

# Can PD Measurements Bring Clarity to HV/EHV Commissioning Tests?

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*Ideas into Energy*

# Background

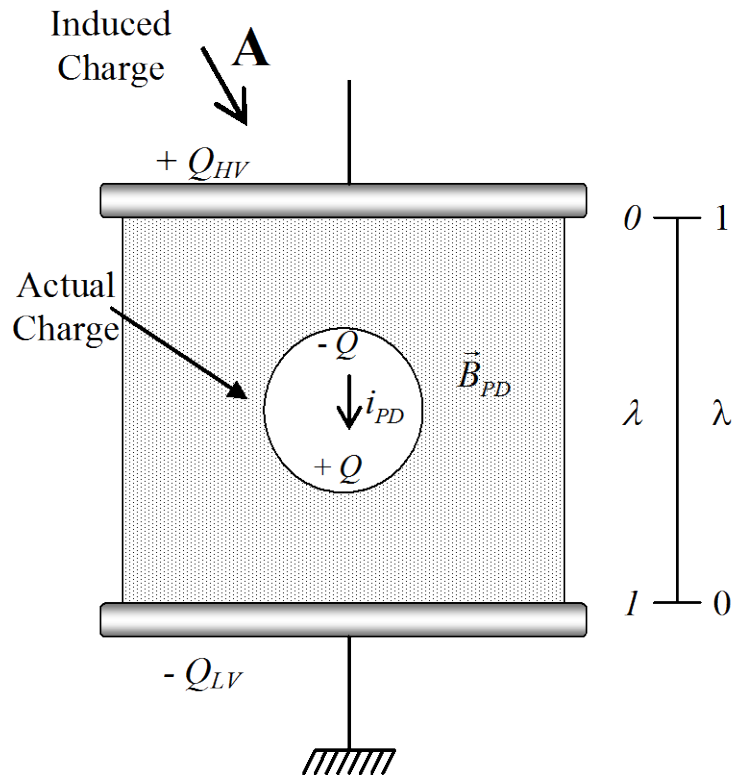
## Background

- PD Testing employed during commissioning testing of cables
- Some specs provide specific acceptance criteria for PD activity (in pC or mV)
- Well known that scientific limitations exist with respect to the diagnostic value of a PD level
- Confusion on laboratory vs field testing methodologies

## Presentation Breakdown

- Review: PD Theory
- Test Methodologies
- Implementation of Testing – practical issues
- Examples
- Conclusions

# Partial Discharge Theory



$$E(x) = \frac{V}{d}$$

$$E_{void} = \frac{3\epsilon}{1+2\epsilon} E(x)$$

$$= \frac{3\epsilon}{1+2\epsilon} \frac{V}{d}$$

$$E(x) = \frac{1}{x \ln \frac{R}{r}}$$

$$E_{void} = \frac{3\epsilon}{1+2\epsilon} E(x)$$

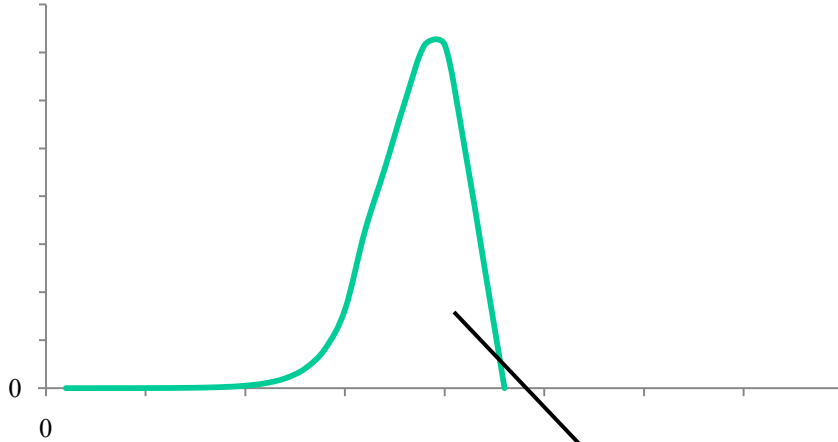
$$= \frac{3\epsilon}{1+2\epsilon} \frac{1}{x \ln \frac{R}{r}}$$

$$F = q \cdot E_{void}$$

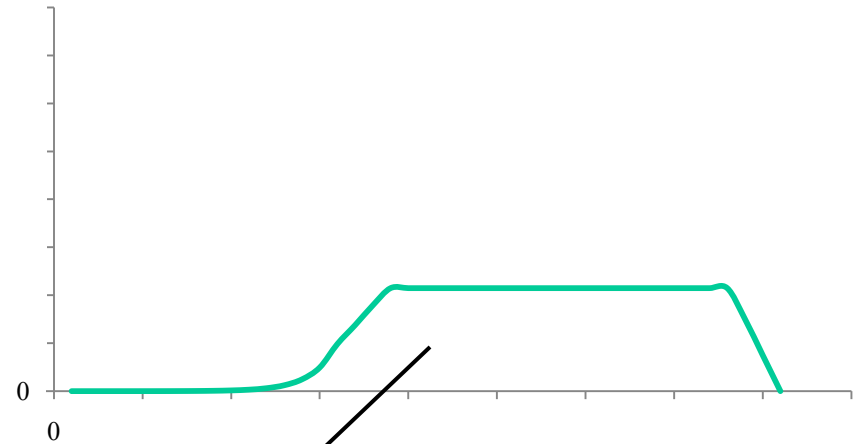
$$\Rightarrow m_q \cdot a = q \cdot E_{void} \Leftrightarrow a = \frac{q}{m_q} \cdot E_{void}$$

# Partial Discharge Theory

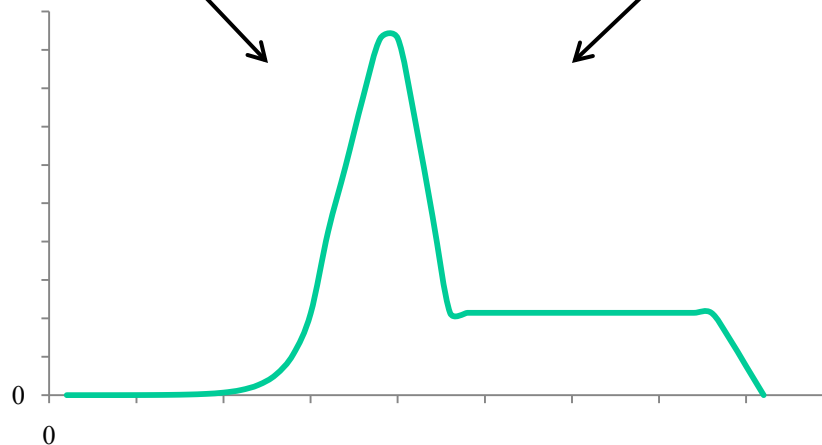
**PD Current - Electronic Component**



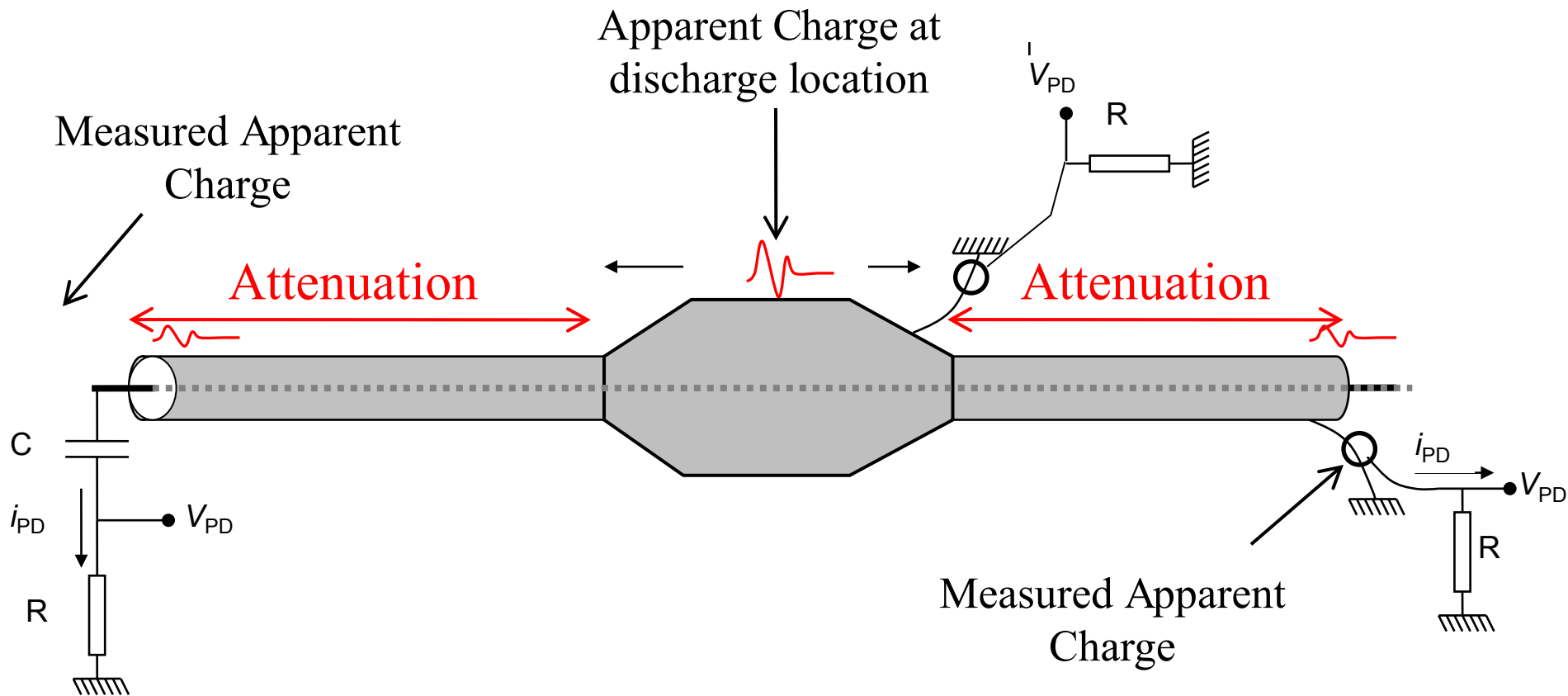
**PD Current - Ionic Component**



**PD Current - Total**

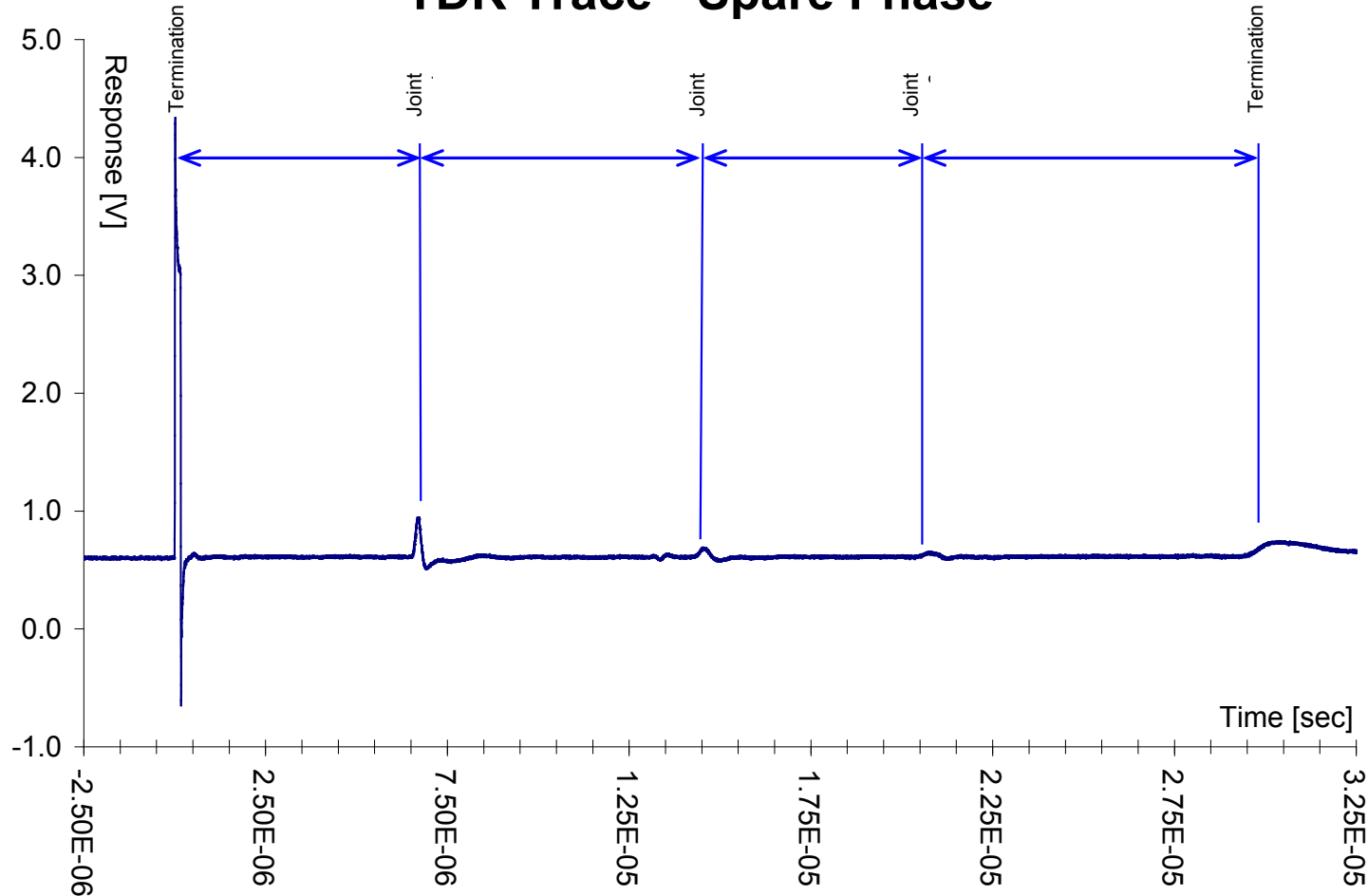


# PD Theory: Apparent Charge

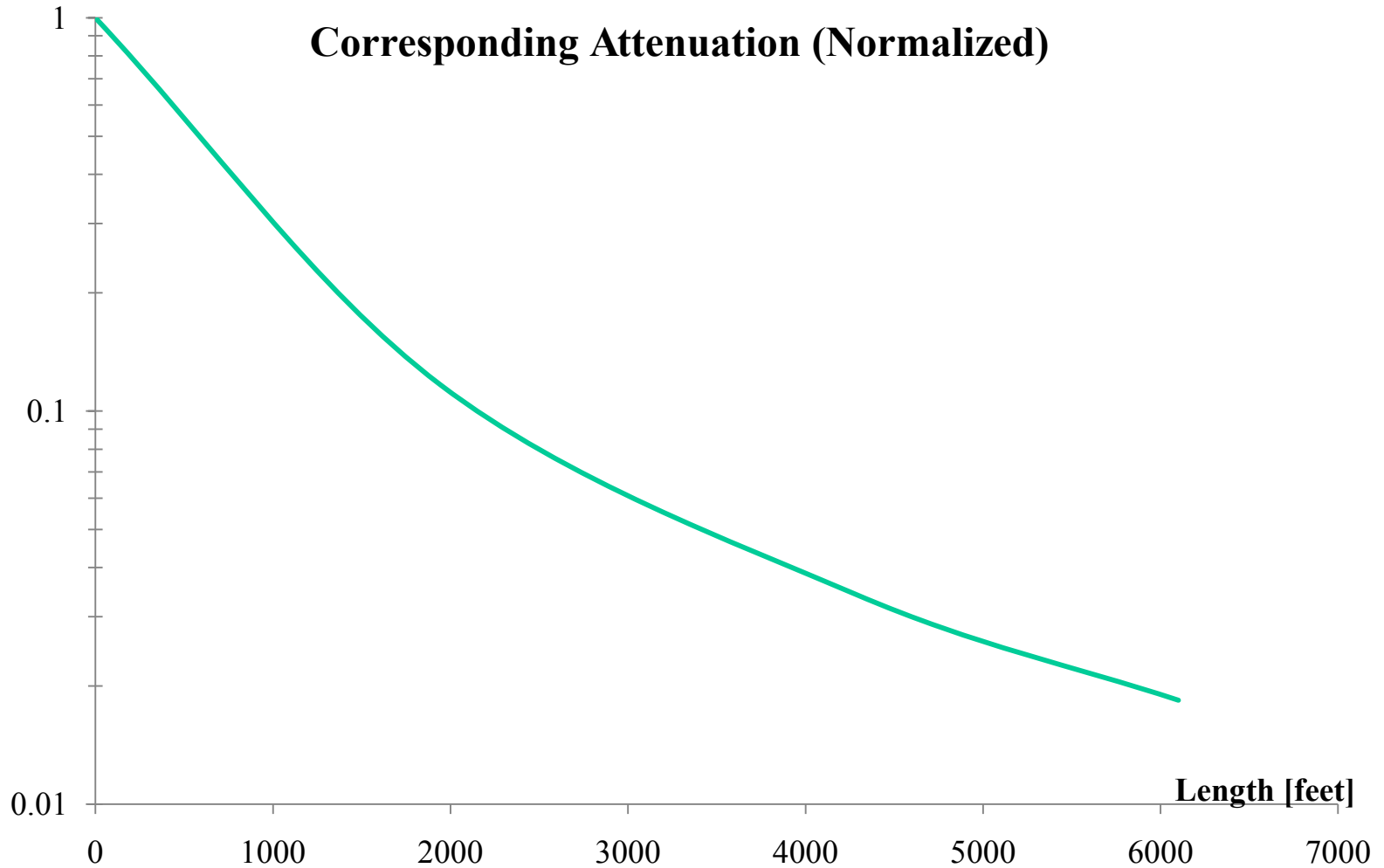


# Apparent Charge & Attenuation

## TDR Trace - Spare Phase



# Apparent Charge & Attenuation

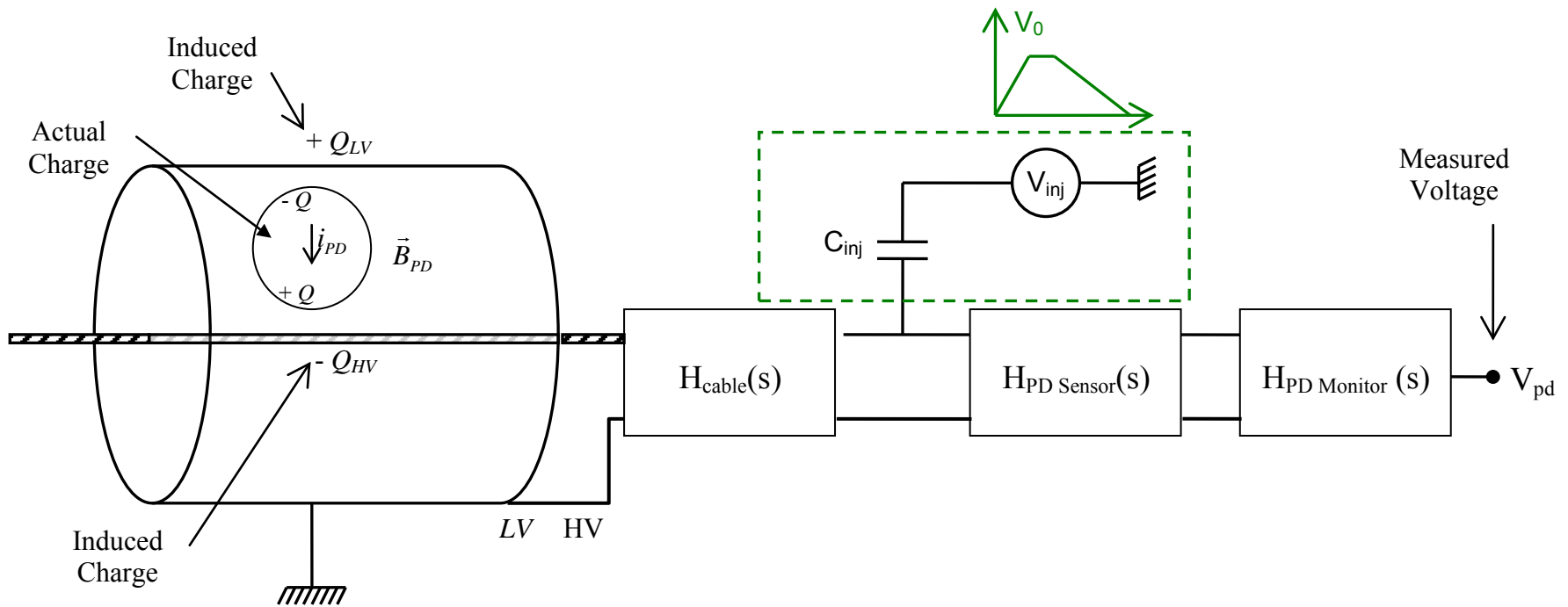


# Issues with PD Magnitudes

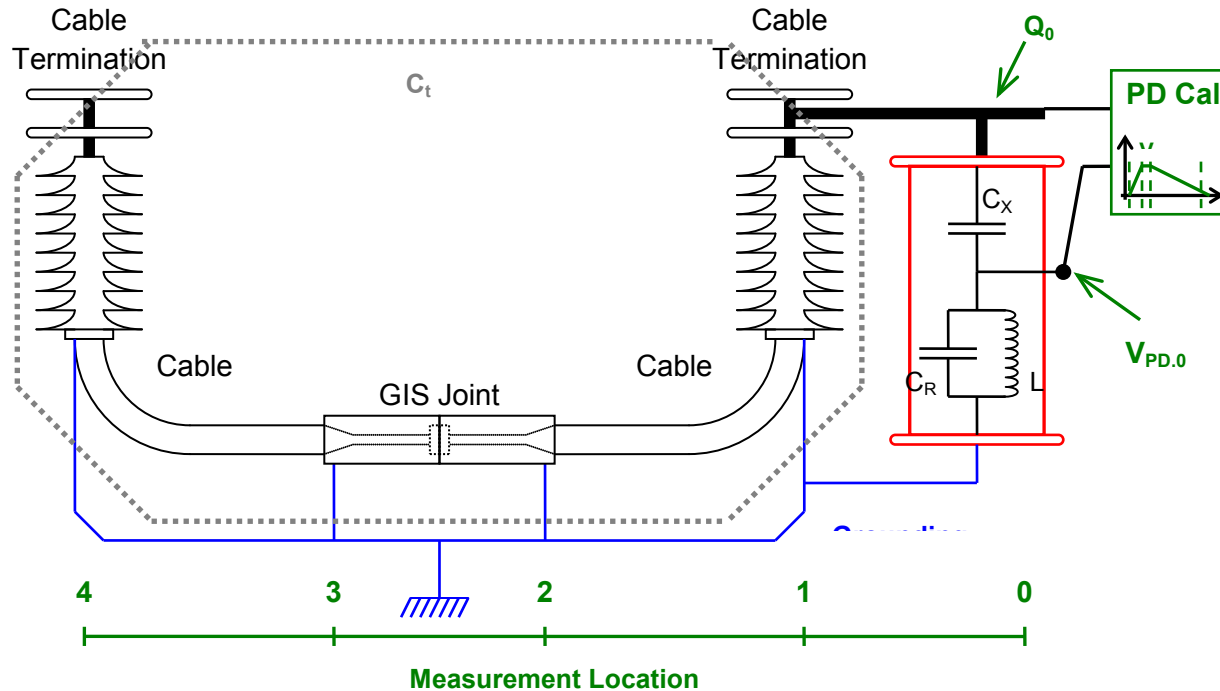
## Limiting Factors

- *Induced* PD magnitude always lower than actual PD magnitude ( $\lambda$ -function)
- *Measured* PD magnitude lower than induced PD magnitude due to
  - Attenuation
  - Signal reflection
  - Signal Pickup
- *Measured* PD magnitude may be higher than induced PD magnitude if one is not measuring the right peak

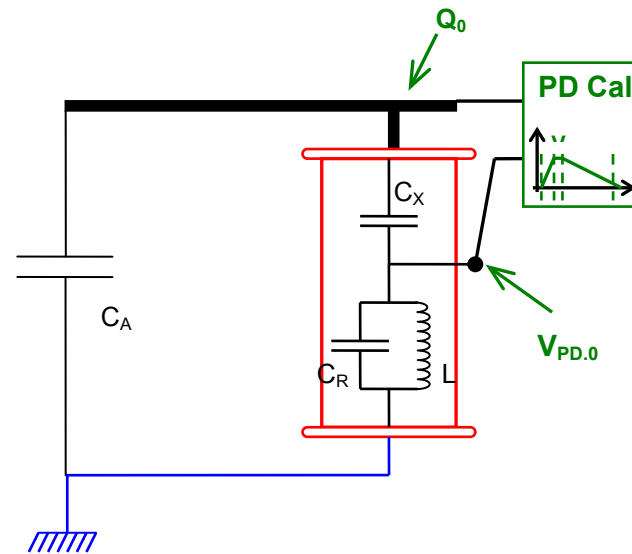
# Sensitivity Assessment



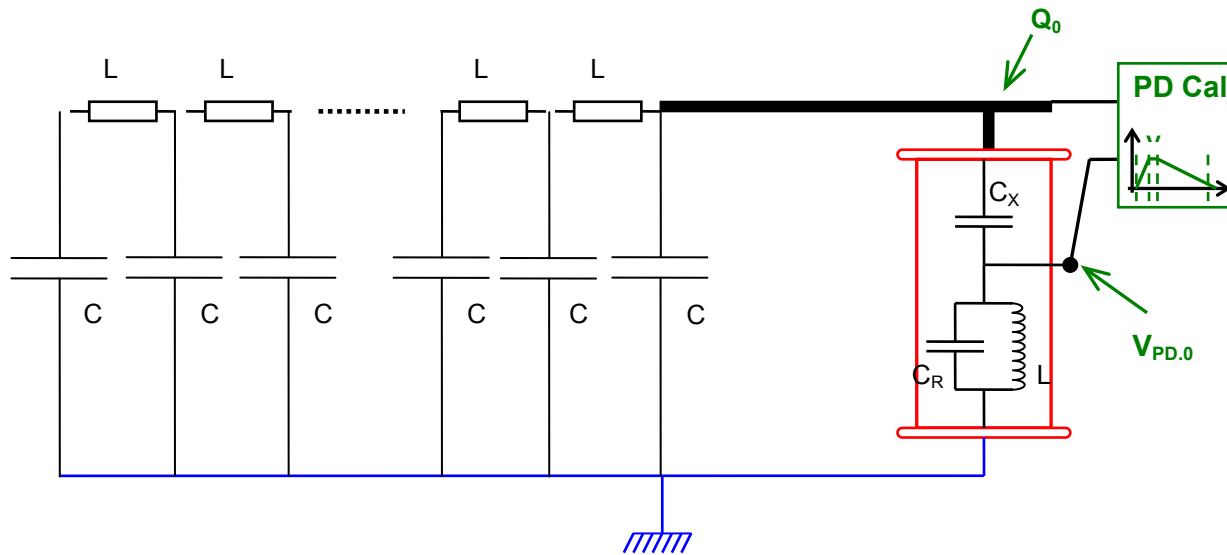
# Laboratory Testing



# Laboratory Testing



# Field Testing



# Issues with Signal Injection

- Signal Type:
  - Magnitude,
  - Shape
  - frequency content
- Impedance (mis)match
  - How much of the signal is transferred into your test object

# Practical Issues

## Preparation of the cable circuit

- Site access for equipment
- Accessible Terminations
- Corona Free Test termination
  - not required but makes life easier....
- Preferably a continuous sheath
  - Grounds lifted
  - Cross Bonding lifted
  - SVL's out of circuit (can fail as a result of a cable failure)
- Installation of PD Sensors (Distributed Measurement)
- If possible, fiber-optic communication infrastructure

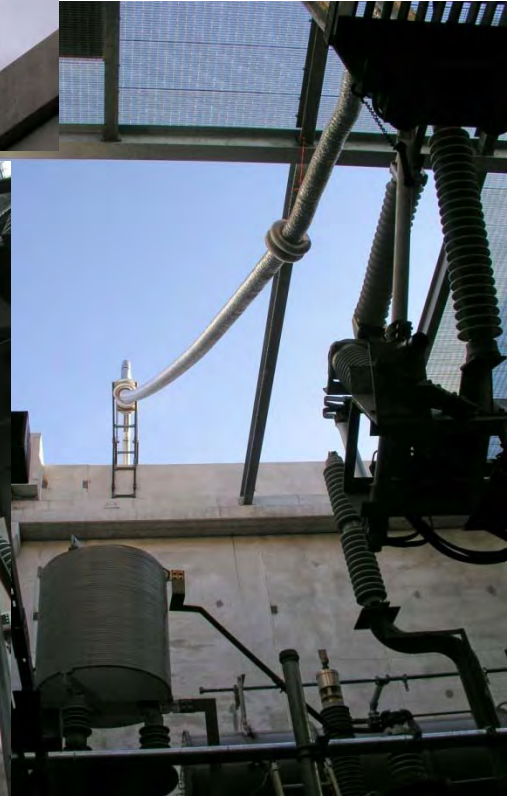
# Site Access



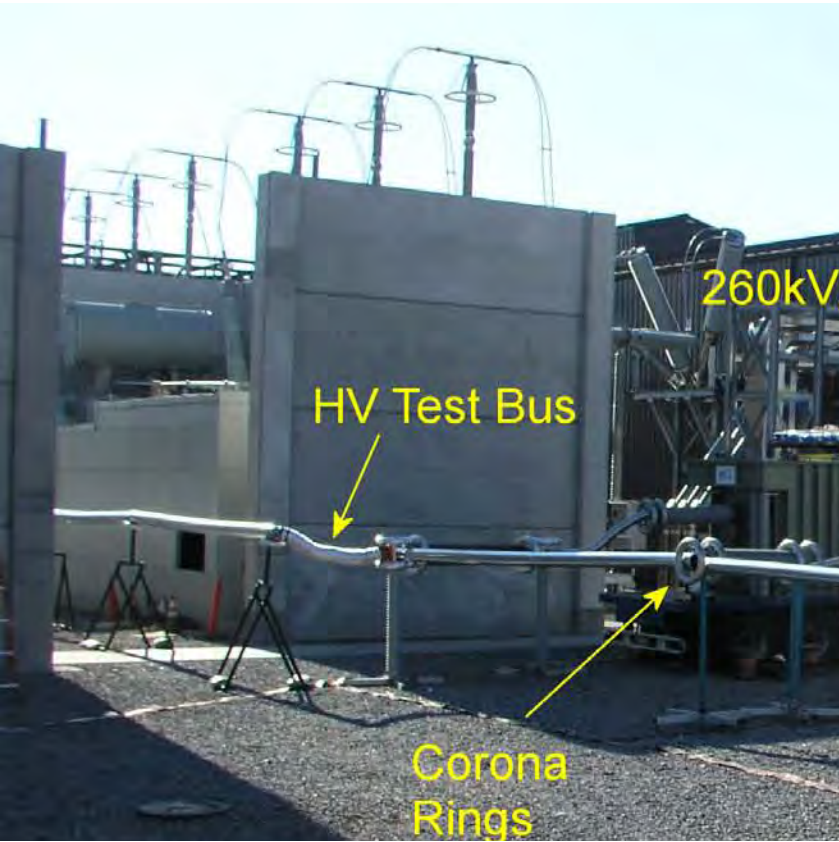
# Site Access



# Site Access



# 25km, 345kV XLPE





# PD Sensors Installation

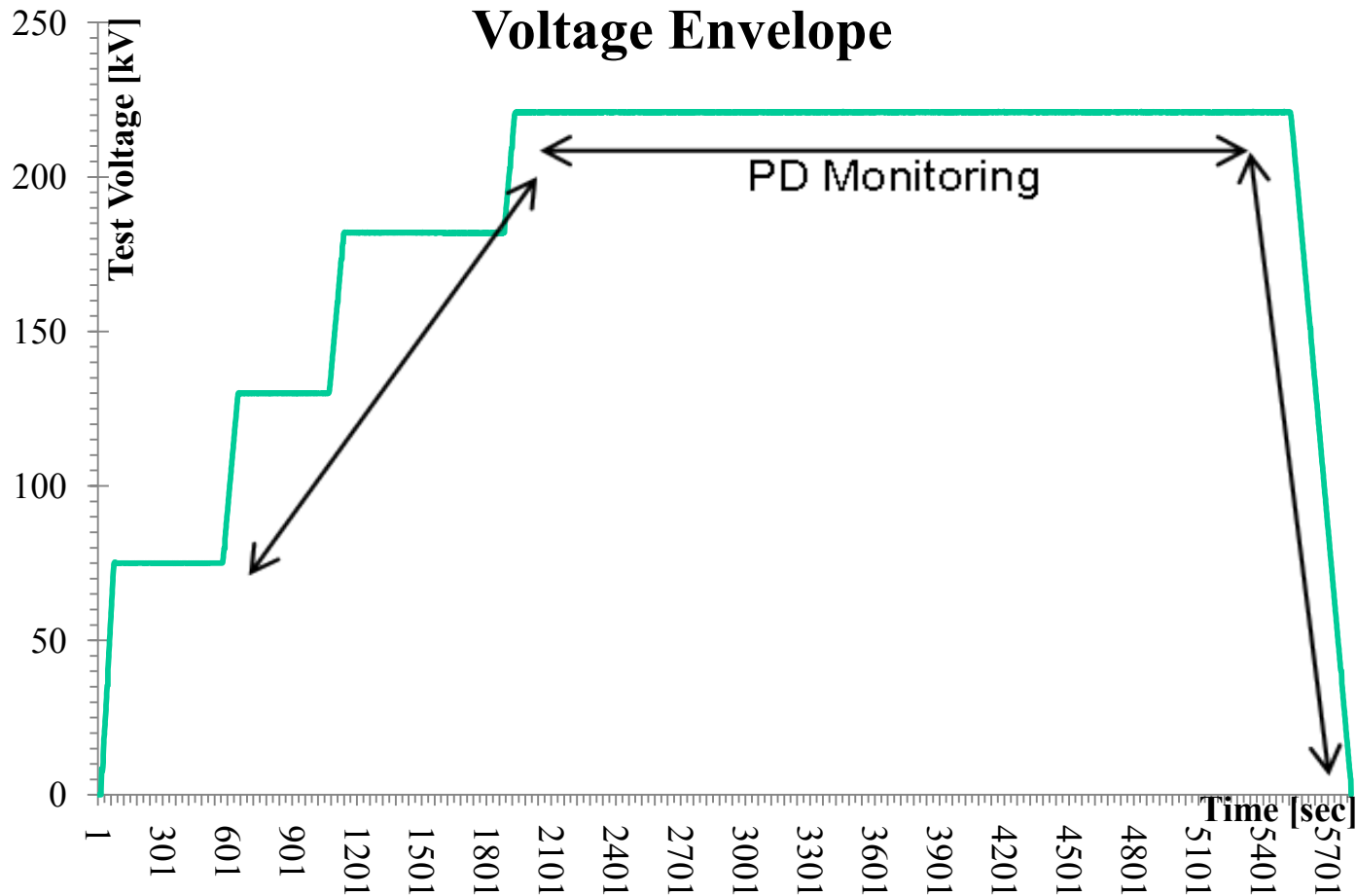
# Integrated PD Sensor



# Test Methodologies

- Test Voltage supplied by resonant test set
  - Voltage level and duration according IEC 60840 & IEC 62067
- Terminal PD Measurement
- Distributed Measurements
  - Periodic (sequential) or Continuous
  - During AC HiPot & After AC Hipot
- Sensors
  - External Sensors
  - Integrated Sensors
- Typically use ultra wideband PD monitors
  - 10kHz to 50 MHz
  - 10kHz to 400 MHz

# Test Voltage Profile



# Preliminary Results

- Testing of 66kV up to 400kV Cable Circuits
- More than 1600 km
- 2,483 accessories
- 267 individual phases

| Rated Voltage [kV] | No of Accessories | Failure Rate During HiPot | PD Occurance but No Failure During AC HiPot |
|--------------------|-------------------|---------------------------|---|
| 115                |                   |                           |   |
| 132/138            | 254               | 0.79%                     | 0.00%                                       |
| 220/230            | 1,239             | 1.78%                     | 0.81%                                       |
| 345/400            | 972               | 0.35%                     | 0.31%                                       |

# Example 1

- 220kV, XLPE 2500mm<sup>2</sup>
- $U_{\text{test}} = 216\text{kV}$ , 109 Amp, 38 Hz
- Failed 6 min & 6 sec into AC HiPot
- Failure located in the immediate vicinity of the joint but not in the joint itself.
- Microscopic examination demonstrated that the failure had resulted from electrical treeing
- Not result of the inclusion of a void or contaminant
- Tree caused by mechanical damage inflicted on the cable during preparation of the cable for splicing

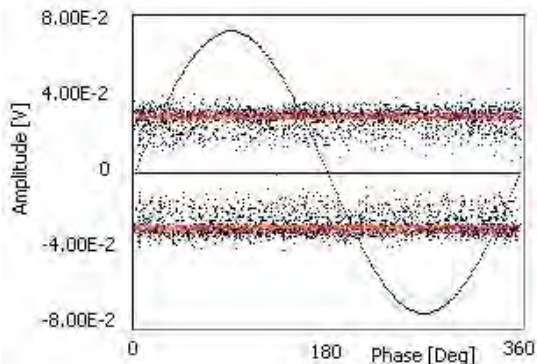


# Example 2

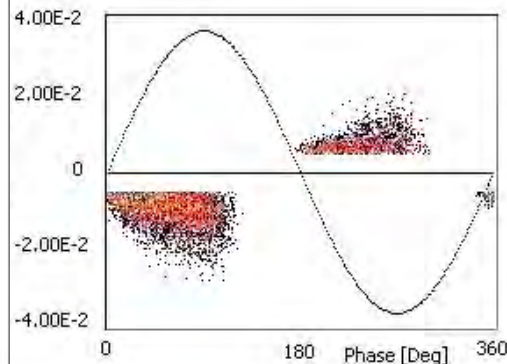
- 138kV XLPE tested 132 kV ( $1.7U_0$ ) for 60 minutes
- PD Sensors around ground links
- Approximately between 1,200' to 1,800' between manholes



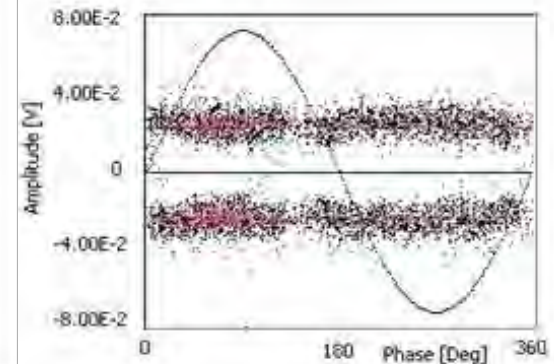
MH 76063



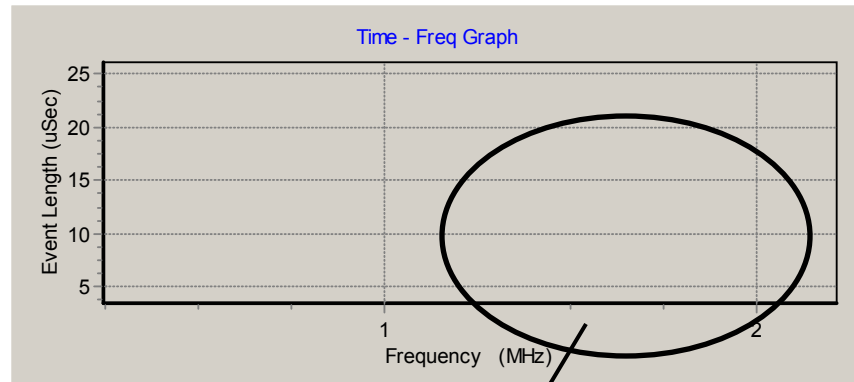
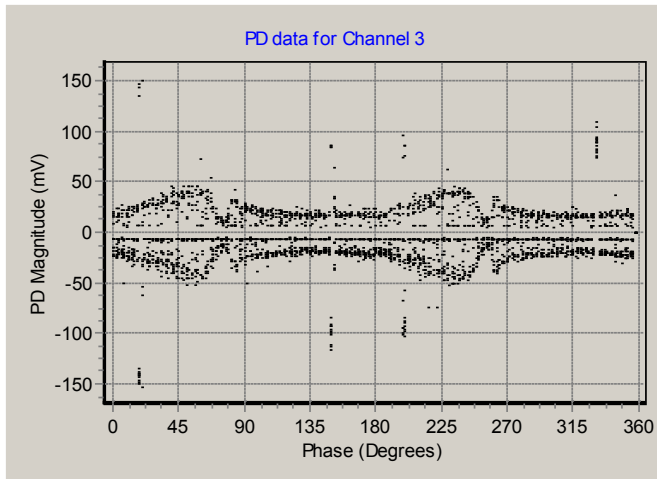
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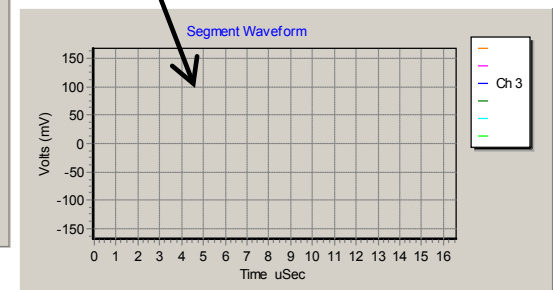
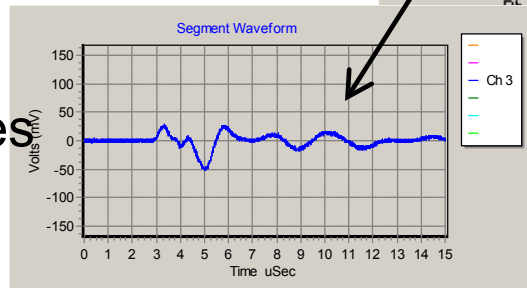
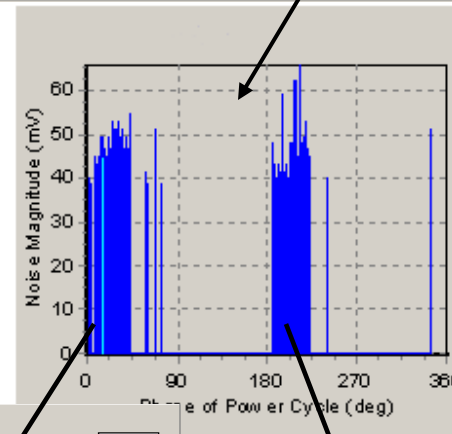
MH 76065



# Example 3



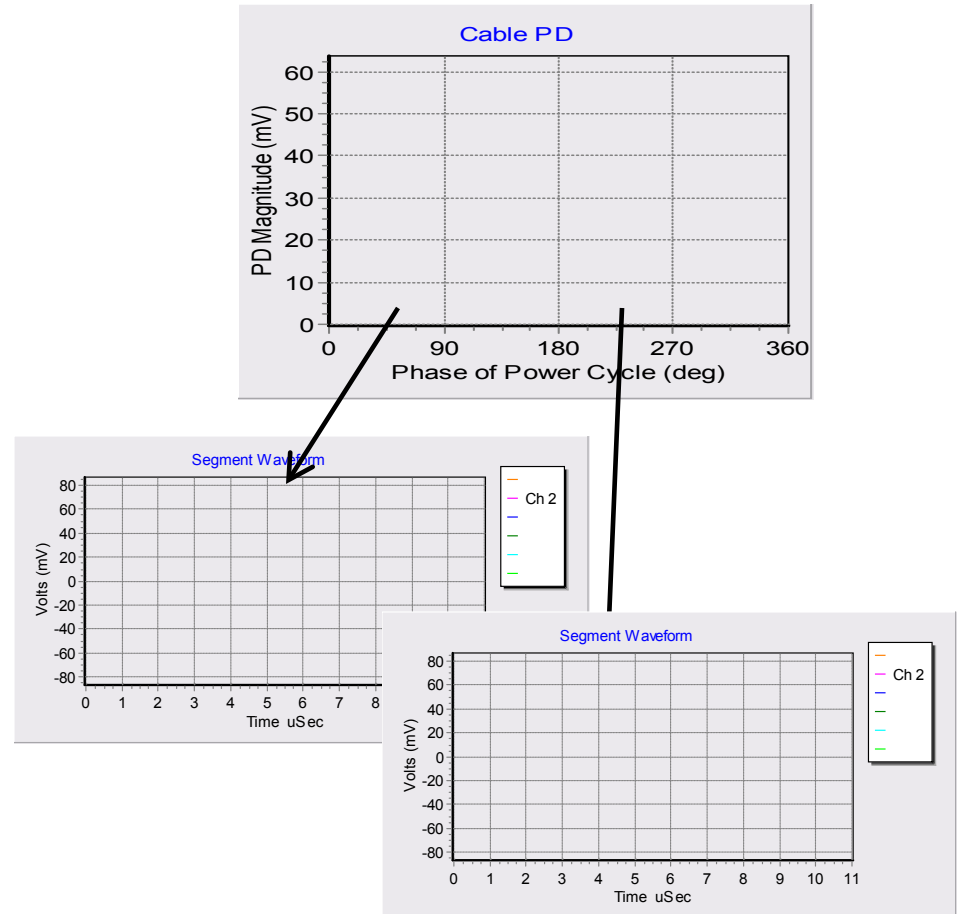
- 345kV XLPE Cable Line
- 250kV Commissioning Test as per IEC 62067
- Inductive Sensor
- Source detected 22 minutes into the test
- -1,100pC/+1,500pC



# Example 4

## 220kV XLPE Joint

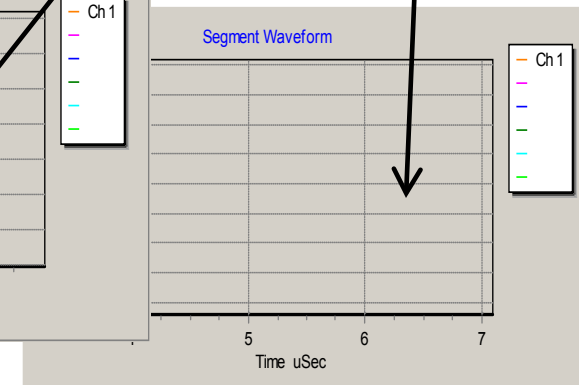
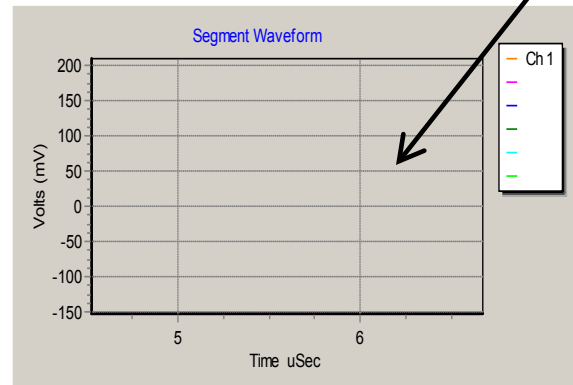
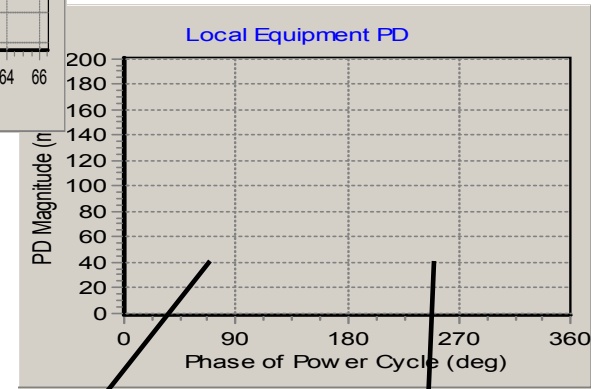
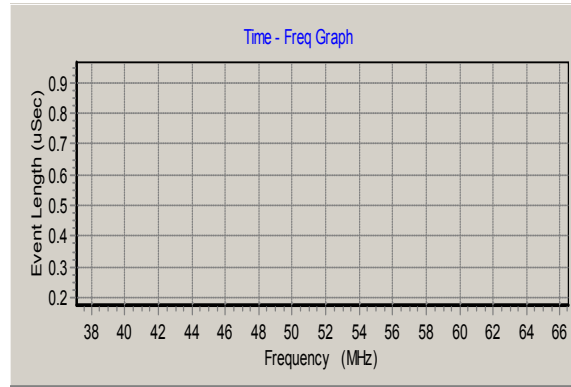
- 216kV Commissioning Re-Test following joint failure.
- Two new joints inserted in circuit.
- Permanently installed inductive PD sensors
- Monitored continuously during AC HiPot
- PD Testing also performed after successful commissioning test at  $1.2U_0$  following 15 second pre-conditioning at  $1.4U_0$ .
- PDIV = 153kV, PDEV = 145kV



# Example 5

## 225kV Termination

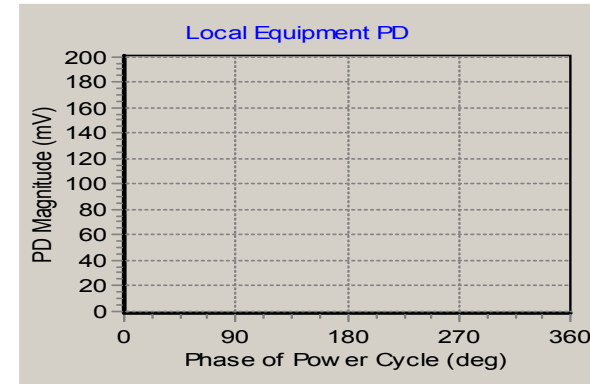
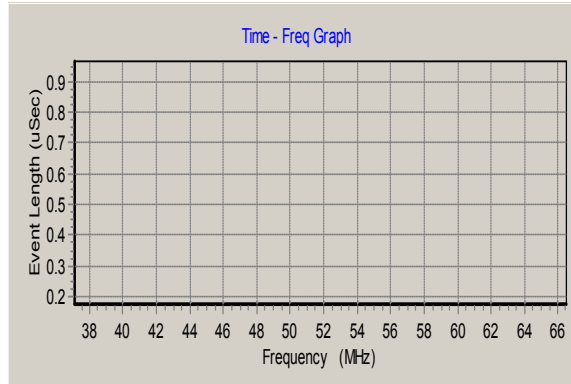
- 221kV Commissioning Test following IEC 62067
- Permanently installed capacitive internal PD sensors
- Monitored continuously during AC HiPot
- PD Testing also performed after successful commissioning test at  $1.2U_0$  following 15 second pre-conditioning at  $1.4U_0$ .
- PDIV = 153kV, PDEV = 145kV
- PD within a void located within the stress cone



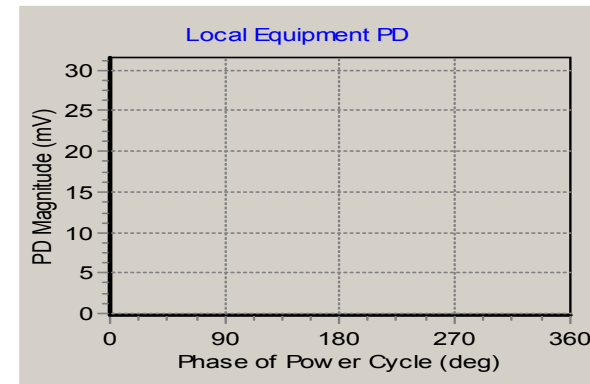
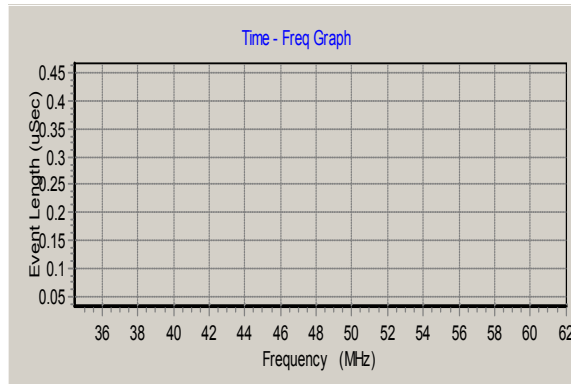
# Example 5 Continued

## Simultaneous PD Measurement

Internal Sensor  
(Capacitive)



External Sensor  
(HFCT)



# Conclusions

- PD Measurements can help bring some clarity to the integrity of the insulation as part of a commissioning test as not all insulation related defects cause failure during a withstand test
- PD Magnitudes are not diagnostic. Several factors affect the magnitude of the measured discharge
  - Coupling from PD to measuring electrode
  - Transformation from induced charge to travelling wave
  - Reflection at joints and terminations
  - EM coupling between sensor and the cable

# Conclusions

- Pass Fail Criteria based on a PD level – whether in pC or mV – are not meaningful
- Guiding criterion is no PD should be present at the test level
- For commissioning test, important to have an idea of sensitivity level (however difficult it is to establish).