Network Transformer Primary Bushing Research – Field and Lab Testing

T. Campbell, I. Roumeliotis, V. Patel, & Y. Wen, Con Edison
A. Bologna, N. Hampton, J. Litten, J. Perkel, & J. Potvin, EPRI
J. Groeger, Mantis Associates, Inc.

Transformer failure and background

Bushing study and analysis

Field tests

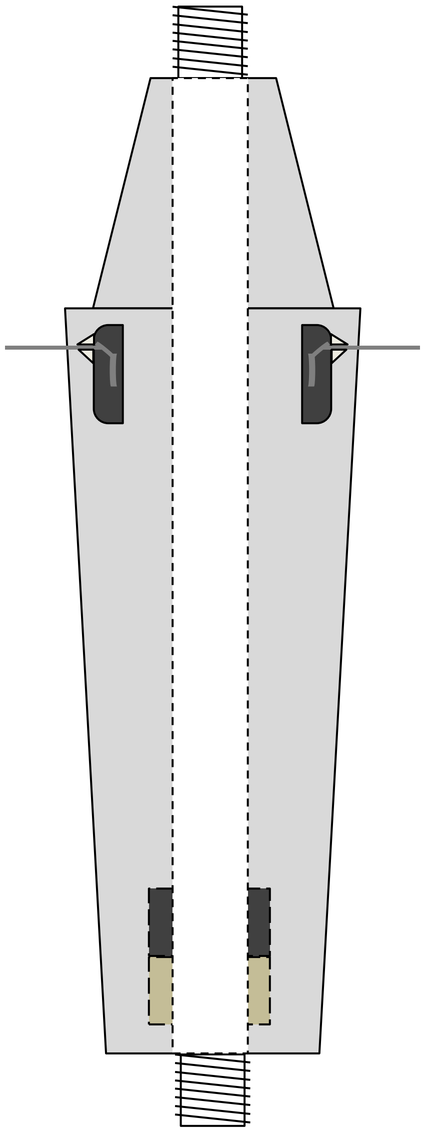
Screening tests

Next steps

Q&A

Importance of the Bushing

- Withstand electrical stresses (electrical insulation)
- Operate across a wide temperature range (thermal stability)
- Survive oil immersion (oil compatibility)
- Maintain mechanical integrity (installation forces and pressure boundary)
- Provide a pressure seal (oil and headspace gas)
- Integrate a weld flange



Bushings Research

Failure Analysis

Analyze field failures to determine potential causes

Field Testing

Explore possibility of field assessments of in-service bushings

Lab Test Setup

Develop HV test setup for screening new bushings

On-Site Tests

Perform screening tests on available stock of new bushings

Background

Con Edison distribution system uses 28,500 3-Phase network transformers & protectors

- 13, 27 & 33 kV primary voltages
- Each network transformer uses three MV welded epoxy bushings to connect to 600 A separable connectors

Failure rates for these bushings have been increasing over the last several years

- Feeder open auto
- Premature Equipment replacement

Con Edison engaged EPRI to conduct investigation into:

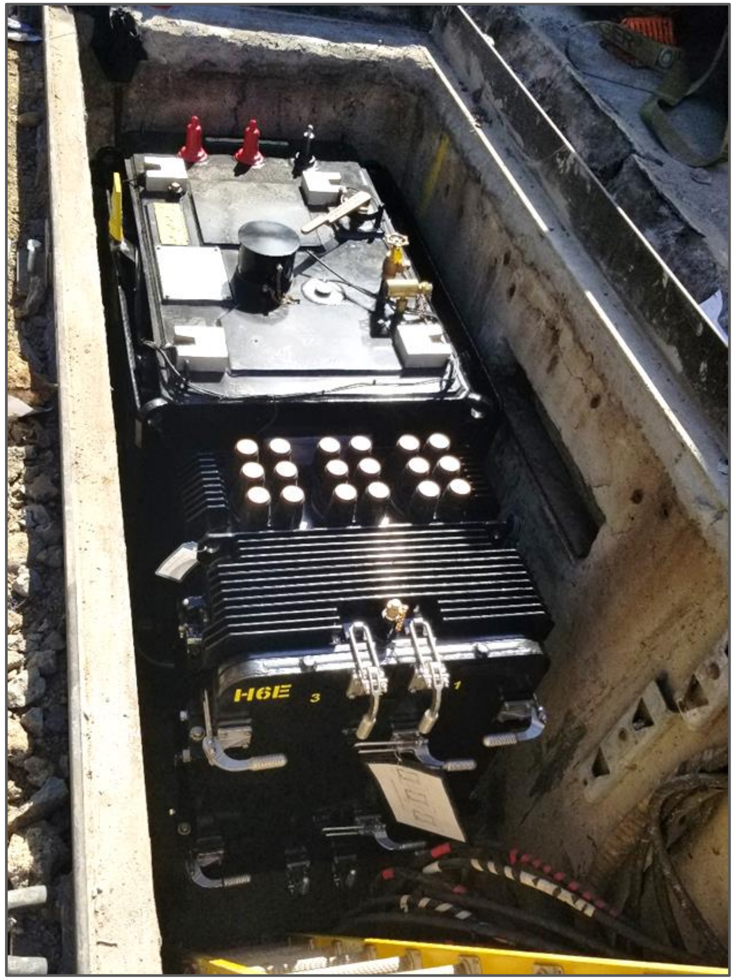
- Root cause(s) of bushing failures (manufacturing, aging, etc.)
- Potential design improvements
- Field assessment methods for identifying potential “bad” bushings

Quality assurance and inspection with existing bushing manufacturer

- Failed sample review
- Review of testing procedure

Network Transformer Overview

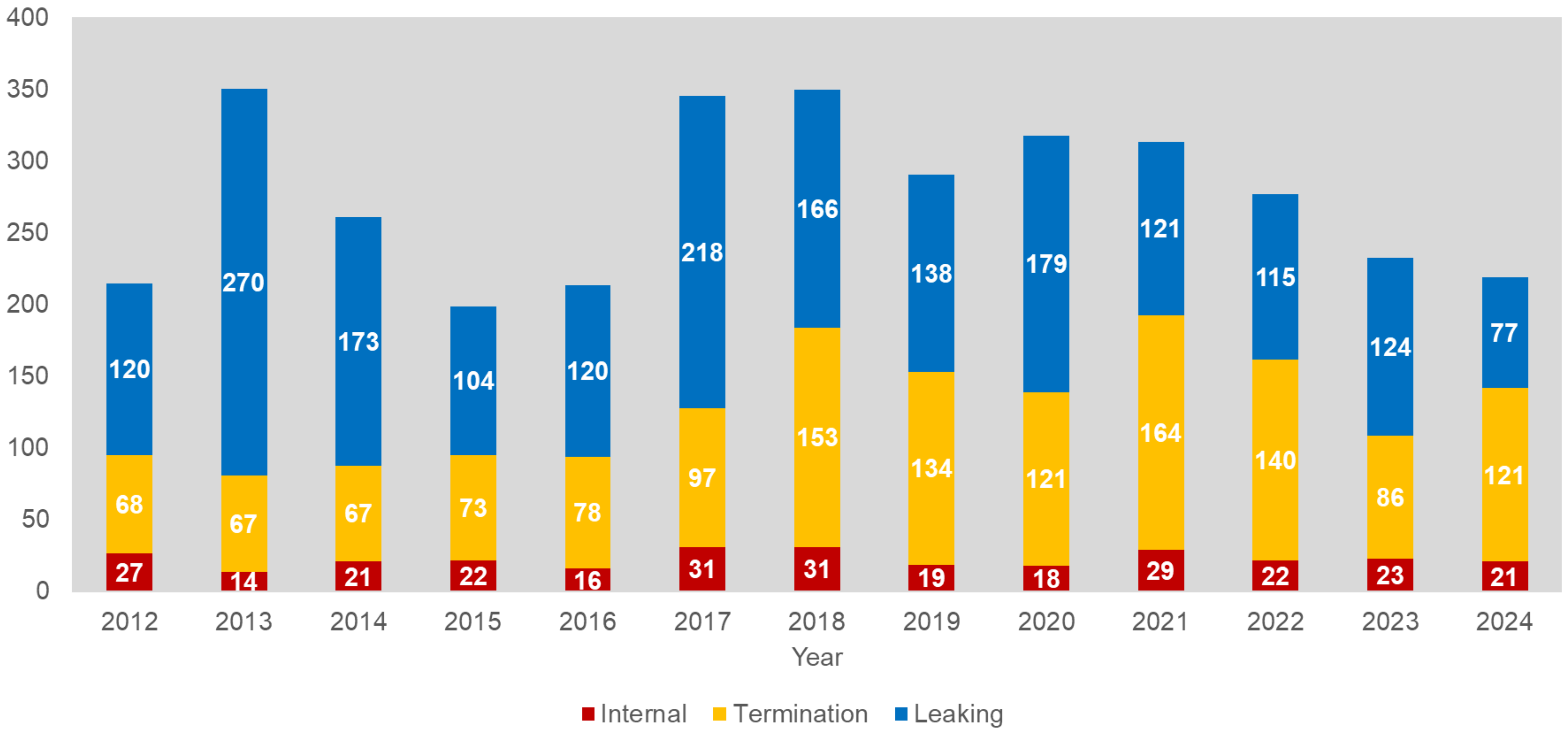
- Approximately 29,000 transformers
- Primary voltages 13, 27 & 33 kV
- Sizes ranging from 500, 1000, 2500 kVA
- Fully welded tank and bushings
- Predominantly installed under sidewalks & street vaults



Primary Bushings

- Epoxy Bushing
- Steel Flange welded to tank
- Aluminum electrode
- 13 and 27 kV
- 600 A
- 150 and 200 BIL

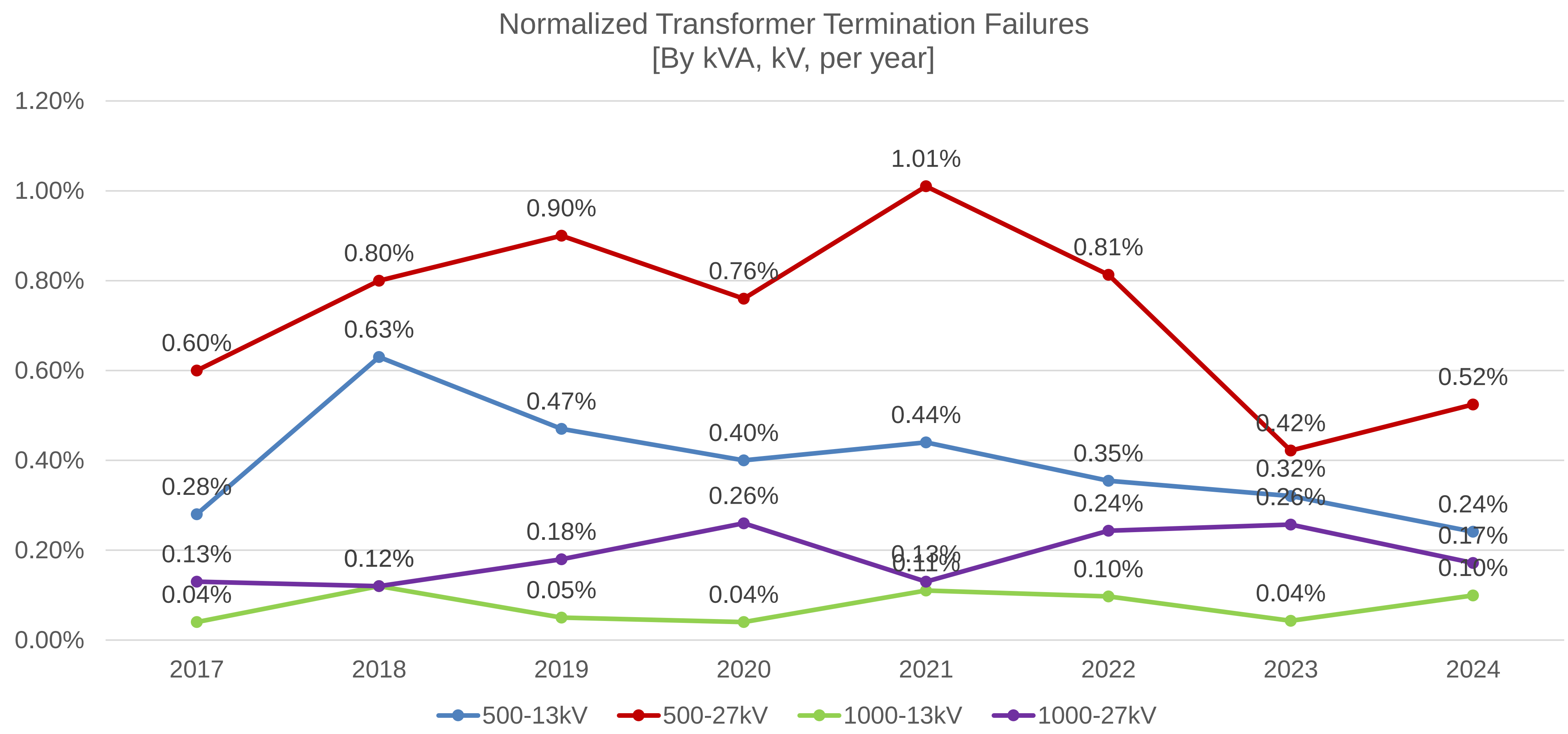
Transformer Removals by Mode of Failure



Termination Population Trends

		Count of Transformer Termination Failures [YTD]								
	Year	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
500 kVA	4 kV	0	2	0	1	0	0	0	0	0
	13 kV	11	17	33	22	19	27	20	19	15
	27 kV	53	59	87	91	82	112	90	49	64
1000 kVA	**13 kV**	6	12	17	4	5	10	15	7	18
	27 kV	3	2	5	9	8	5	9	8	7
	33 kV	0	0	1	0	0	1	0	0	0
2500 kVA	**13 kV**	0	1	3	1	3	2	0	0	2
	27 kV	1	3	2	5	3	4	1	1	4
	33 kV	0	0	1	0	1	0	0	1	1
	Totals	74	96	149	133	121	161	135	85	111

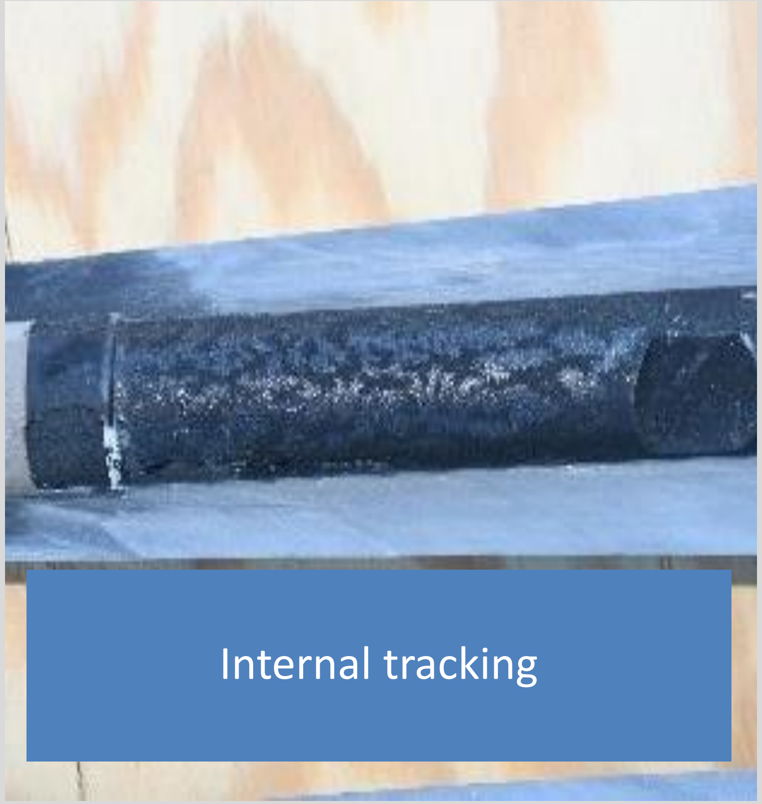
Termination Population Trends



Objectives

- **Analyze** / determine the root cause of additional failed bushings and associated cable accessories
- **Develop and execute** a test approach to investigate the long-term performance of medium voltage epoxy bushings
- Identify and assess the **effectiveness** of online PD methodologies by performing field inspections to assess the ability to identify healthy and degraded bushings
- Potential review of **new / alternate** bushing designs

Quality defects that can lead to failure



Internal tracking

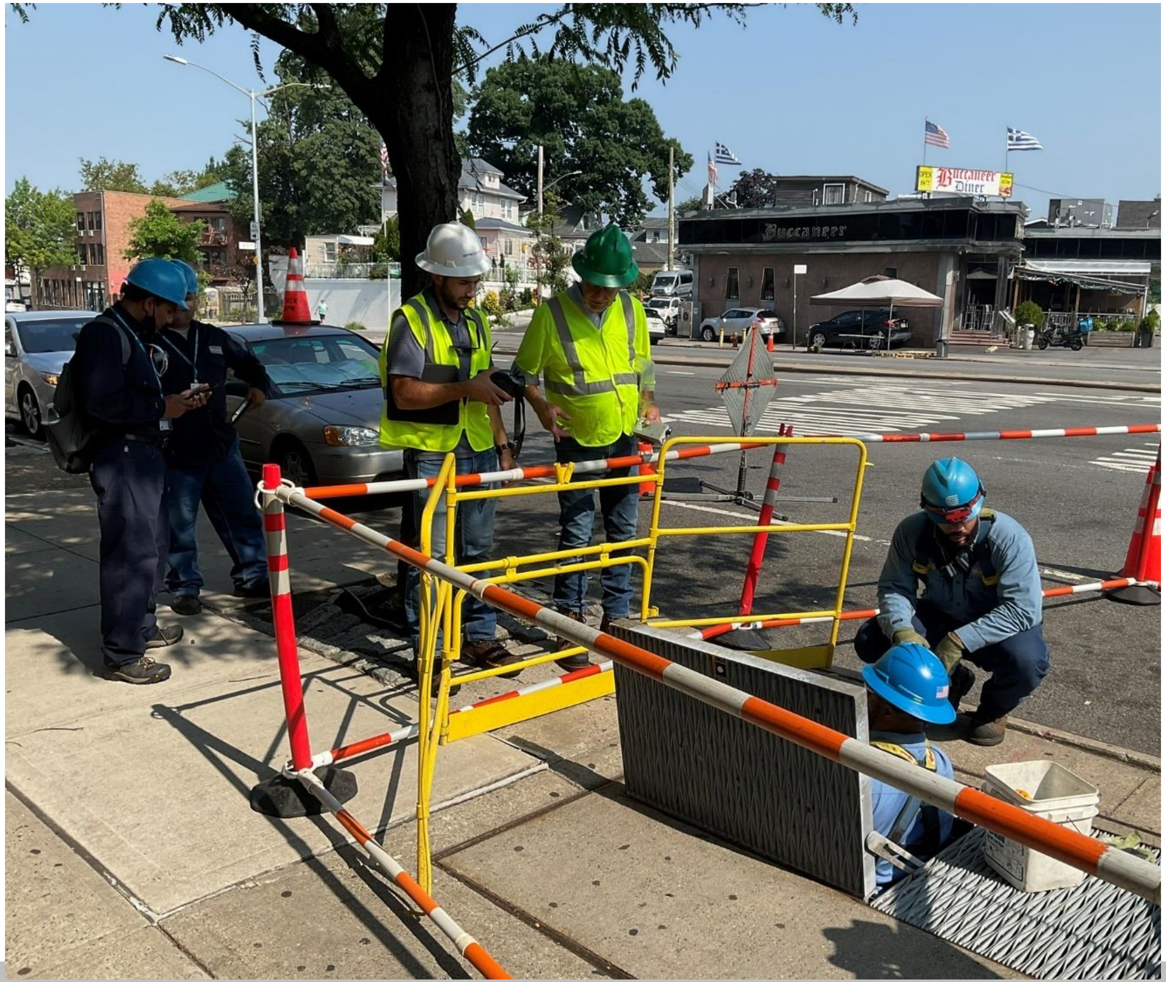
Defective weld flange shielding and void

Defective internal oil seal

Field Testing

Queens, NY

Field Sites


Buccaneer Diner
Buccaneer


choose Energy Star.
You could save 30%
on your energy bills.

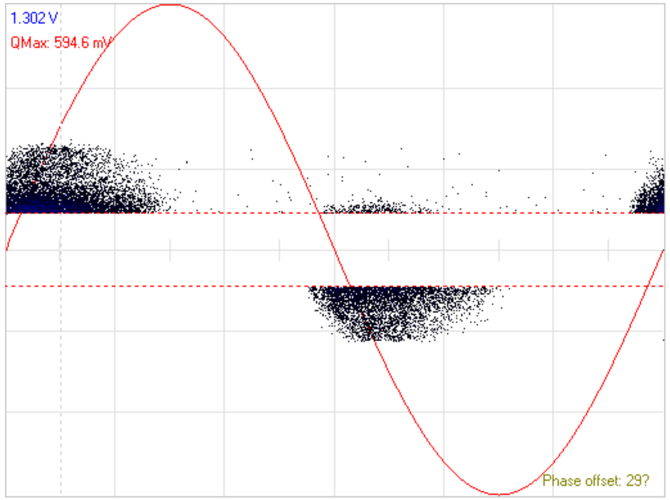
Field Sites

Data Analysis

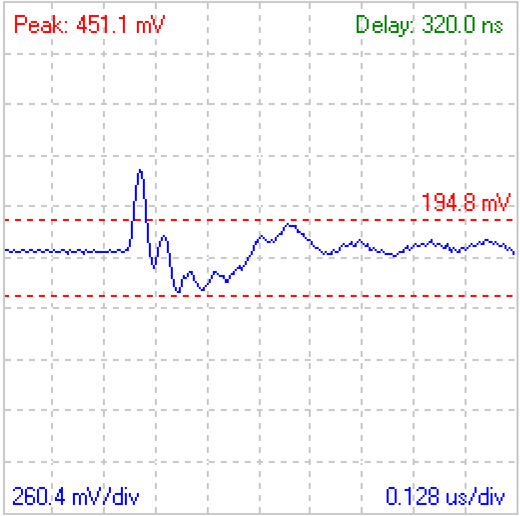
- Explore potential analysis routes using companion software tools
  - Manual waveform analysis possible via PC-based tool
  - Software-based post-test filtering allows for elimination of unwanted pulse shapes

- Heuristics used for analysis
  1. Phase-resolved PD pattern
  2. Pulse shape
  3. Frequency distribution (FFT) of each pulse

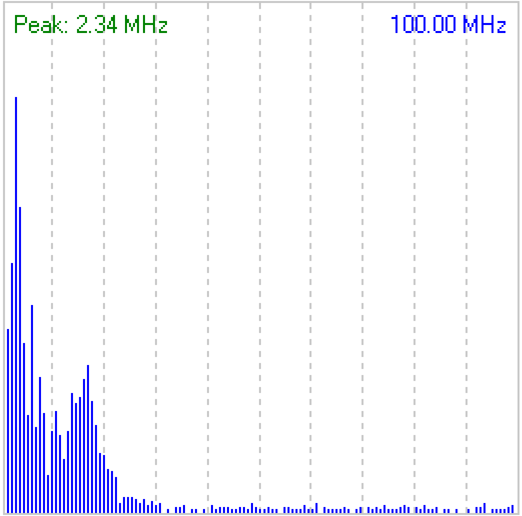
PRPD Pattern



Pulse Shape

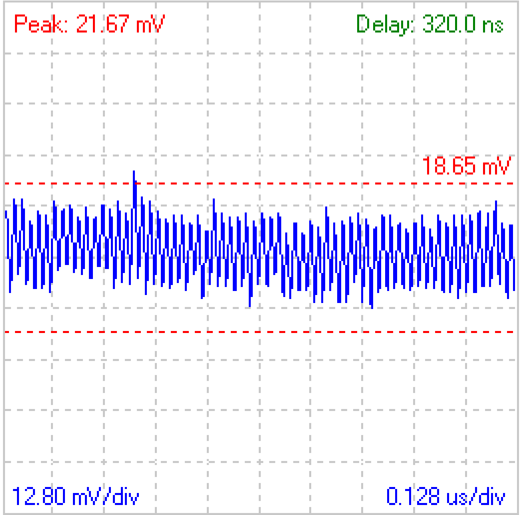


Frequency Distribution

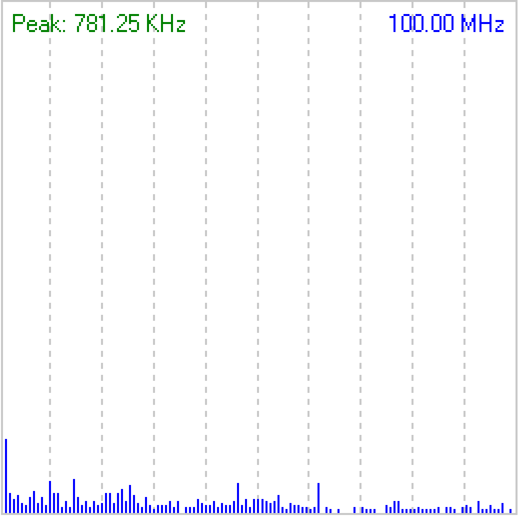


Example – Loc 1 Phase A

Waveform

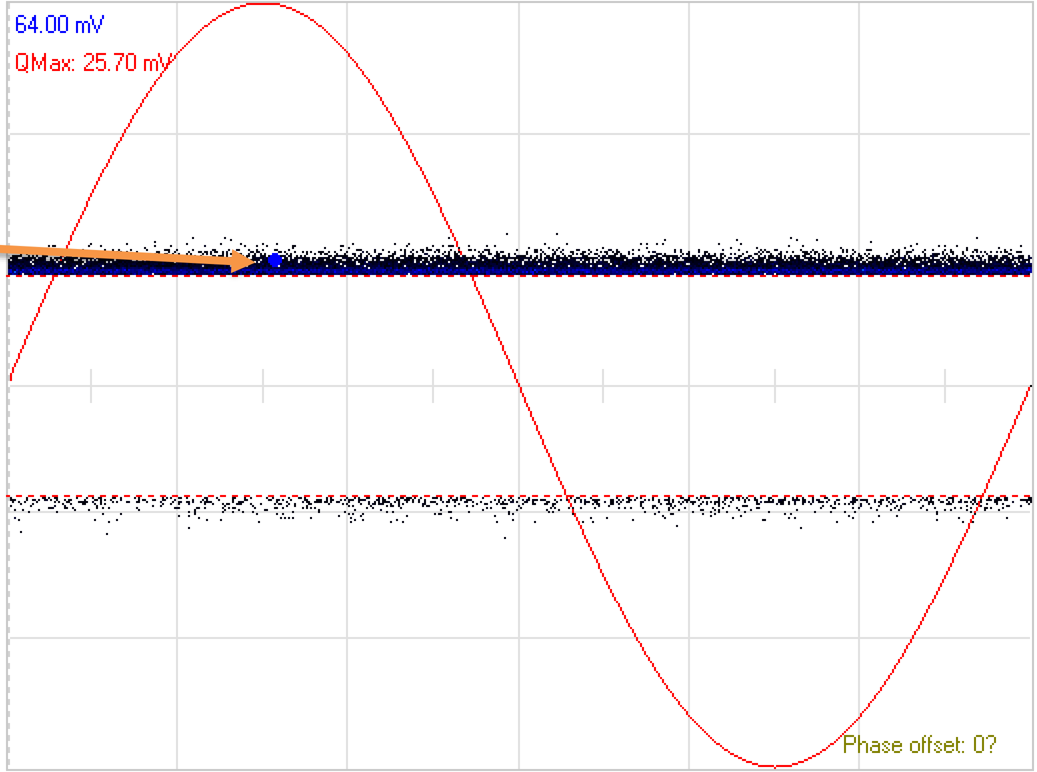


Frequency Spectrum



Typical uncorrelated noise

Phase-Resolved PD Pattern

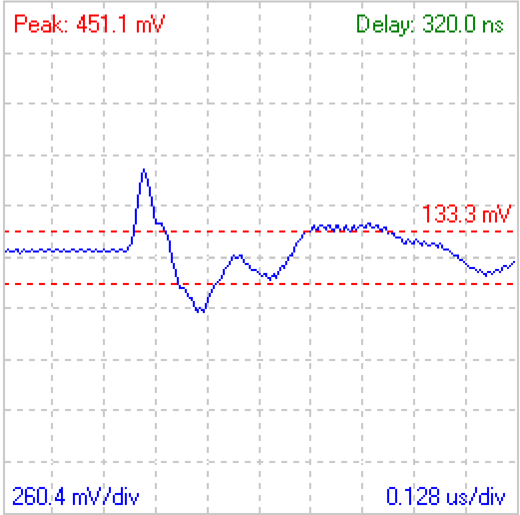


Observations

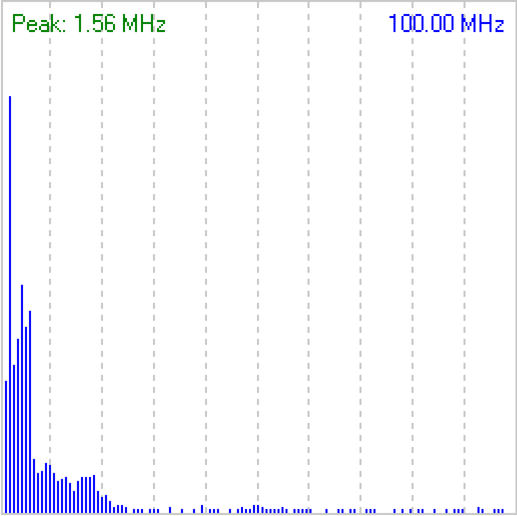
1. No correlation to energizing voltage
2. No distinct pulse shape
3. Broad-spectrum noise

Example – Loc 3 Phase C

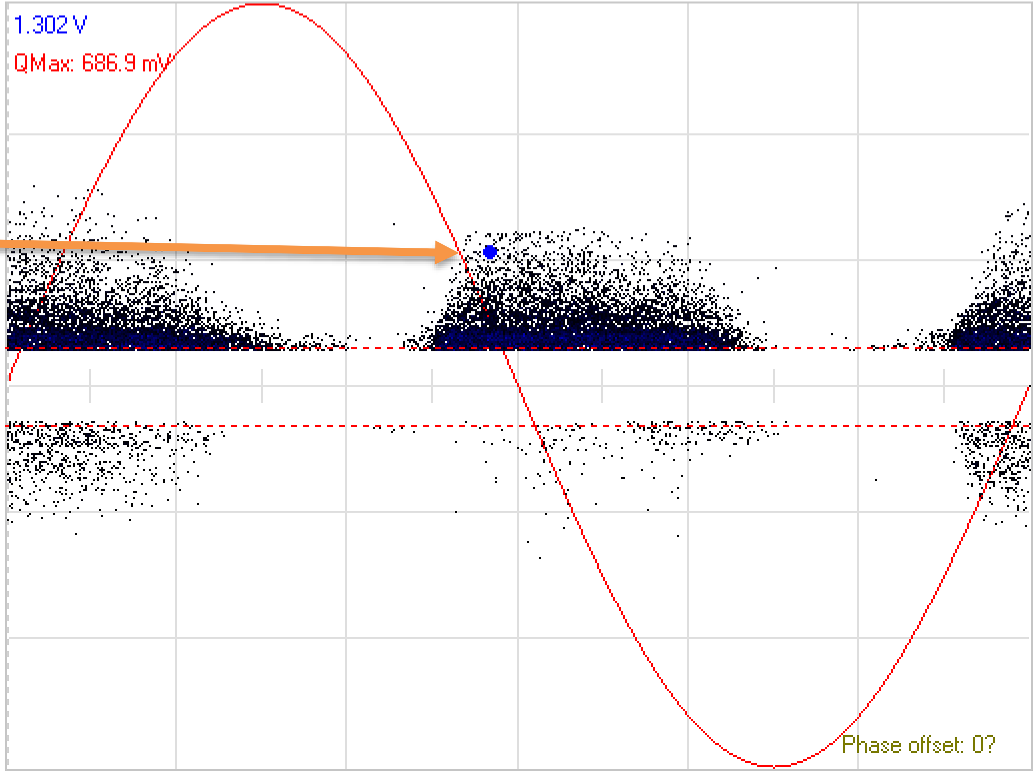
Waveform



Frequency Spectrum



Phase-Resolved PD Pattern



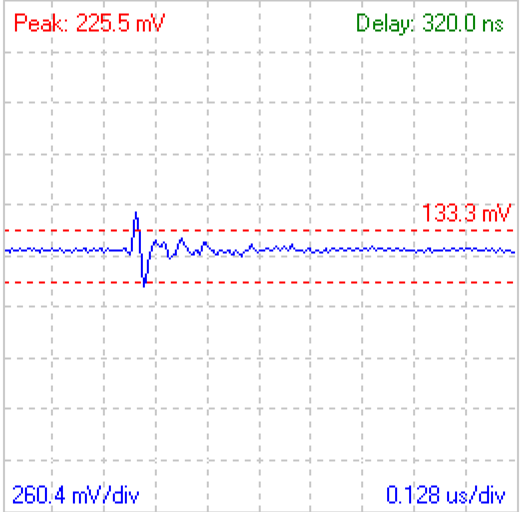
Frequency content provides indication of distance to PD source

Observations

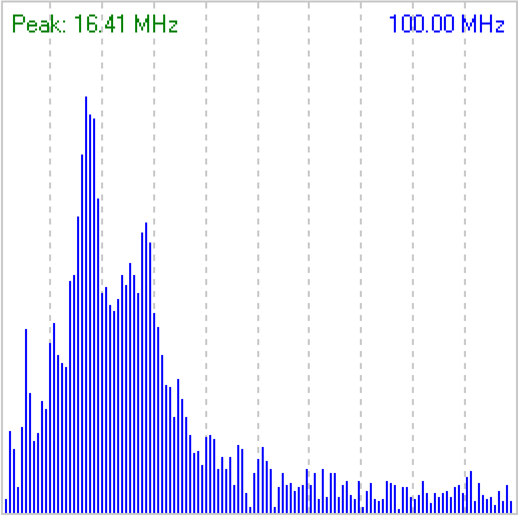
1. Correlated to energizing voltage
2. Distinct pulse shape
3. Concentrated spectrum

Example Loc 3 Phase C – Closer Look

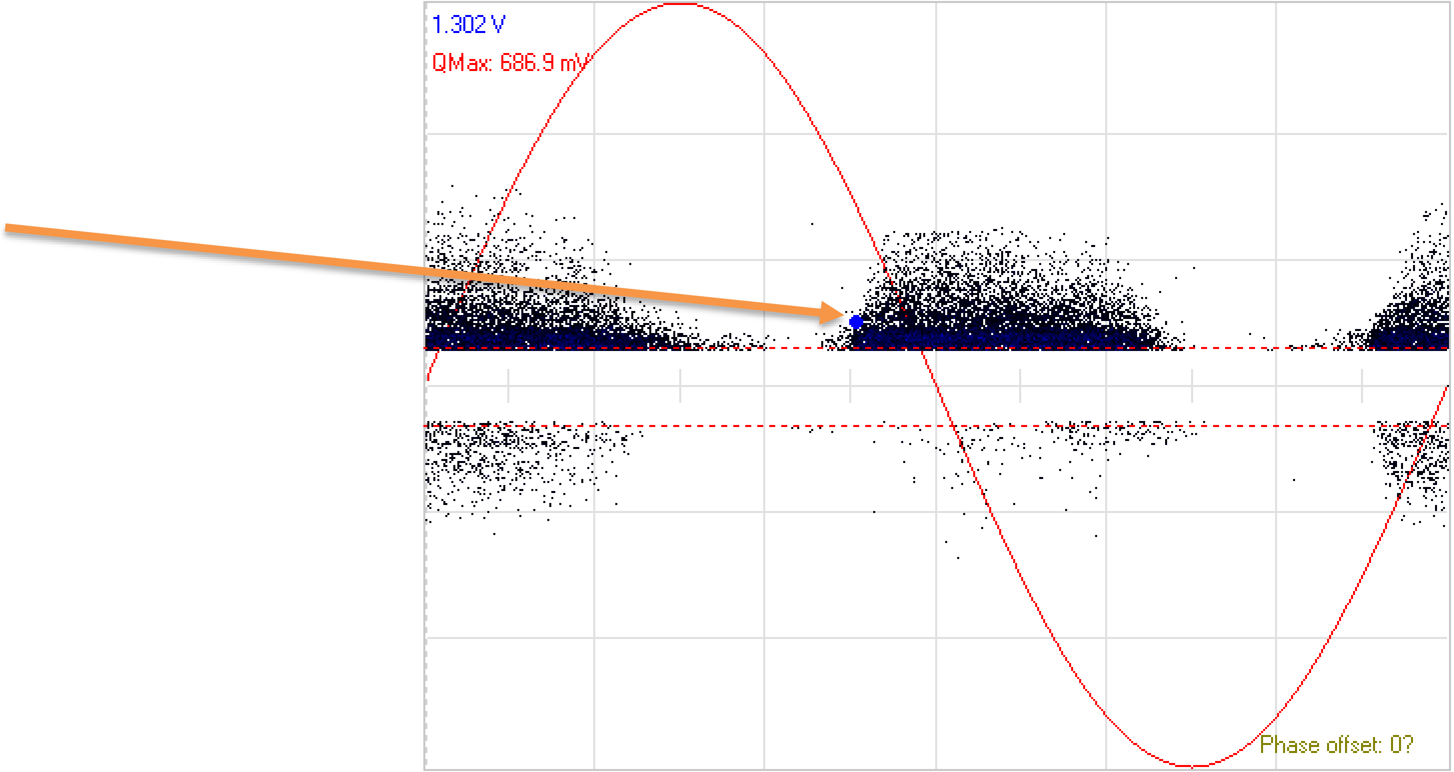
Waveform



Frequency Spectrum



Phase-Resolved PD Pattern

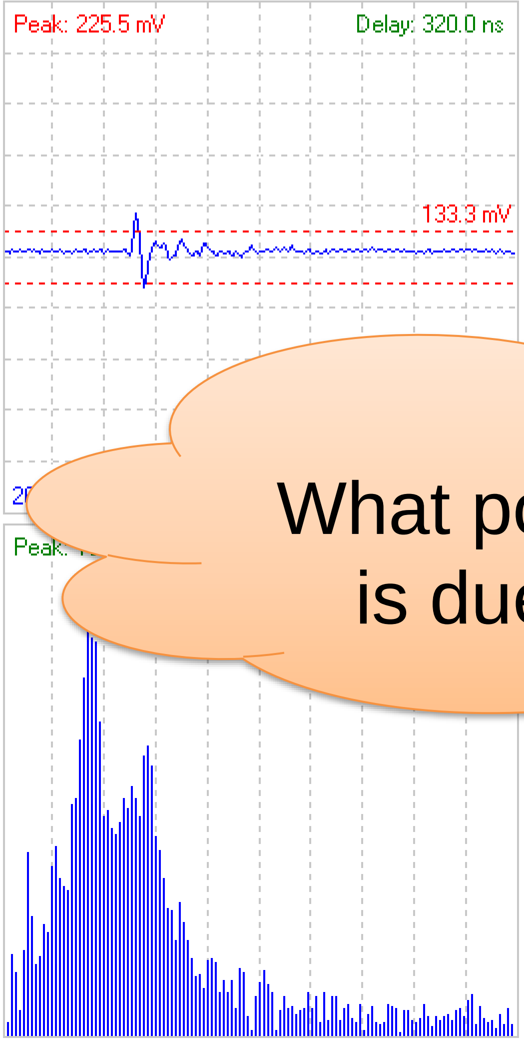


Smaller pulse height compared to other pulses but includes high frequency components

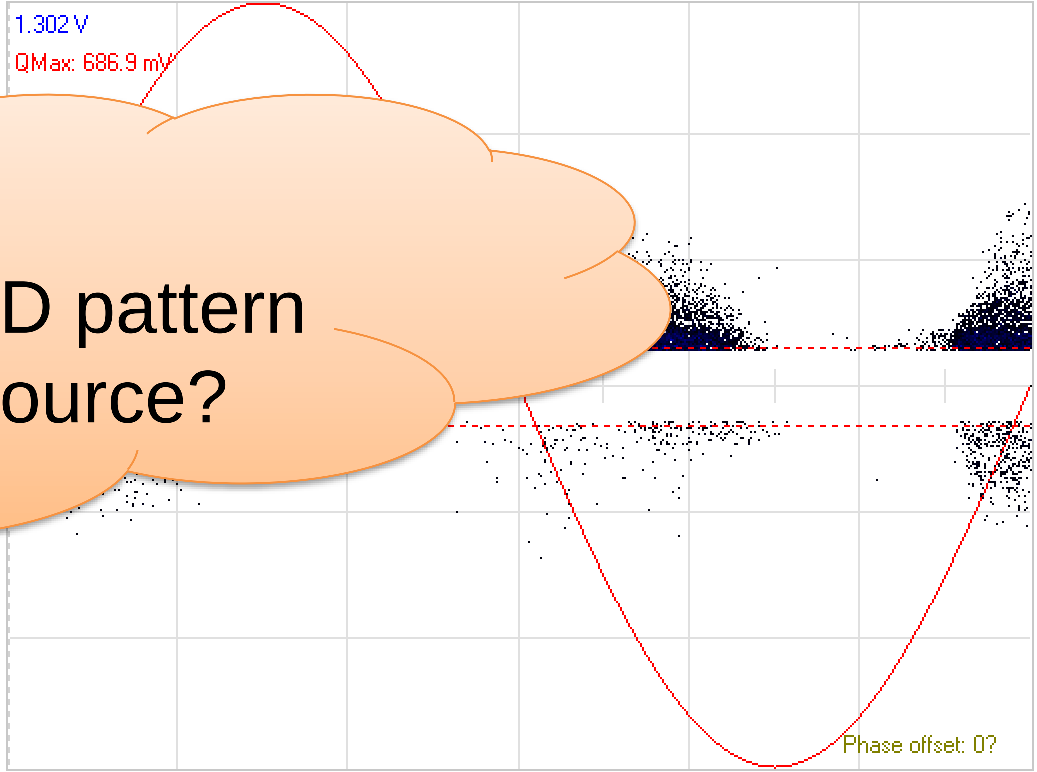
Example Loc 3 Phase C – Closer Look

Waveform

Frequency Spectrum



Phase-Resolved PD Pattern



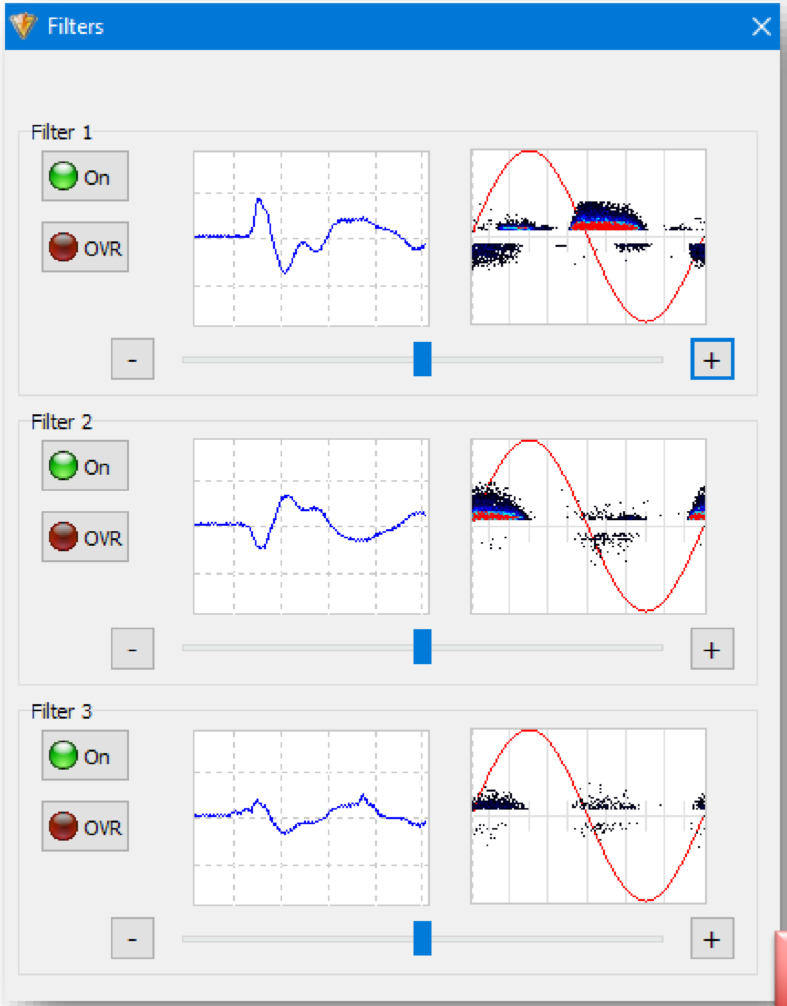
Question

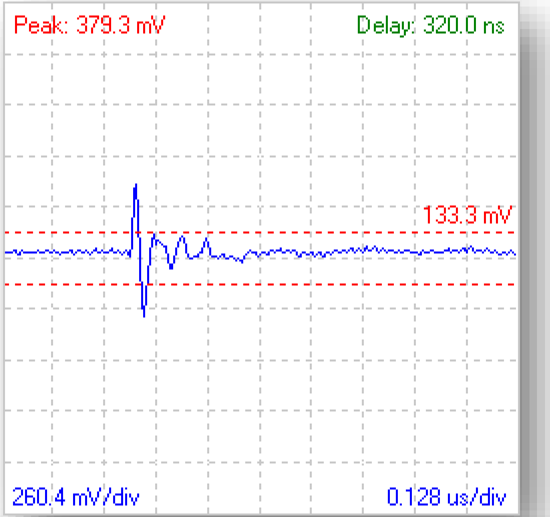
What portion of PRPD pattern is due to this PD source?

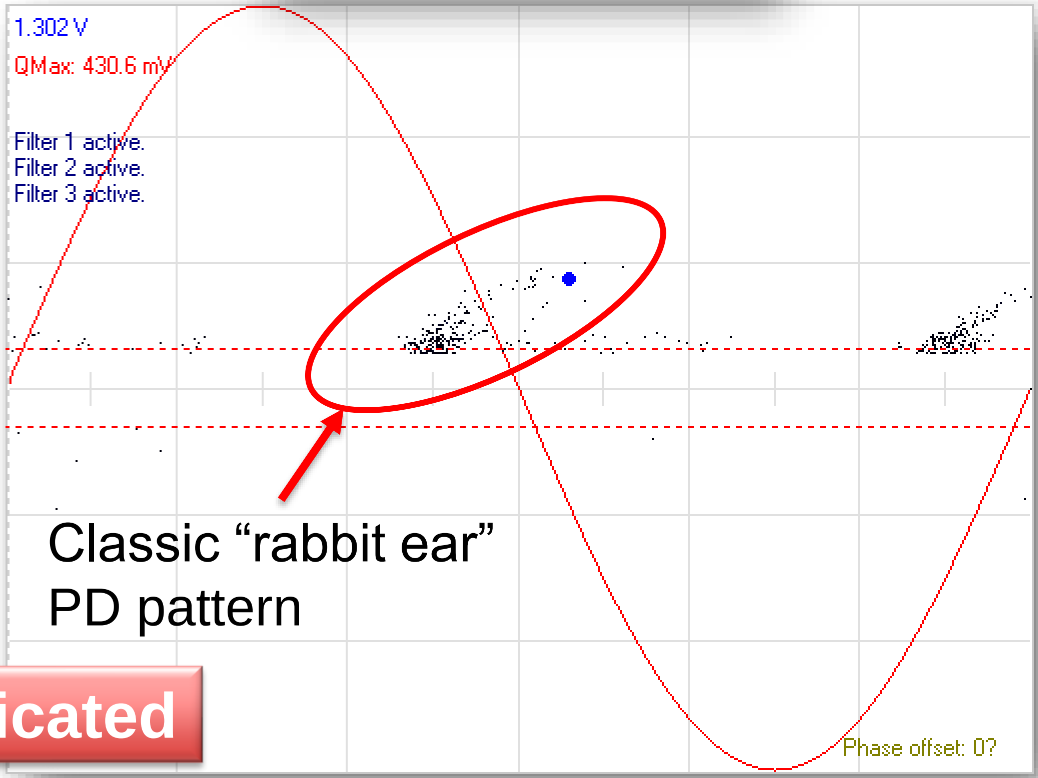
Smaller pulse height compared to other pulses but includes high frequency components

Applying Filters – Phase C

Software Filters (User-Defined)



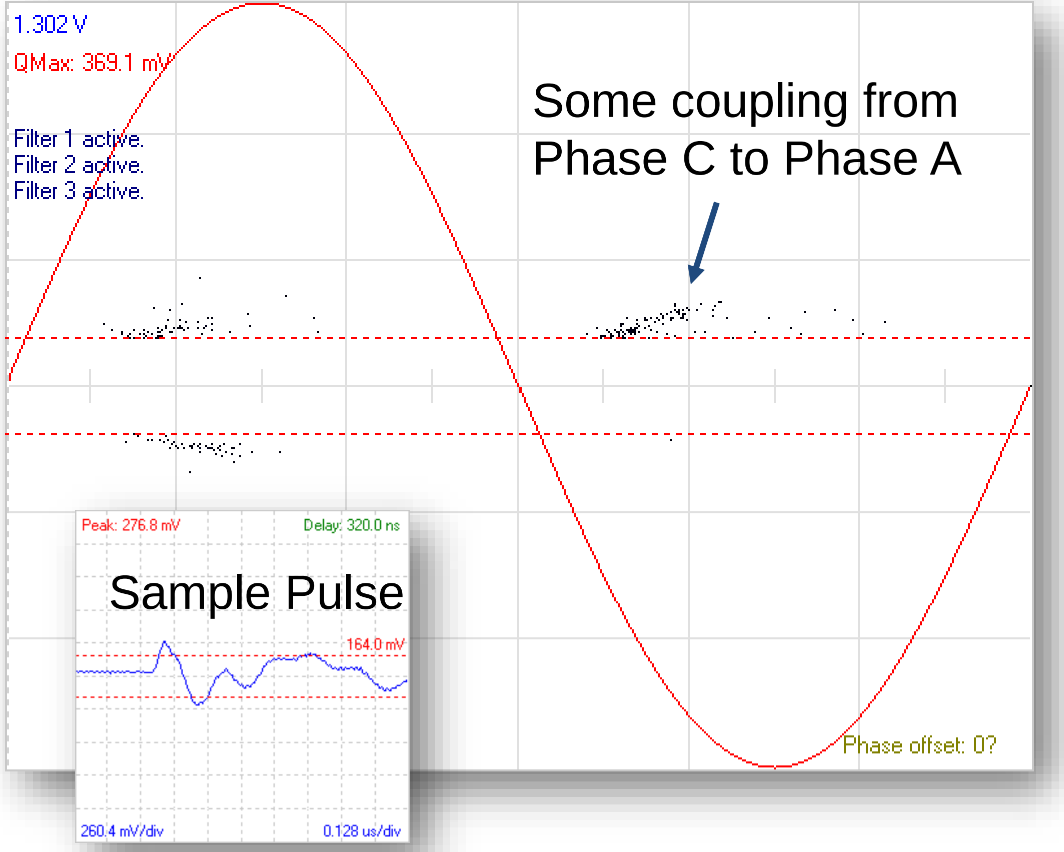




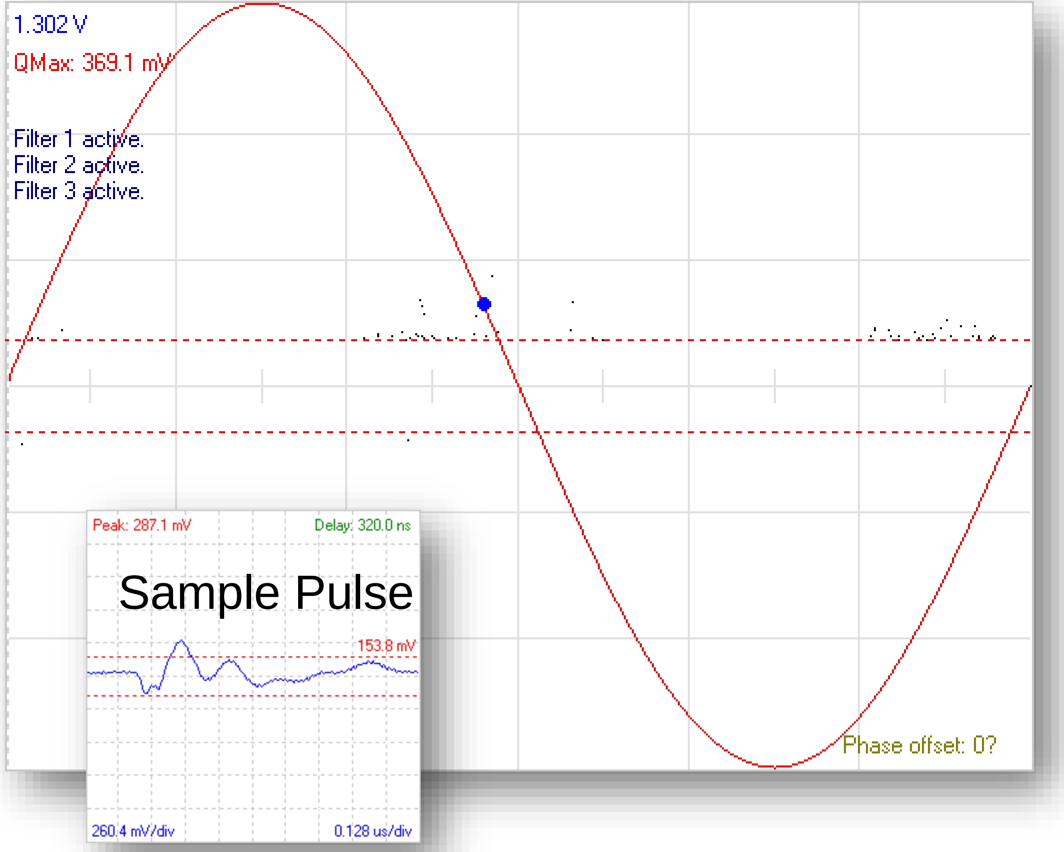
Internal PD indicated

Phase Localization - Apply Filters to Phases A & B

Phase A



Phase B



Phase C is the likely source

PD Assessment – Post Analysis

Loc	Transformer Manufacturing Date	Transformer Installation Date	Age (at time of test) [Years]	Initial PD Assessment	Comment
1	5/16/2023	7/18/2023	< 1	No PD Detected	
2	9/27/2000	1/19/2001	22	PD Detected	Same signal on all phases
3	8/13/2002	12/24/2002	21	PD Detected	Phase C
4	3/21/2001	3/5/2001	22	No PD Detected	
5	5/25/2006	6/15/2006	17	No PD Detected	
6	1/7/2008	2/5/2008	15	No PD Detected	
7	--	--	< 1	No PD Detected	

No PD Detected

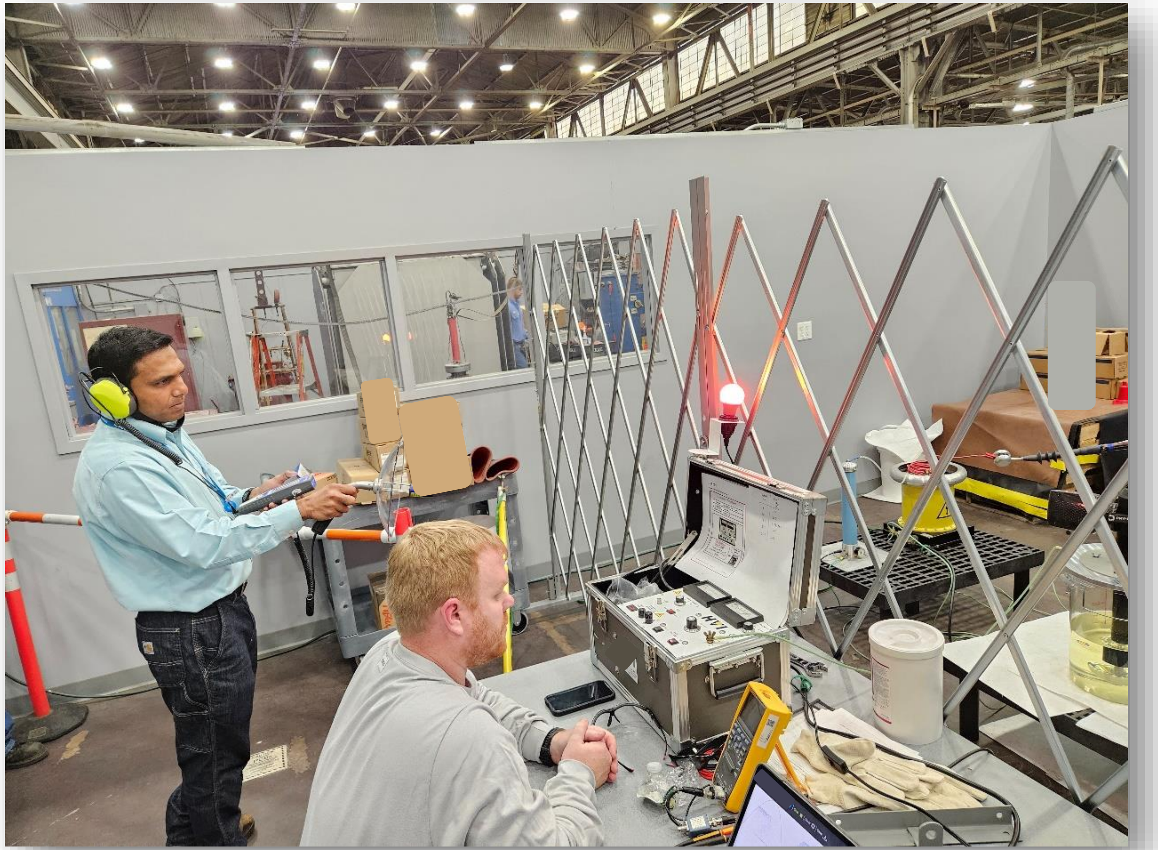
Data was examined for similar waveshapes to those bushings where PD was detected, none were observed in these units

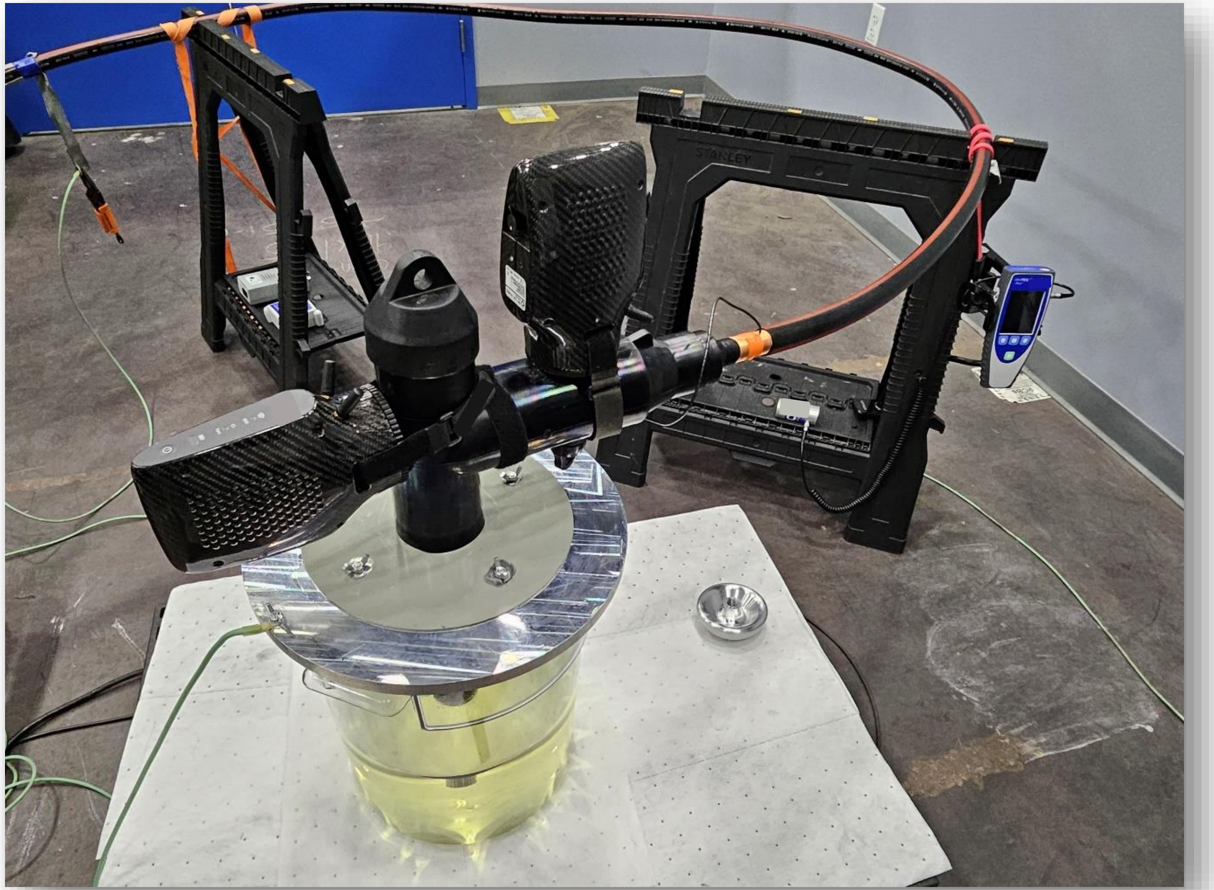
Screening Tests

Astoria Yard

On Site Screening Tests

Screen new bushings using partial discharge to select candidates for laboratory aging test

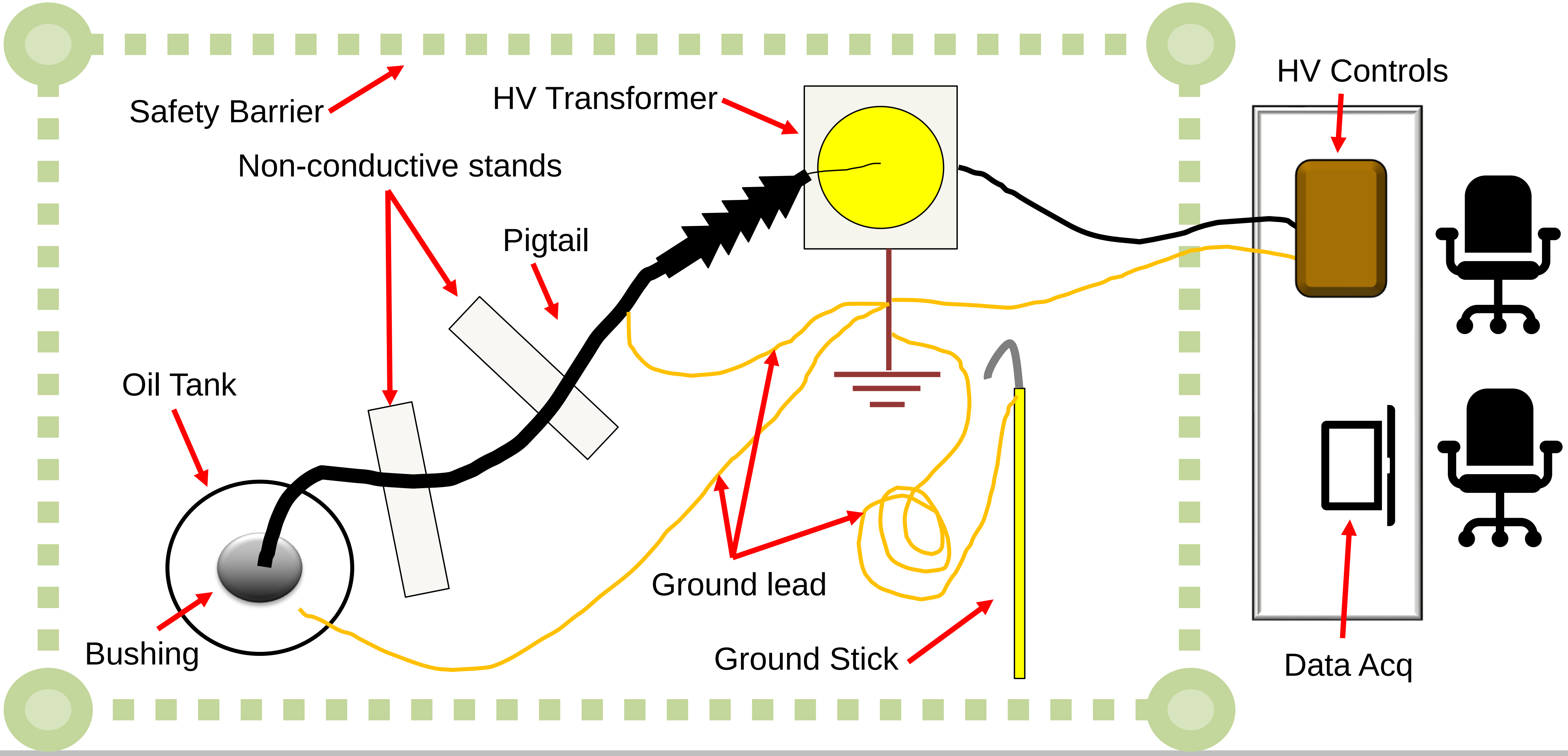




Tested >35 new bushings
Evaluating multiple manufacturers
3 PD detection instruments

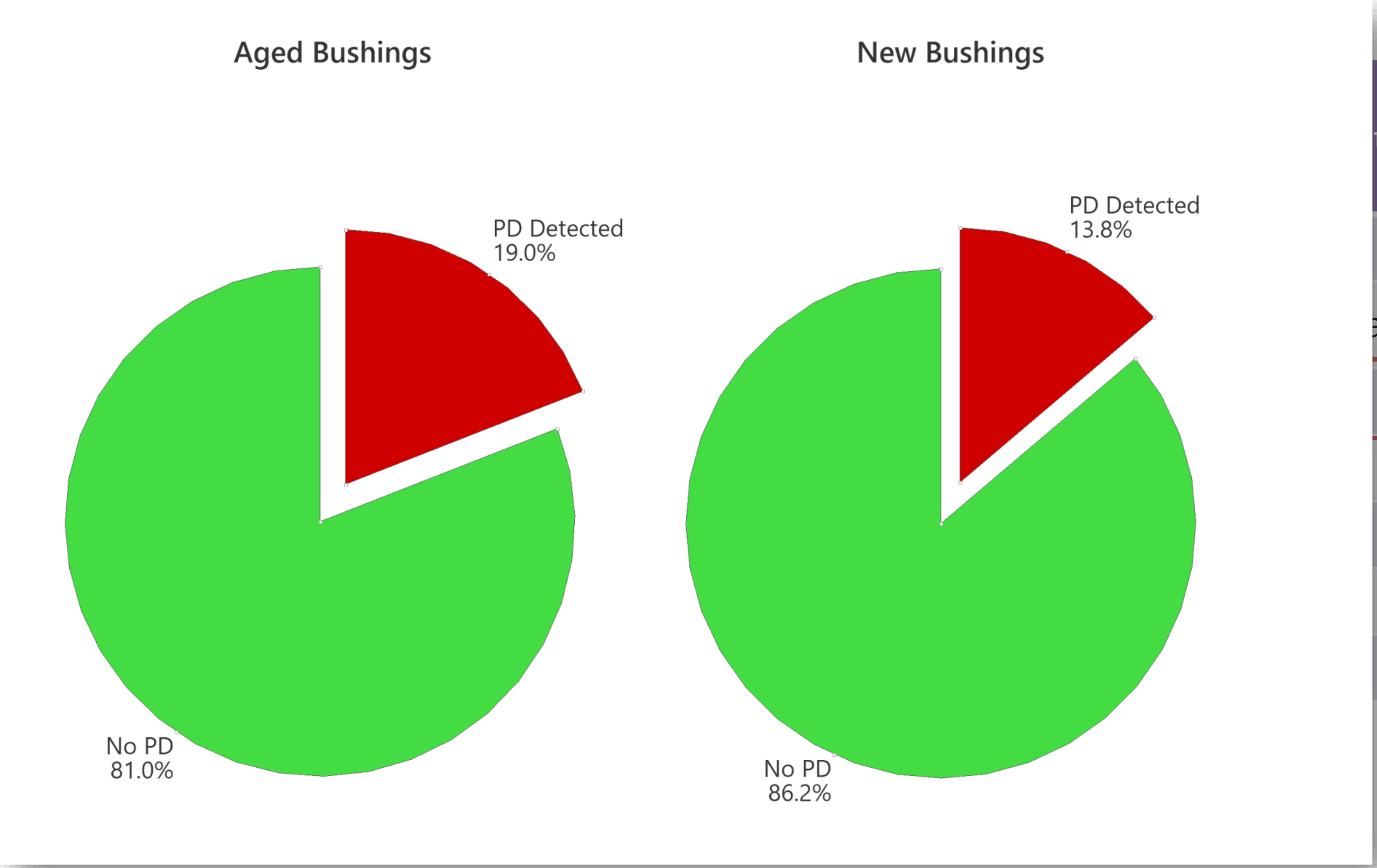
Temporary Test Area

Con Edison Requirement
PD free at 21 kV

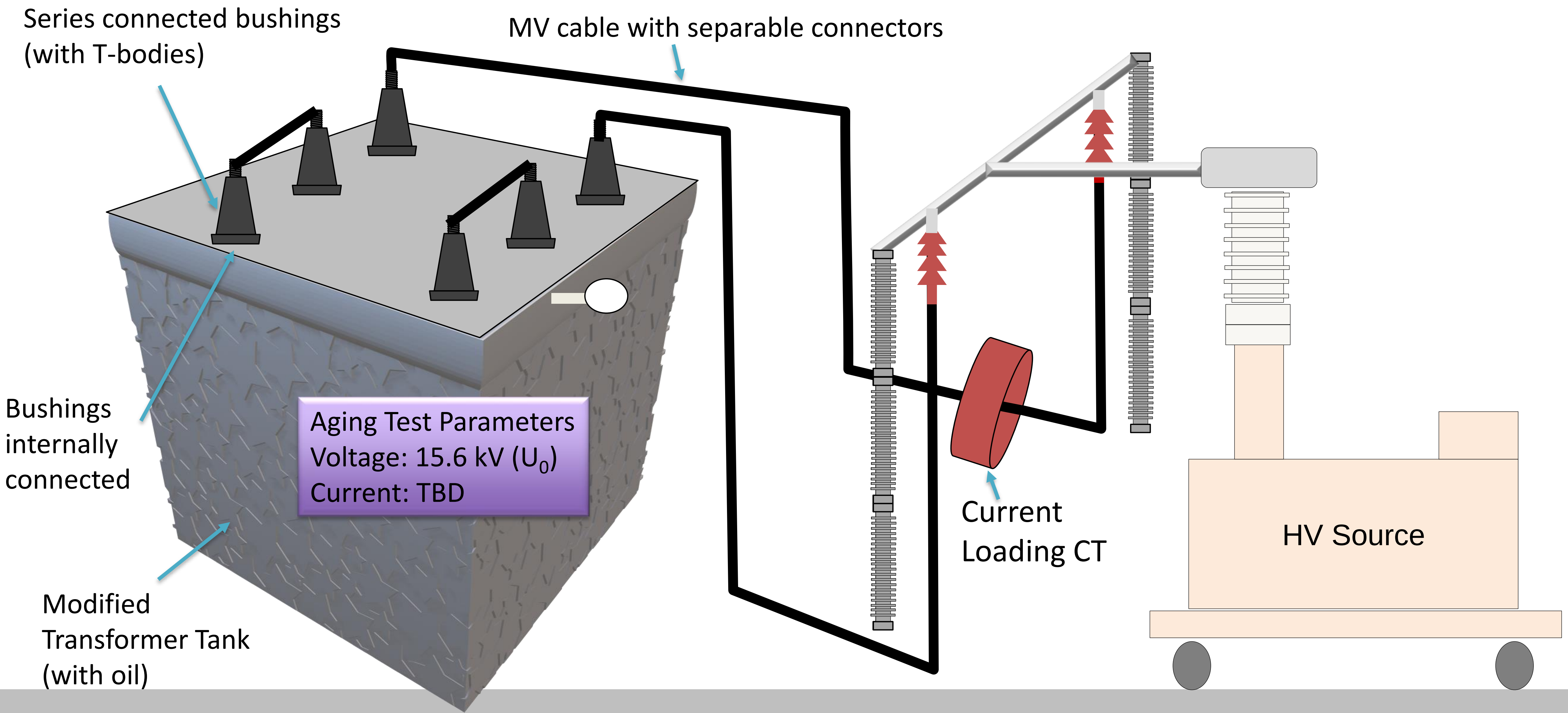


PD Assessment – Post Analysis

Loc	Tran Manu	t
1	5/1	
2	9/2	all phases
3	8/1	
4	3/2	
5	5/2	
6	1/	
7		



Bushing Endurance Test Setup



Next Steps

- Endurance testing of new bushings
  - New samples with and without PD

- Additional field tests
  - Revisit selected locations
  - Additional locations

- Exploring new transformer bushing designs
  - Screening tests
  - Aging test

Questions?