EPRI Cable and Robotics Update

NSRP Joint Welding and Electrical Technologies Panel

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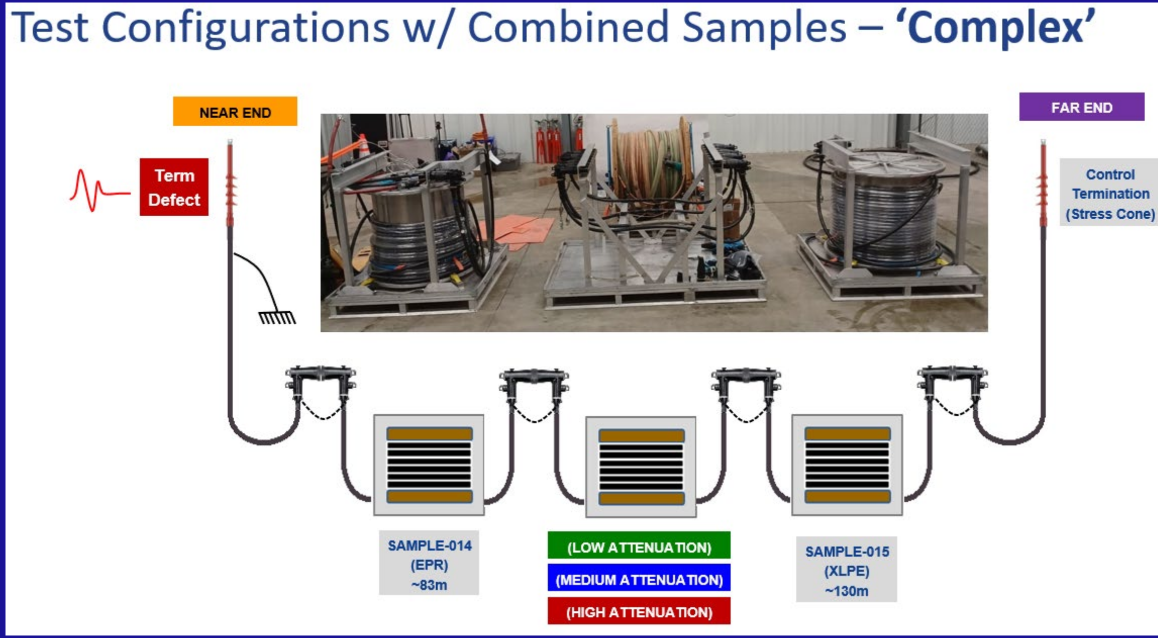
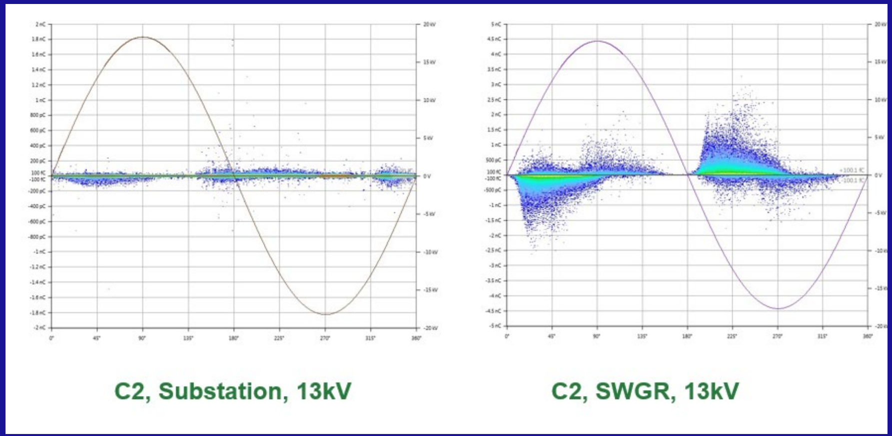
Wednesday, October 16, 2024

Medium Voltage Cable Program

MV High Frequency Attenuation Study

- Aimed at understanding impact of shield attenuation on High Frequency (HF) measurement techniques such as Partial Discharge (PD) and Reflectometry (TDR, FDR).
- Goals of research include creating and field trialing mitigation strategies for highly attenuating cables.
- Combination of experimental simulation studies and field application.



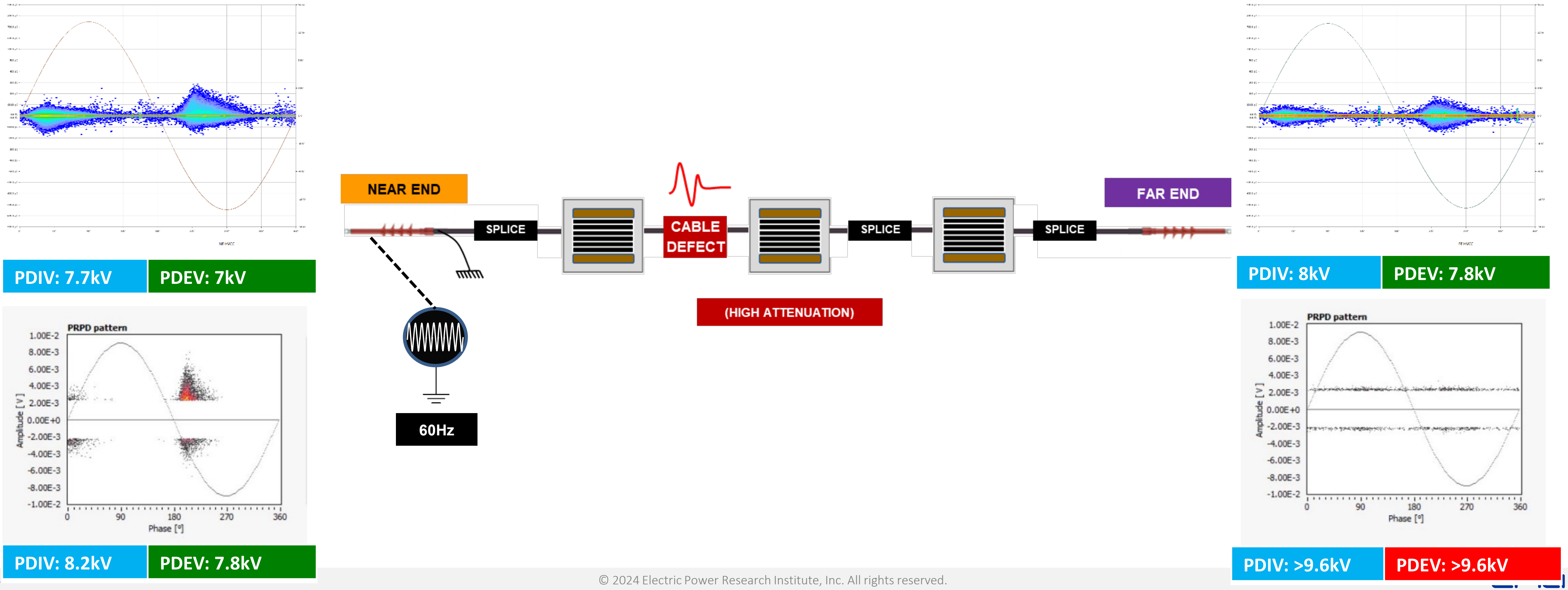


Report Releasing Fall 2024

Example Results (PD)

Topic: PD Meas. System Characteristics (inc. Sensor Strategy)

- **HIGH** Attenuation Case (C-09b) – 60Hz Test Source w/ 2 Separate PD Systems based on different functional principles

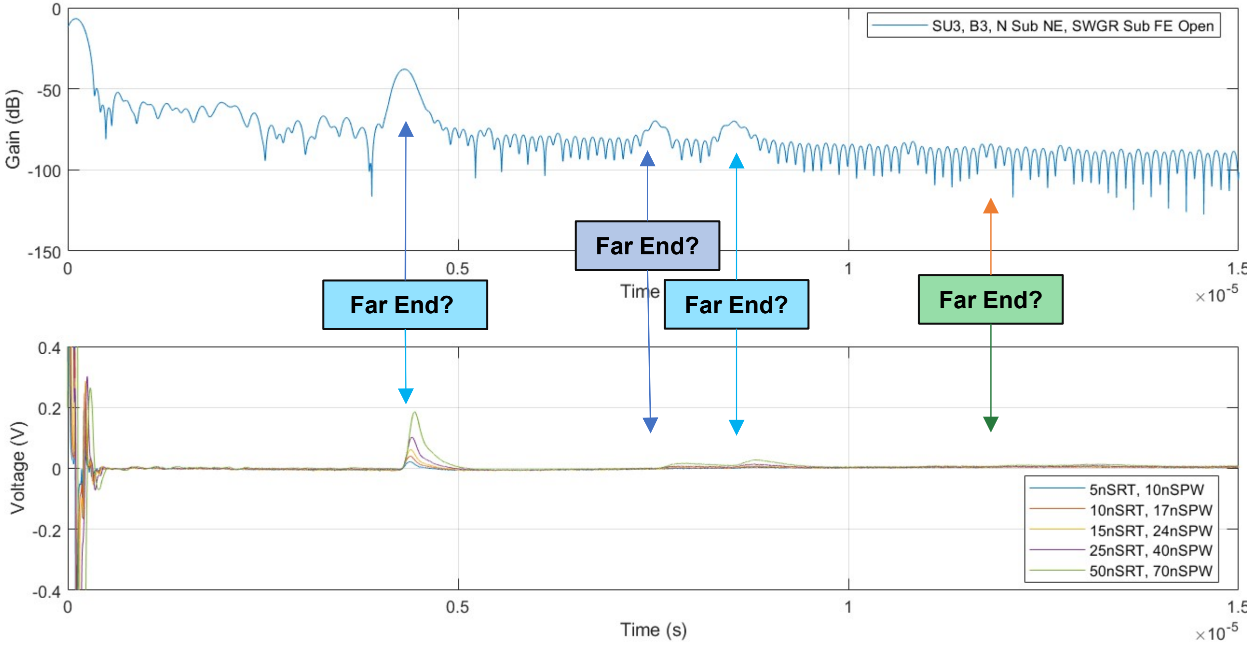


Example Data

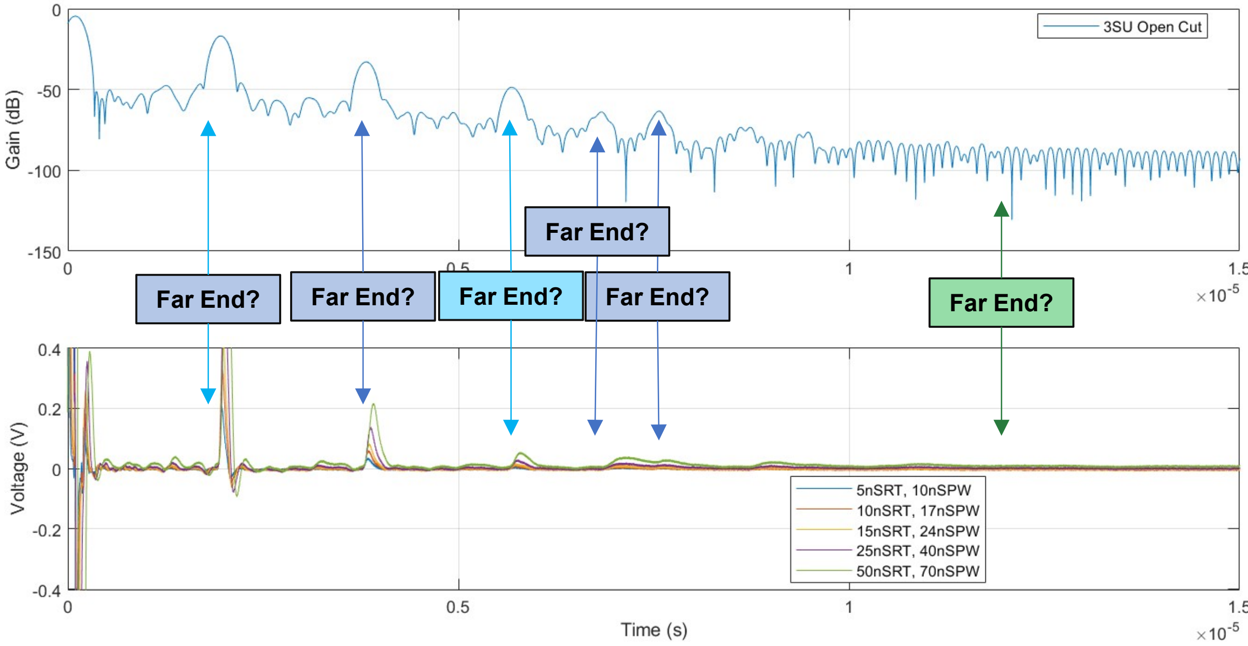
TDR & FDR

- Initial TDR/FDR Results are inconclusive – **Where is the Far End?**
  - 1006m → Assume 150m/μs → x2 distance for TDR → **~ 13.4μs?**

North Substation Injection



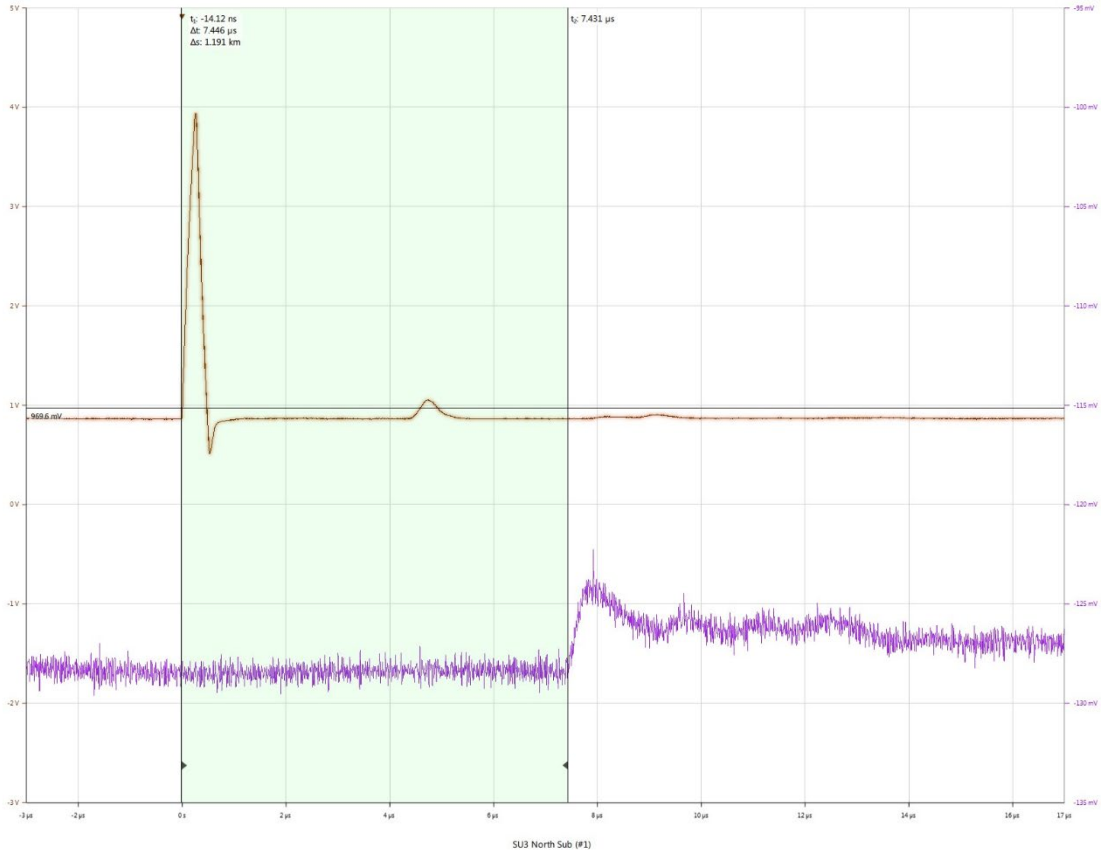
SWGR Injection



Example Data

Time Domain Transmission (TDT)

- Signal only travels the length of the cable once, halving attenuation path
- Based on TDT, propagation time is ~7.3μs (or 14.6μs in TDR)
- Length of 1006m
- Therefore, propagation speed is **~132m/μs**



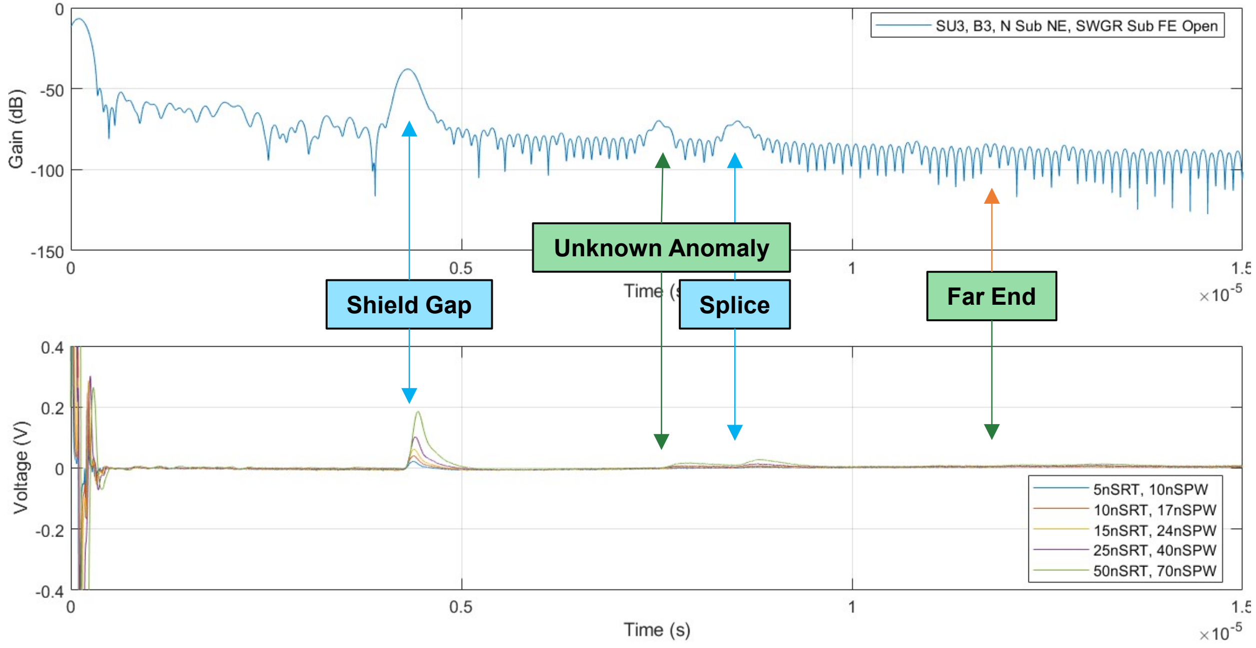
EPRI

Example Data

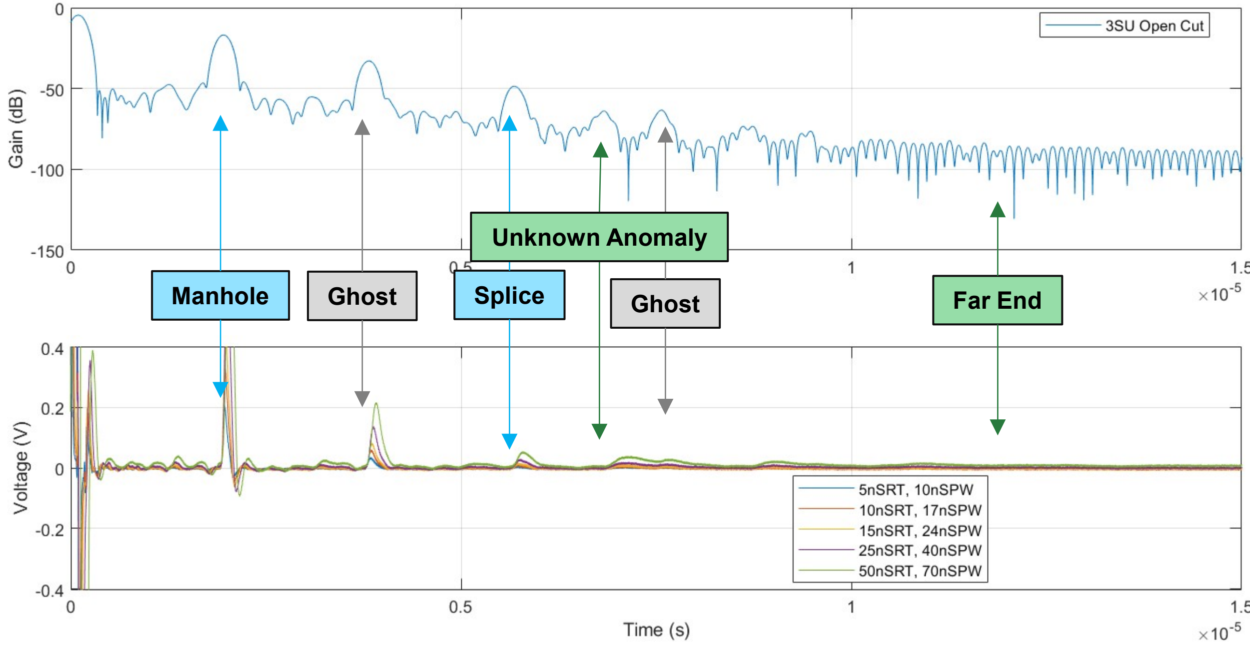
TDR & FDR - Revisited

- Knowing propagation speed allows for correlation of anomalies to known features
- **Confirmed very highly attenuating cable – advanced measurement techniques required**

North Substation Injection



SWGR Injection



Study Outcomes

- Set of "Do's and Don'ts" for mitigating impacts of attenuation on cable systems

- **How can one characterize high frequency attenuation in NPP MV cables, using reflectometry-based methods, balancing accuracy and practical constraints?**
  - **DO** – Start with TDR (single-ended) for attenuation characterization but consider TDT (dual-ended) for higher accuracy where needed.
  - **DO** – Consider utilizing more accuracy signal injection methods (e.g., impedance streamliner) to increase accuracy of HF characterization
  - **DO** – Use open versus short testing of Far End to help clarify the Far End location
  - **KNOW** - Energy of a pulse (e.g., area under a curve) attenuates less than the actual peak value of the pulse (e.g., in mV)

- **Once PD is identified, how does one accurately determine where it is originating from in attenuating cables, while lowering the risk of False Positive (F+) locations?**
  - **DO** – Start with TDR based localization and localized probing as a starting point, if PD is detected.
  - **DO** - If TDR + localized probing is NOT successful, proceed with more advanced techniques including Time-of-Flight across intermediate points, or NE/FE
  - **DON'T** – Rely on a single localization technique on PD signal(s) (especially TDR) – significantly increases the risk of **F+** results and wasted time, $$
  - **KNOW** – Accurate PD identification and assessment are core objectives of a PD measurement, followed by localization (not the other way around!!!)

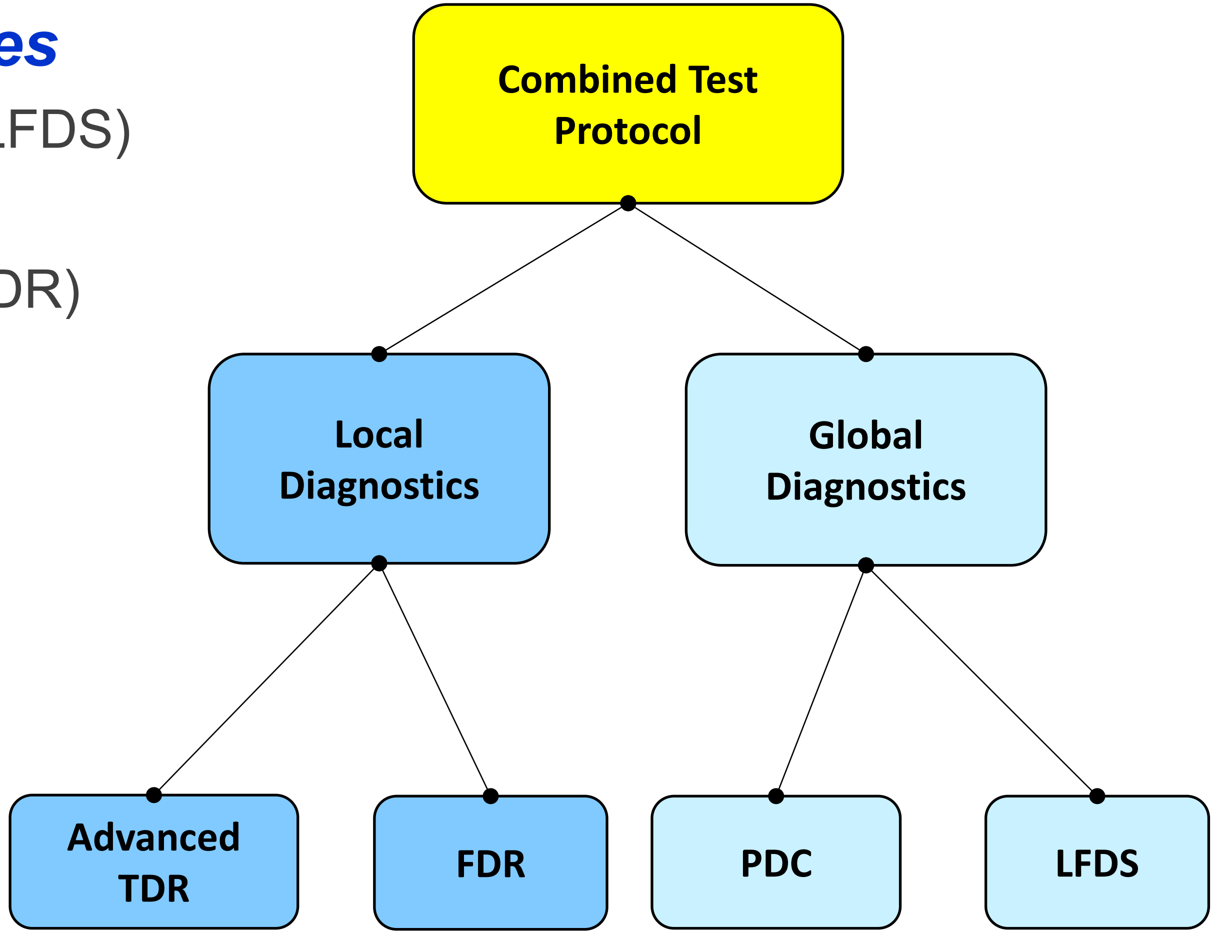
Beyond Tan Delta: Medium Voltage Applications of Low Voltage Test Methodology

- Intended to discriminate, localize, and assess issues in medium voltage cables.
- More information to decision makers to facilitate prioritization of intervention.
- Include applications of Dielectric Spectroscopy, Pol/Depol, and other techniques.
- Work to begin in 2024 and expected to take several years.

Low Voltage Cable Program

Test Program

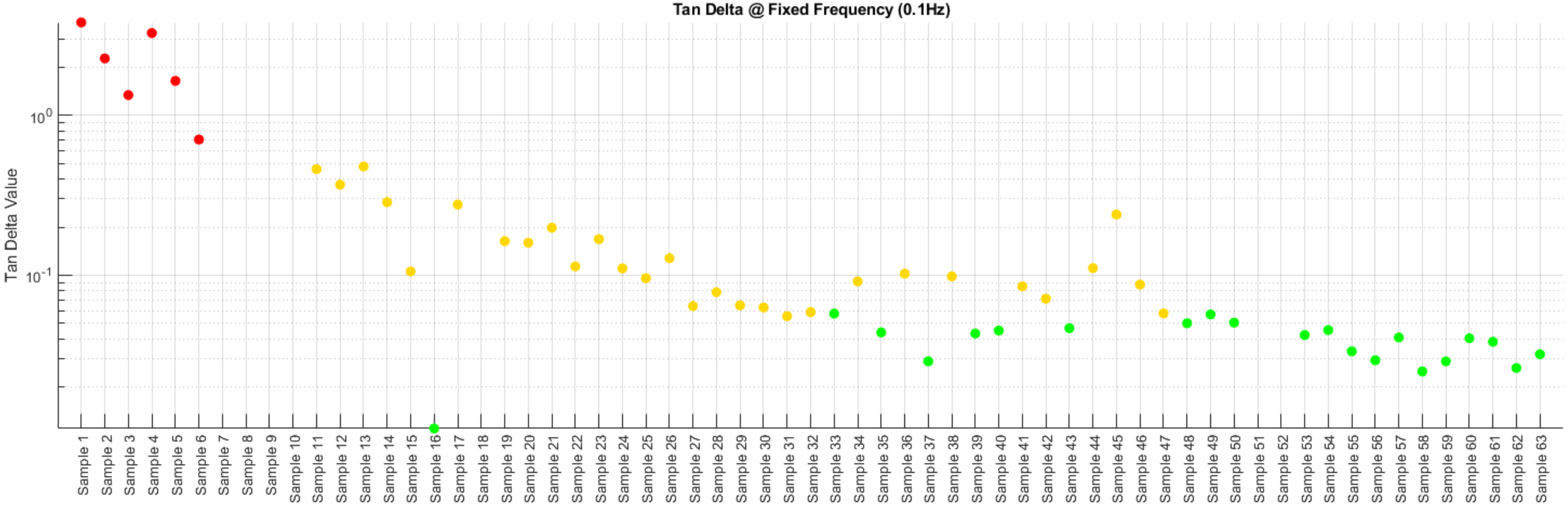
- Compare results of ***multiple techniques***
  - Low Frequency Dielectric Spectroscopy (LFDS)
  - Polarization Depolarization Current (PDC)
  - Advanced Time Domain Reflectometry (TDR)
  - Frequency Domain Reflectometry (FDR)

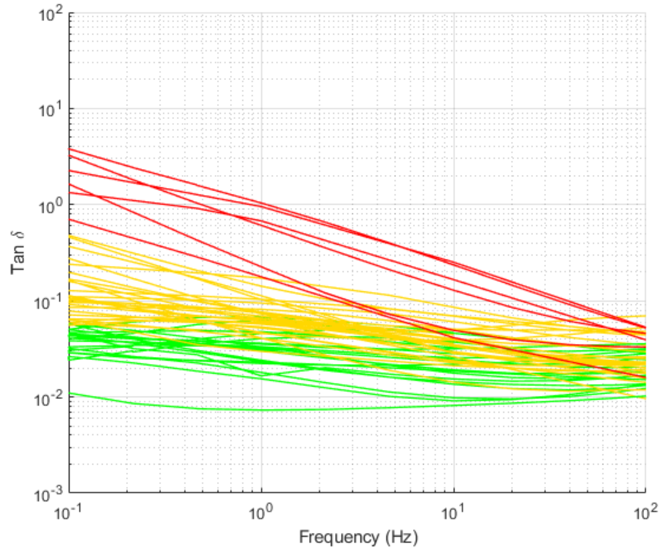


Diagnostic Function / Objective of Testing Strategy	
Identification	Is there a problem?
Discrimination	Is it an internal and real problem? What is the nature of the problem?
Localization	Where is the problem?
Assessment	How bad is the problem?

Example LFDS Results

Population - Tan δ vs. Frequency





No Anomalies Observed

(i.e. 'No Action Needed')

- ❑ *Relatively low Tan δ Magnitude*
- ❑ *33 % of Population*
- ❑ *11% of population could not be calculated*

Moderate Anomalies Observed

(i.e. 'Investigate/Trend')

- ❑ *Moderate Tan δ Magnitude*
- ❑ *46% of Population*

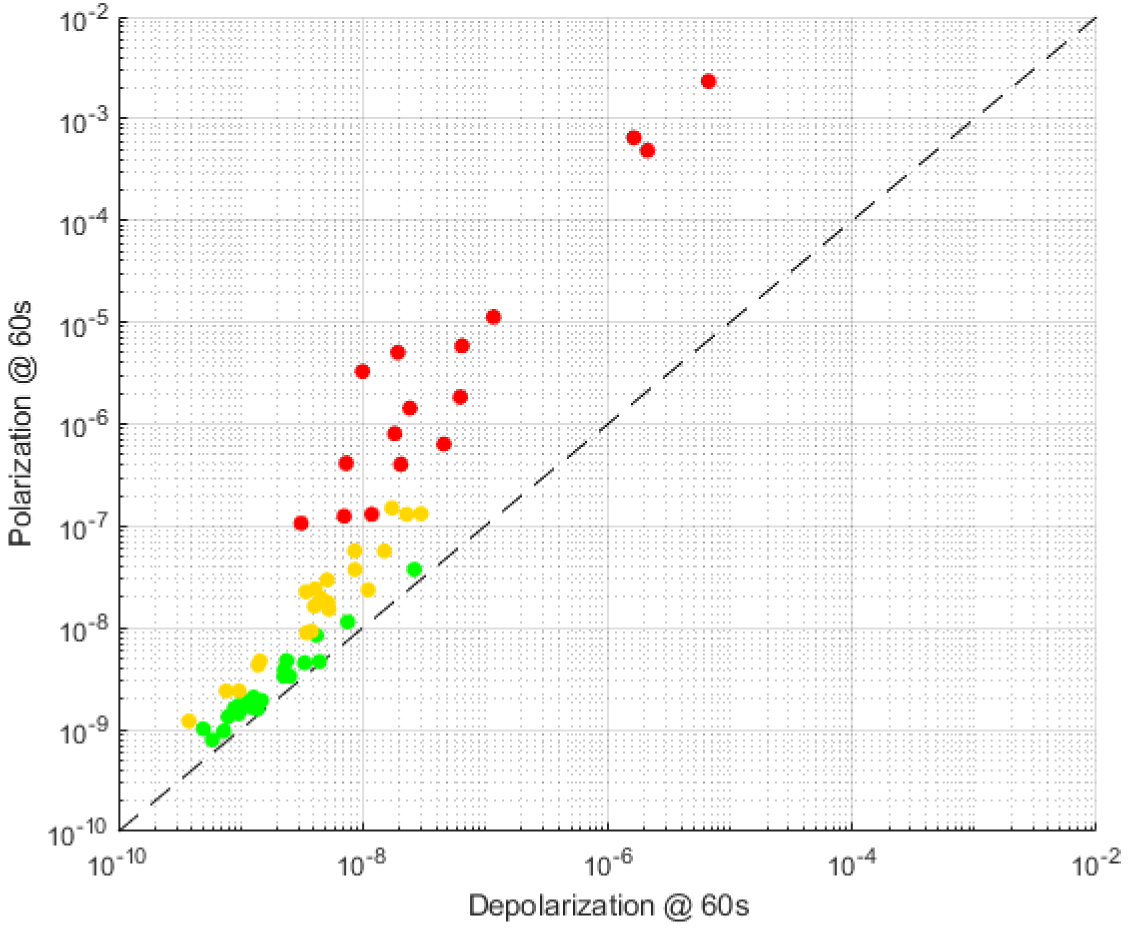
High Anomalies Observed

(i.e. 'Action Recommended')

- ❑ *Relatively large Tan δ Magnitude (compared to reference values)*
- ❑ *10% of Population*

Example PDC Results

PDC – I_{POL} vs. I_{DEPOL}



No Anomalies Observed

(i.e. 'No Action Needed')

- ❑ $I_{pol} / I_{depol} \approx 1$
- ❑ *36% of Population*

Moderate Anomalies Observed

(i.e. 'Investigate/Trend')

- ❑ $I_{pol} / I_{depol} > 1$
- ❑ *33% of Population*

High Anomalies Observed

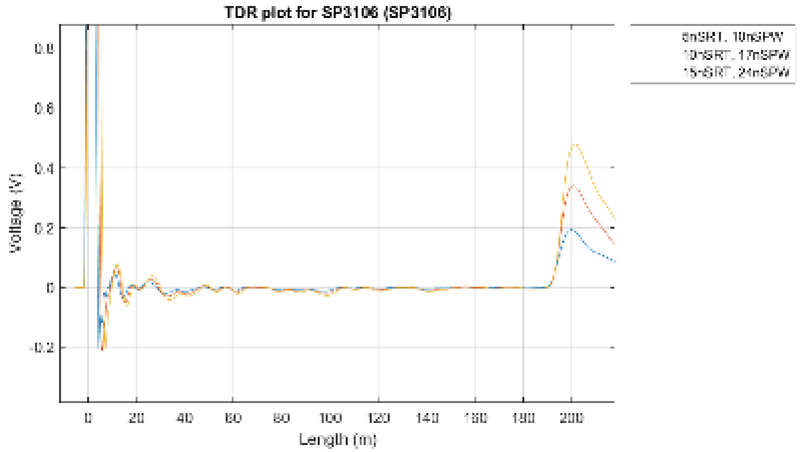
(i.e. 'Action Recommended')

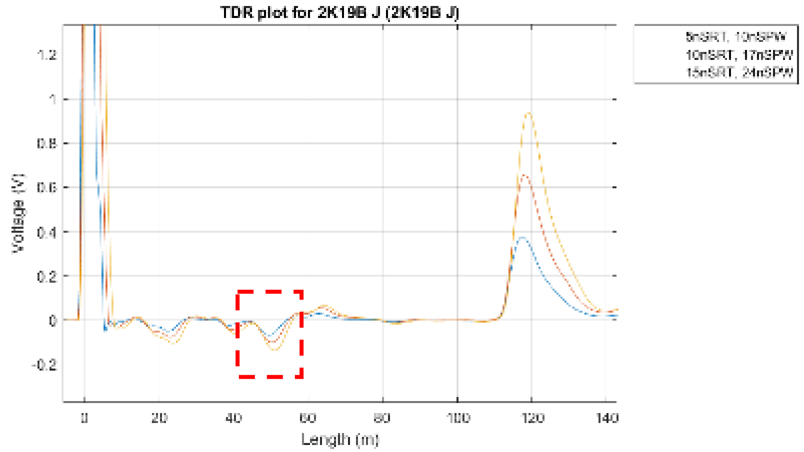
- ❑ $I_{pol} / I_{depol} >> 1$
- ❑ *25% of Population*

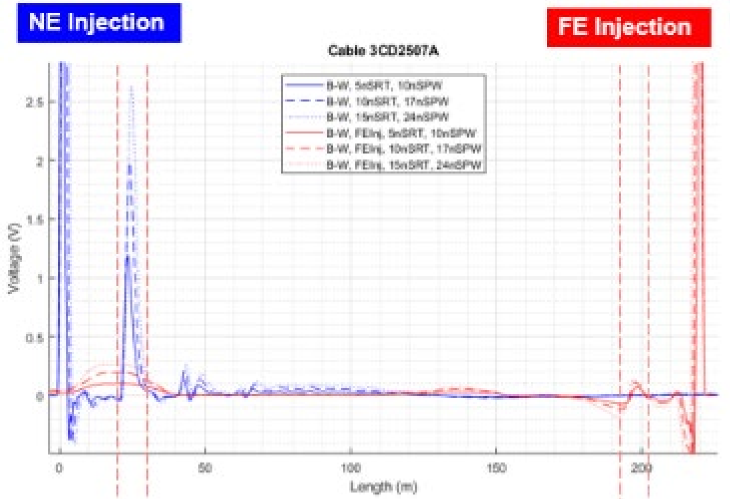
- ❑ *6% of population could not be calculated*

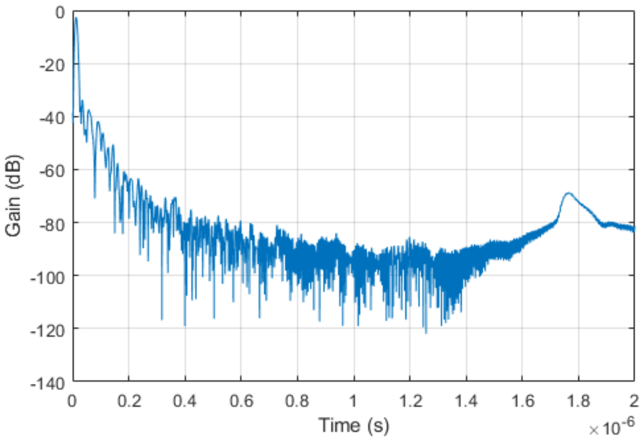
Test Results

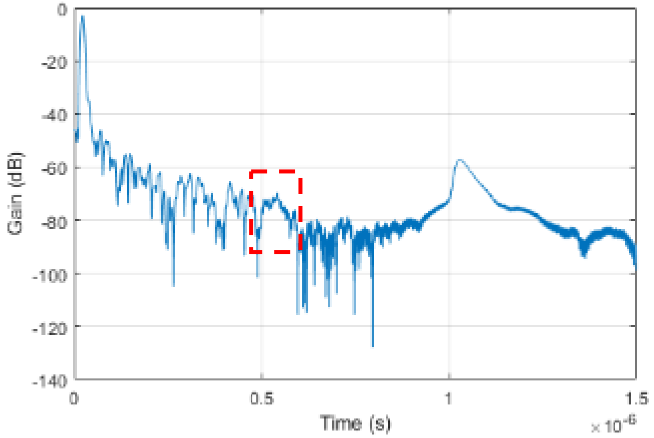
Advanced Time and Frequency Domain Reflectometry (TDR and FDR)

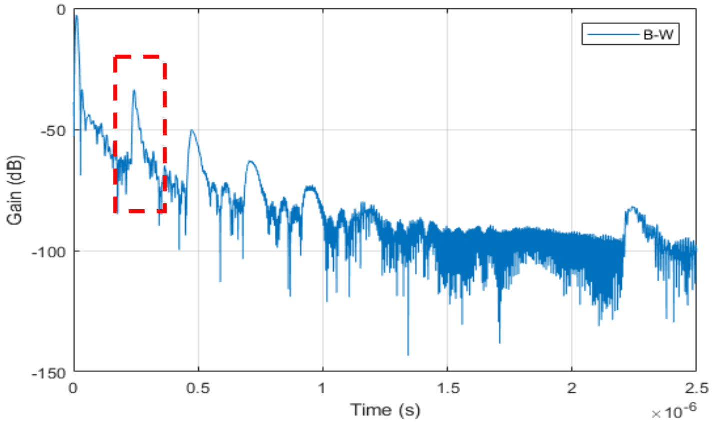












No Anomalies Observed (i.e. 'No Action Needed')

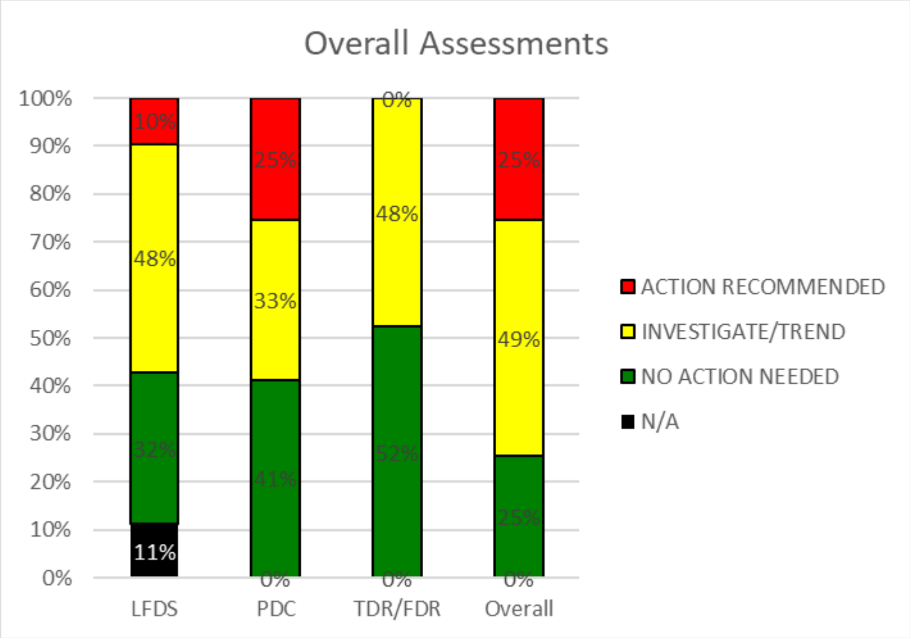
Anomalies Observed (i.e., Investigate / Trend)

Significant Anomalies Observed (Indication of Fault) – i.e., Action Recommended

Overall Assessment Summary

- Total of 70 cables tested across 6 campaigns
- Including 7 faulted cables, leaving 63 to be assessed
- Final assessment based on "*Worst performing*" individual assessment
- Of those 63:
  - 25% were overall assessed as **ACTION RECOMMENDED**
  - 50% were overall assessed as **INVESTIGATE / TREND**
  - 25% were overall assessed as **NO ACTION NEEDED**

Assessment	LFDS Assessment	PDC Assessment	TDR/FDR Assessment	Overall Assessment
ACTION RECOMMENDED	6/63 (10%)	16/63 (25%)	0/63 (0%)	16/63 (25%)
INVESTIGATE/TREND	30/63 (48%)	21/63 (33%)	30/63 (48%)	31/63 (49%)
NO ACTION NEEDED	20/63 (32%)	26/63 (41%)	33/63 (52%)	16/63 (25%)
N/A	7/63 (11%)	0/63 (0%)	0/63 (0%)	0/63 (0%)



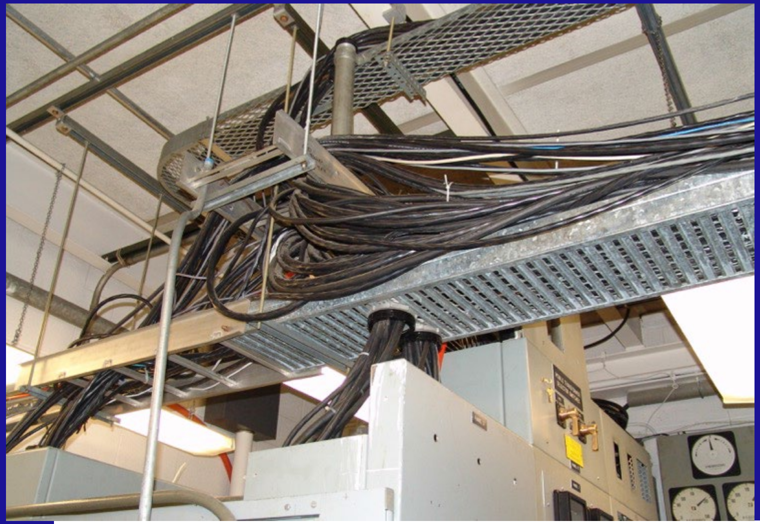
Results Overview

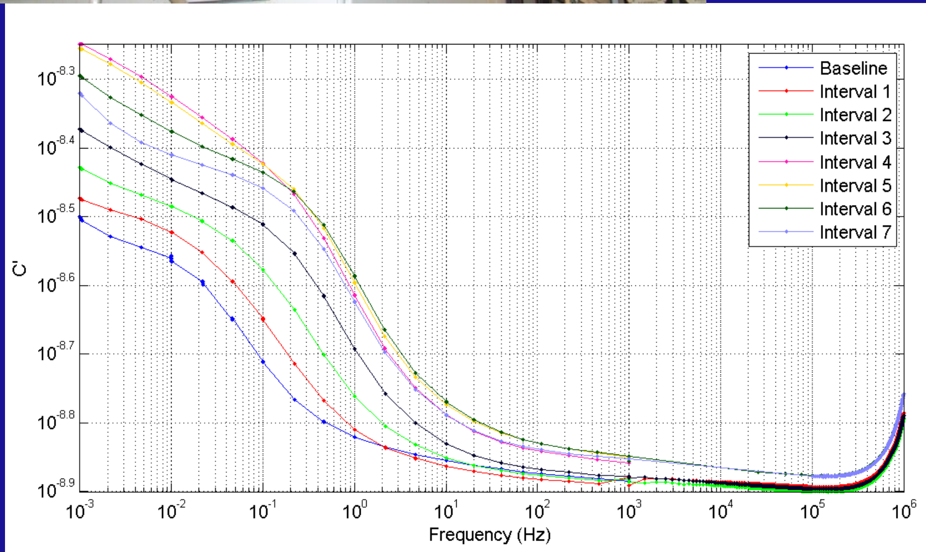
- Use of single test per existing industry practice (DC Insulation Resistance) would have resulted in high **(60%, 38 / 63)** rate of '**False Negative**' assessments for *un-faulted* cables

Sample	LFDS Metrics				PDC Metrics			
	C' Slope	Tan Delta @ 0.1 Hz	Tan Delta Slope	Overall Assessment	IR @ 60s	Pol. Curr. Slope	Pol/Depol @ 60s	Overall Assessment
Sample 10	N/A	N/A	N/A	N/A	247.8 MΩ	0.07856	44.07	ACTION RECOMMENDED
Sample 11	-0.0706	0.4605	-0.6495	INVESTIGATE/TREND	482.4 MΩ	-0.2274	117.7118	ACTION RECOMMENDED
Sample 12	-0.0964	0.3683	-0.5135	INVESTIGATE/TREND	494.2 MΩ	-0.4509	19.6904	ACTION RECOMMENDED
Sample 13	-0.0966	0.4787	-0.5271	INVESTIGATE/TREND	314.1 MΩ	-0.3788	13.747	ACTION RECOMMENDED
Sample 14	N/A	0.2863	N/A	INVESTIGATE/TREND	1.537 GΩ	-0.4454	11.0084	ACTION RECOMMENDED
Sample 15	-0.03962	0.1057	-0.2289	INVESTIGATE/TREND	1.59 GΩ	-0.6737	17.8	ACTION RECOMMENDED
Sample 16	-0.0028	0.011	-0.1785	NO ACTION NEEDED	1.87 GΩ	-1.4189	34.1853	ACTION RECOMMENDED
Sample 17	-0.05186	0.277	-0.5778	INVESTIGATE/TREND	1.32 GΩ	-0.5205	8.688	INVESTIGATE/TREND
Sample 18	N/A	N/A	N/A	N/A	1.51 GΩ	-0.4407	4.4142	INVESTIGATE/TREND
Sample 19	-0.03222	0.164	-0.6005	INVESTIGATE/TREND	3.49 GΩ	-0.575	6.672	INVESTIGATE/TREND
Sample 20	-0.0518	0.160	-0.4194	INVESTIGATE/TREND	6.74 GΩ	-1.009	5.788	INVESTIGATE/TREND
Sample 21	-0.05434	0.198	-0.4126	INVESTIGATE/TREND	1.53 GΩ	-0.737	5.697	INVESTIGATE/TREND
Sample 22	-0.0374	0.1136	-0.3848	INVESTIGATE/TREND	10.60 GΩ	-1.0129	6.254	INVESTIGATE/TREND
Sample 23	-0.05998	0.1680	-0.3513	INVESTIGATE/TREND	8.81 GΩ	-0.8123	6.601	INVESTIGATE/TREND
Sample 24	-0.0384	0.1104	-0.3708	INVESTIGATE/TREND	3.50 GΩ	-1.0591	3.7888	INVESTIGATE/TREND
Sample 25	-0.0592	0.0958	-0.1077	INVESTIGATE/TREND	21.56 GΩ	-1.8444	6.7401	INVESTIGATE/TREND
Sample 26	-0.0737	0.1278	-0.0919	INVESTIGATE/TREND	7.32 GΩ	N/A	1.9619	INVESTIGATE/TREND
Sample 27	-0.0179	0.0642	-0.3336	INVESTIGATE/TREND	5.33 GΩ	-1.2725	4.3323	INVESTIGATE/TREND
Sample 28	-0.03914	0.0784	-0.1778	INVESTIGATE/TREND	11.31 GΩ	-1.427	3.391	INVESTIGATE/TREND
Sample 29	-0.0396	0.0649	-0.08321	INVESTIGATE/TREND	12.21 GΩ	-1.522	4.082	INVESTIGATE/TREND
Sample 30	-0.0327	0.0630	-0.1894	INVESTIGATE/TREND	22.34 GΩ	-1.816	2.584	INVESTIGATE/TREND
Sample 31	-0.04183	0.0556	0.02814	INVESTIGATE/TREND	46.30 GΩ	-2.194	3.103	INVESTIGATE/TREND
Sample 32	-0.04596	0.0589	0.04322	INVESTIGATE/TREND	83.15 GΩ	-2.549	3.151	INVESTIGATE/TREND
Sample 33	-0.01714	0.0577	-0.378	NO ACTION NEEDED	8.29 GΩ	-0.9355	5.917	INVESTIGATE/TREND
Sample 34	-0.04525	0.0916	-0.174	INVESTIGATE/TREND	5.31 GΩ	-2.025	1.424	NO ACTION NEEDED
Sample 35	-0.0196	0.0440	-0.2759	NO ACTION NEEDED	42.17 GΩ	-1.616	3.278	INVESTIGATE/TREND
Sample 36	-0.05543	0.1030	-0.1703	INVESTIGATE/TREND	51.42 GΩ	-1.934	1.706	NO ACTION NEEDED
Sample 37	-0.0147	0.029	-0.1008	NO ACTION NEEDED	13.07 GΩ	-1.4954	2.8922	INVESTIGATE/TREND
Sample 38	-0.05236	0.0984	-0.1735	INVESTIGATE/TREND	59.58 GΩ	-2.013	1.48	NO ACTION NEEDED
Sample 39	-0.02432	0.0433	-0.08659	NO ACTION NEEDED	82.94 GΩ	-1.784	2.474	INVESTIGATE/TREND
Sample 40	-0.0223	0.0452	-0.4351	INVESTIGATE/TREND	120.93 GΩ	-2.414	1.339	NO ACTION NEEDED
Sample 41	-0.05427	0.0853	-0.0189	INVESTIGATE/TREND	139.36 GΩ	-1.831	1.491	NO ACTION NEEDED
Sample 42	-0.0415	0.0714E	-0.09579	INVESTIGATE/TREND	148.92 GΩ	-1.949	1.698	NO ACTION NEEDED
Sample 43	-0.03028	0.0467	0.00957	NO ACTION NEEDED	164.6 GΩ	-1.837	3.214	INVESTIGATE/TREND
Sample 44	-0.0665	0.1109	-0.0684	INVESTIGATE/TREND	23.41 GΩ	N/A	2.0348	NO ACTION NEEDED
Sample 45	-0.1239	0.24	-0.1435	INVESTIGATE/TREND	43.97 GΩ	-1.7	1.3598	NO ACTION NEEDED
Sample 46	N/A	0.0875	N/A	INVESTIGATE/TREND	112.2 GΩ	-1.7904	1.2935	NO ACTION NEEDED
Sample 47	-0.03272	0.0579	-0.1026	INVESTIGATE/TREND	250.9 GΩ	-2.512	1.357	NO ACTION NEEDED

Future Low Voltage Methodology Focus

- More Pilot Trials, Europe and Elsewhere
  - 2024: Two European facilities participating.
  - We are looking for plants that would like to try this methodology, please contact me if interested.
- Phase 3 Study, focusing on improving applied techniques
- Condition-based Qualification (CBQ) Evaluation
- Scoping Study for Online Monitoring
- Machine Learning for Defect Localization





Cable Aging Management Training

EVENT

Low and Medium Voltage Cable Aging Management Training Course

Last Updated 12/18/2023 **Duration** 36 hours

Details

This training course for low and medium voltage cables will provide members and others responsible for managing cable aging, design, installation, testing and replacement of cables the technical foundation needed to understand the key concepts and knowledge to perform that function.

Target Audience
Technical staff responsible for managing electrical cables' aging management programs, electrical design engineers responsible for cable installations/replacements, or others interested in how cables are manufactured, installed, degrade, and how to monitor that degradation.

Ontario Dec 2nd- 6th, 2024

Charlotte Summer 2025

EPRI Robotics

Prior Efforts

- Nuclear industry is very rapidly adopting robotics and drone technologies.
- Previous EPRI work has created guides and reports that are critical to industry, but the traditional publication cycle is not adapted to a rapidly developing environment.
- Live exchanges of information such as the Digital Worker Conference are great OpEx exchange opportunities, but this needs to be a continuous year round process.
- Utilities often hesitate to adopt new technologies in part because they are unaware of the success of these technologies elsewhere in the industry or the lessons learned.

In scope:

- Commercial and near off-the-shelf unmanned systems.
- Remote and Autonomous
- Flying, ground, and submersible

EPRI Robotics Supplemental

User Group

Pilot Support/Lessons Learned

Robotics Expo

Forum Site