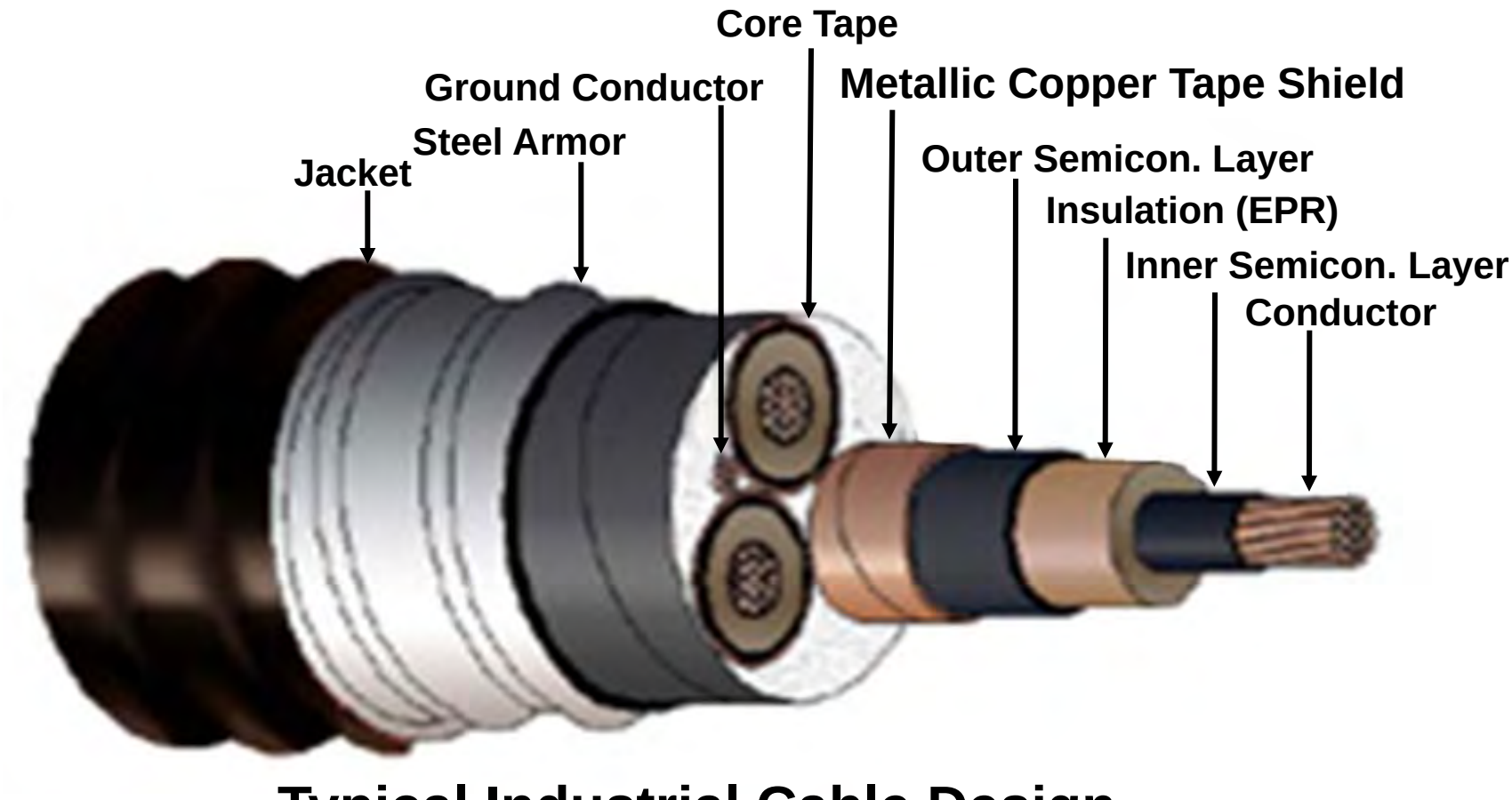


Example Comparison Case Study

Type 1: DC, AC Type 2: T.D., On-line PD



Tape Shield Cable Systems



Typical Industrial Cable Design

Aging Metallic Shield

- History – PILC
- Shields can start to corrode <5 yrs- no contact in overlaps
- Fault current can burn through shield
- Non-destructive diagnostics/fault location techniques limited on corroded shields

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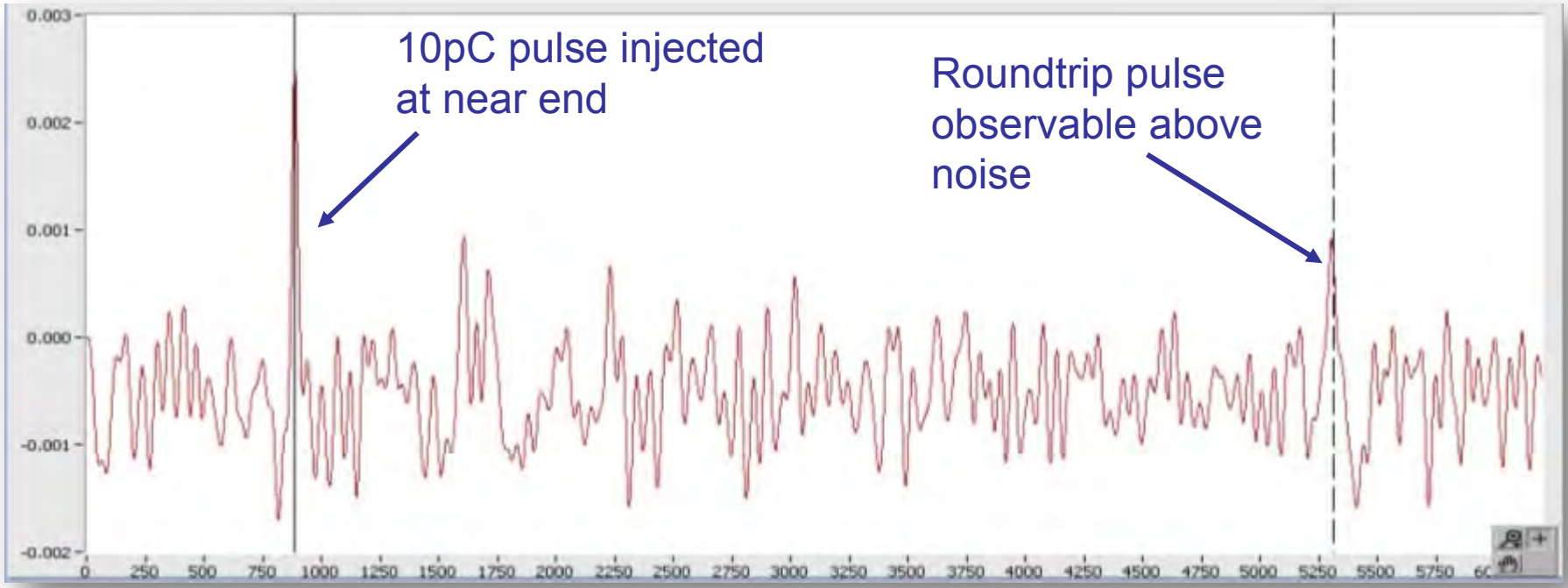
Pictures 2 & 3 are courtesy of NEETRAC used by permission

Sensitivity Assessment Case Study

3,626m (11899ft), New EPR, Tape Shield



- Single shot –no averaging
- Calibrator designed & calibrated according to IEC 60270

Critical Cable System Case Study

- All cables pass VLF AC HIPOT commissioning test
- DSD test performed immediately VLF test.
- Pinpoints 7 massive cable insulation defects pinpointed

Cable defect was located within 3 inches on a 2000’ cable.

Critical Plant System Case Study

- PD activity detected near Uo -second repair did not pass
- Contactor sent splice back to manufacturer's lab
- Manufacturer's lab detects PD in joint
- 60 minute 2Uo VLF test does not break down defect
- Lab confirm gross workmanship defect