Regional Seminar, Russia, June 2014

UHF PD GIS monitoring

Thomas Linn, Qualitrol

Agenda

1. UHF PD monitoring
2. PD defect types
3. Insides of partial discharges!
4. PD localization
5. Return of experiences – some case studies!

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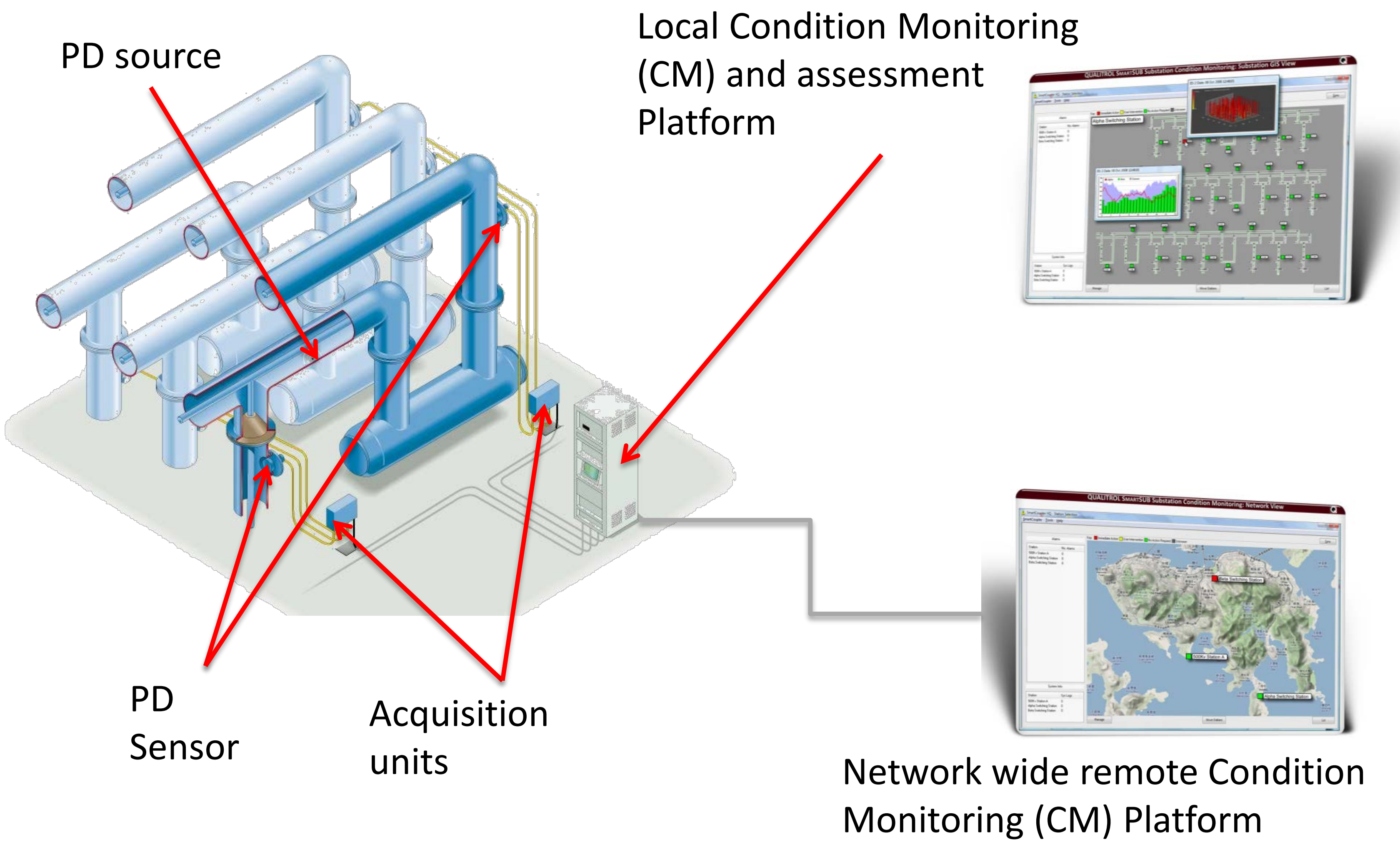
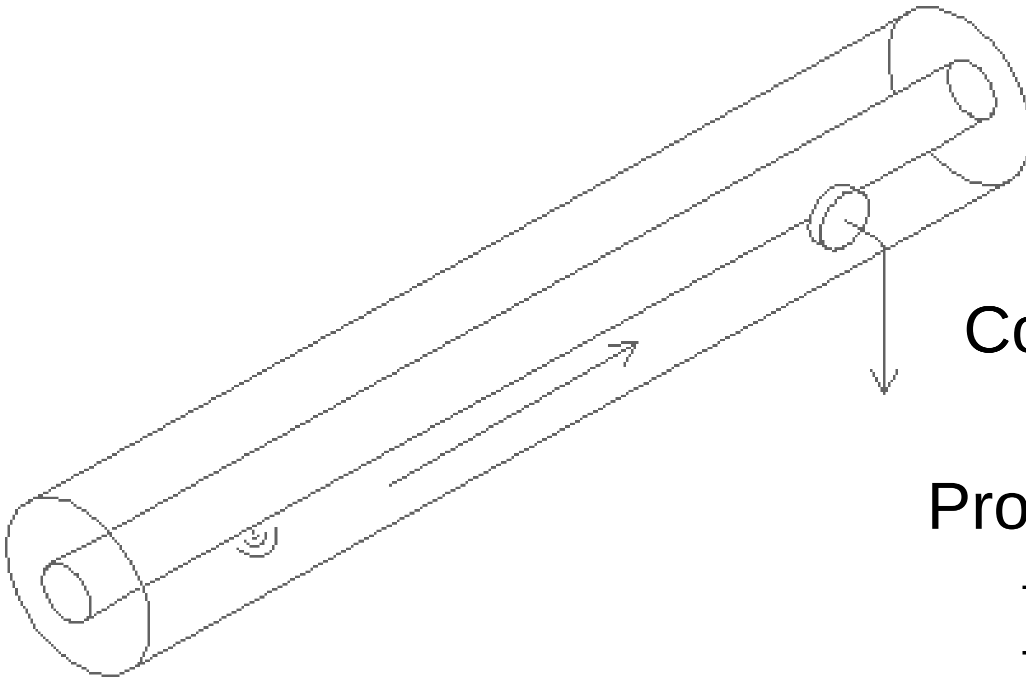
Components of PD monitoring system



PD Signal - Stages in Transmission



Couplin
g

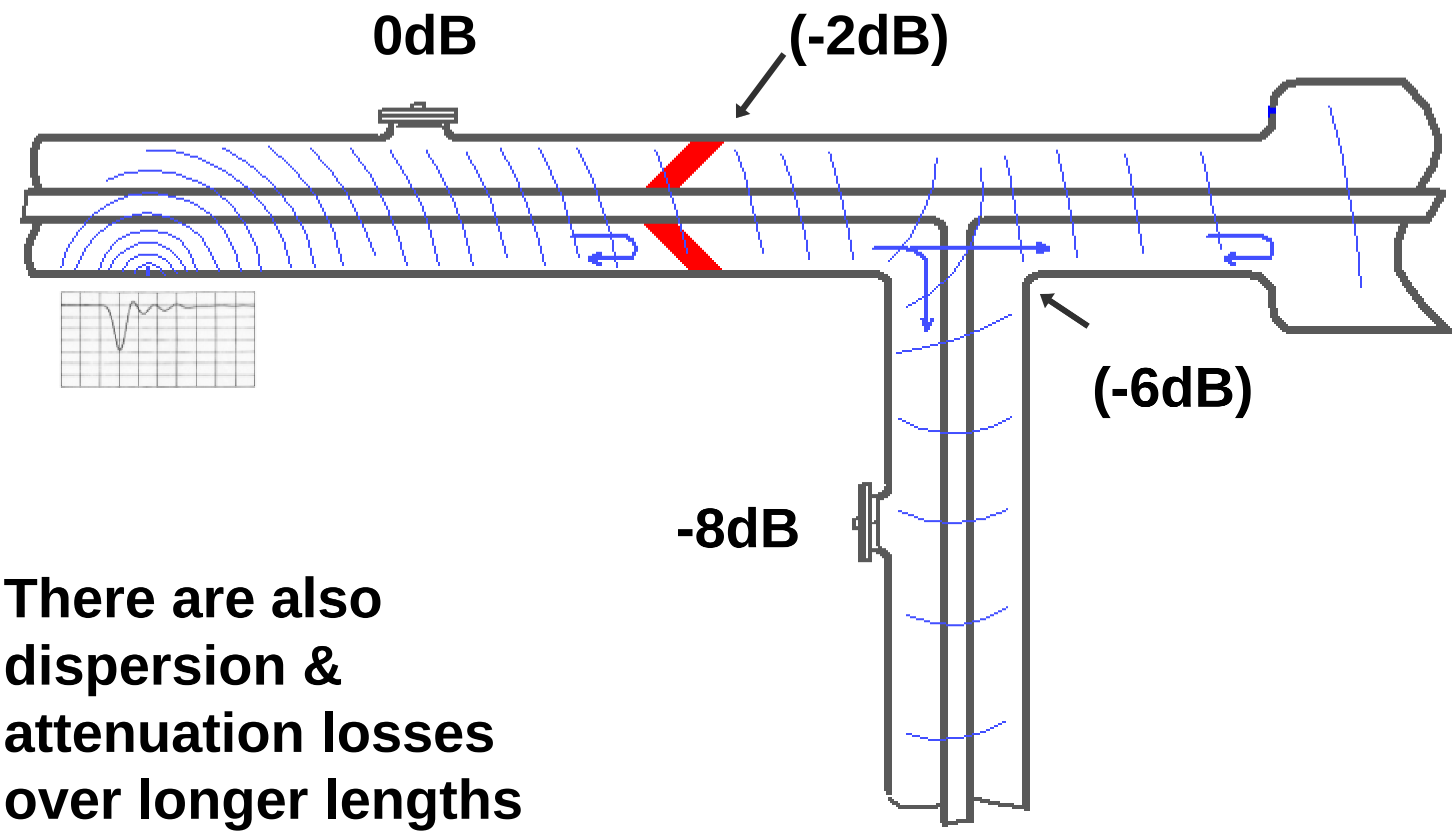
Propagation

- attenuation
- reflections at bends, barriers & changes in diameter
- division of signal at T sections

Excitation

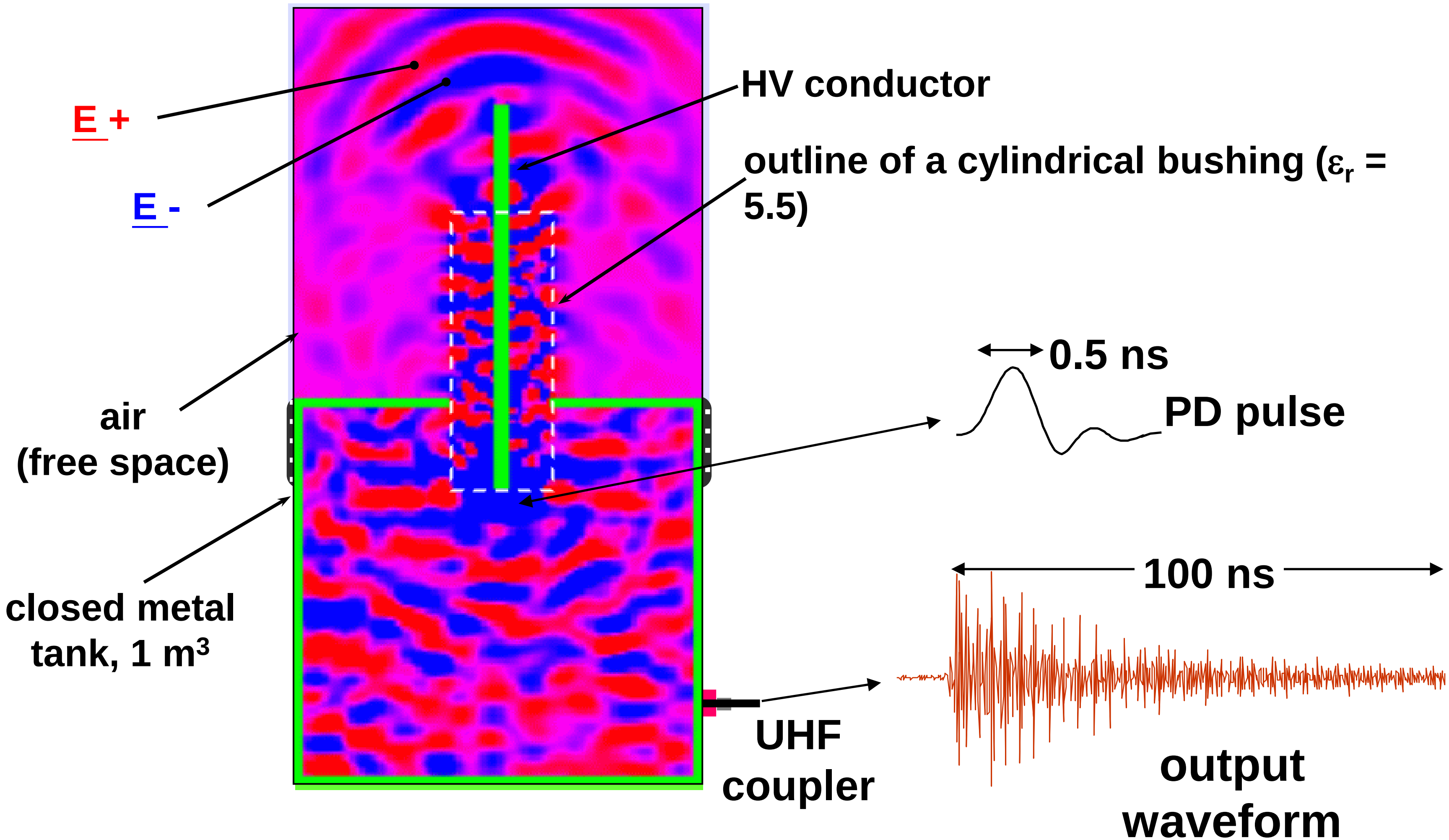
- location of the PD
- length of the discharge
- shape of the current pulse

Signal Propagation – Losses in the GIS



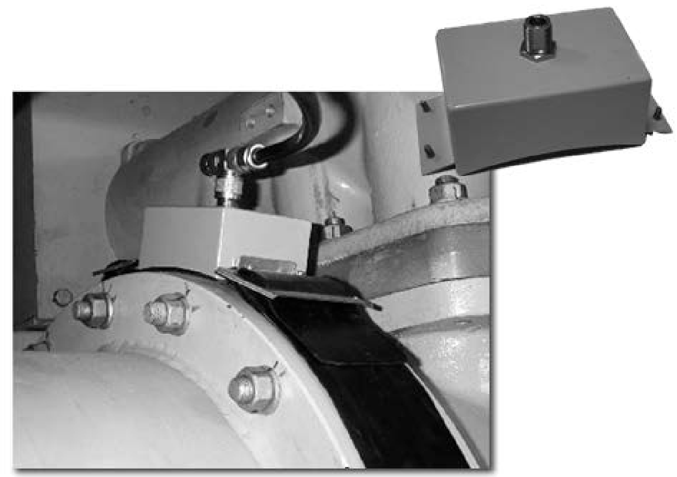
There are also dispersion & attenuation losses over longer lengths

Physics of UHF PD Detection

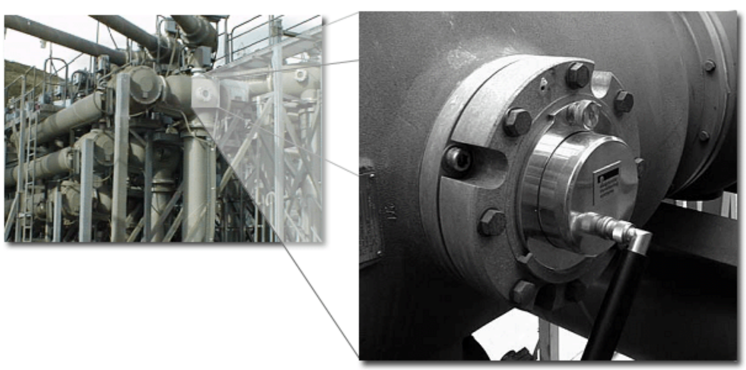


PD monitoring UHF PD sensors

Example for internal UHF PD sensors



Example for UHF PD barrier sensors (external)



Example for UHF PD window sensors (external)

What Makes a UHF PDM System so Effective:

- can detect all known types of PD in GIS or Transformers
- can record data in a way which allows the analysis of PD using expert system PD pattern interpretation by ANN and feature extraction
- can instantly warn of active PD (no time delay)
- gives indication of the type of PD and therefore helps in determining the risk of failure
- suitable for periodic and continuous, on-line monitoring in-service
- applicable to all system voltages
- only IEC approved technique for use during HV commissioning tests (of GIS)
- Also suitable for other metal enclosed electrical plant such as, dead tank CBs, cable end boxes and switch-panels

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3. Insides of partial discharges!
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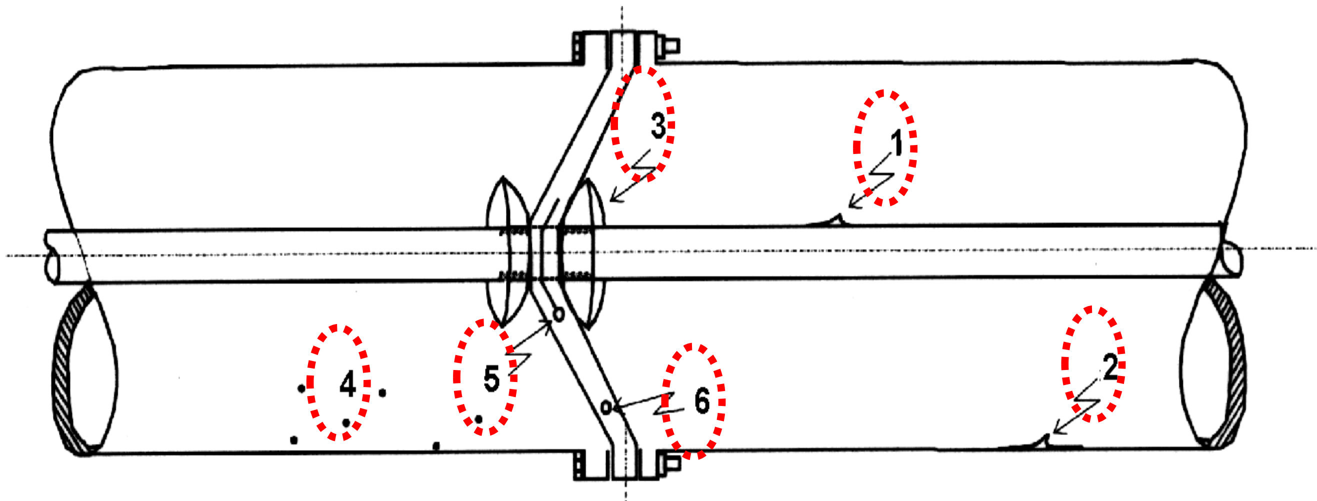
Major Types of Defects in GIS

Causes of partial discharge in GIS



1- protrusions on conductor (fixed particle)

2- protrusions on enclosure (fixed particle)

3- floating parts (bad galvanic contact)

4- free particles on live parts and insulators

5- voids (delamination) between screens and insulation

6- voids and treeing in insulation

Protrusions on conductor (fixed particle)

Possible causes:

- Metallic particles glued by grease on the busbar
- Damages on the conductor tube due to improper handling during installation
- Metallic particles or protrusions covered by paint (production process)

Relevance:

- Very sensitive to impulse voltage/ transients (e.g. breaker or disconnect switch switching)

Remarks:

- Once protrusion covered by paint or metallic particle inside of paint, no PD, is present, but still there is the risk of flashover during switching events exists.
- Happens very seldom nowadays due to very excessive quality control
- Not the main focus in terms of PD monitoring

Protrusions on enclosure (fixed particle)

Possible causes:

- Metallic particles glued by grease on the inner surface of the enclosure
- Damages on the inner surface of the enclosure due to improper handling during installation
- Metallic particles or protrusions covered by paint (production process)

Relevance:

- Very sensitive to impulse voltage/ transients (e.g. breaker or disconnect switch switching)

Remarks:

- Once protrusion covered by paint or metallic particle inside of paint, no PD, is present, but still there is the risk of flashover during switching events exists.
- Happens very seldom nowadays due to very excessive quality control
- Not the main focus in terms of PD monitoring

Floating part (bad galvanic contact)

Possible causes:

- To much paint on electrodes or screens
- Electrodes or screens are badly tighten
- Aging: metallic parts could get lose or break due to mechanical vibrations/ forces

Relevance:

- Permanent discharge are resulting an eroding of the material and with the result, that the parts can break, fall down and cause a flashover
- Parts can break due to mechanical forces combined with aging

Remarks:

- Usually this type of defect will give very high and clear readings (except in case of a sudden loss of mechanical strength
- This kind of discharges related to aging is well in the focus of online monitoring

Free particles on live parts and insulators

Possible causes:

- Introduced during assembly (onsite)
- Created by aging of moving contacts

Relevance:

- Important to detect and removed during onsite testing to avoid break downs in service (related to the infant phase – very dangerous on the surface of a insulator)
- PD activity related to particles after switching operations are giving an indication about the condition of the breaker/ disconnect switch/ ground switch

Remarks:

- During stabilized condition PD activity due to particles is very seldom (particles moving to a place with lower field strength and will remain there without any sign)
- A mechanical impact like switching a breaker can make to particles to move and might cause in very seldom cases also a sudden breakdown without any sign of PD before.

Voids (delamination's) between screens and insulation

Possible causes:

- No proper cleaning of the inserts for insulators.
- Delamination’s on the inserts due to mechanical or thermal stress (aging)

Relevance:

- Once a discharge related to insulation material, the discharges are starting to erode the insulation material and will lead to an flashover in most of the cases (time between start of discharges and breakdown can be between several weeks and up to several years)

Remarks:

- Delamination's due to improper cleaning should be detected already during routine or onsite testing
- Delamination’s due to aging (thermal of mechanical) will be detected by use of PD monitoring

Voids and treeing in insulation

Possible causes:

- Voids due to casting process
- Voids due to delamination inside of insulation material (very rare)
- Cavities surrounded by insulating material

Relevance:

- Once a discharge related to insulation material, the discharges are starting to erode the insulation material and will lead to an flashover in most of the cases (time between start of discharges and breakdown can be between several weeks and up to several years)

Remarks:

- 60 to 80 % of detected PD activities are related to this type of defect
- Difficult to detect due to the ignition delay (up to several days)

What type of defects can be monitored?

Failure types, which can/ should be detected by online PD monitoring

Type of partial discharge	Causes
Floating part (bad galvanic contact	• Aging: metallic parts could get lose or break due to mechanical vibrations/ forces
Free particles on live parts and insulators	• Created by aging of moving contacts
Voids (delamination's) between screens/ inserts and insulation	• Delamination's on the inserts due to mechanical or thermal stress (aging)
Voids and treeing in insulation	• Voids due to casting process • Voids due to delamination inside of insulation material (very rare) • Cavities surrounded by insulating material

What type of defects can be not monitored?

Failure types, which can not be detected by online PD monitoring

Type of partial discharge	Causes
Protrusions on conductor (fixed particle)	• Metallic particles or protrusions covered by paint (production process)
Protrusions on enclosure (fixed particle)	• Metallic particles or protrusions covered by paint (production process)
Free particles on live parts and insulators	• During normal operation PD activity due to particles is very seldom (particles moving to a place with lower field strength and will remain there without any sign) • A mechanical impact like switching a breaker can make to particles to move and might cause in very seldom cases also a sudden breakdown without any sign of PD before

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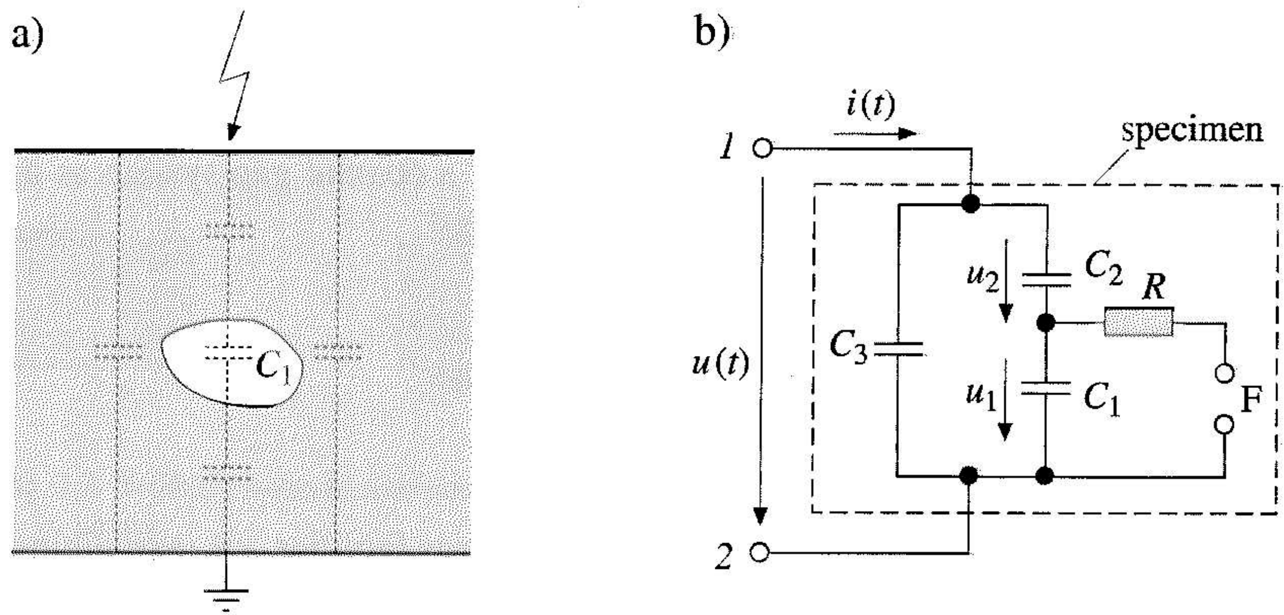
Inner PD equivalent circuit of void type discharges

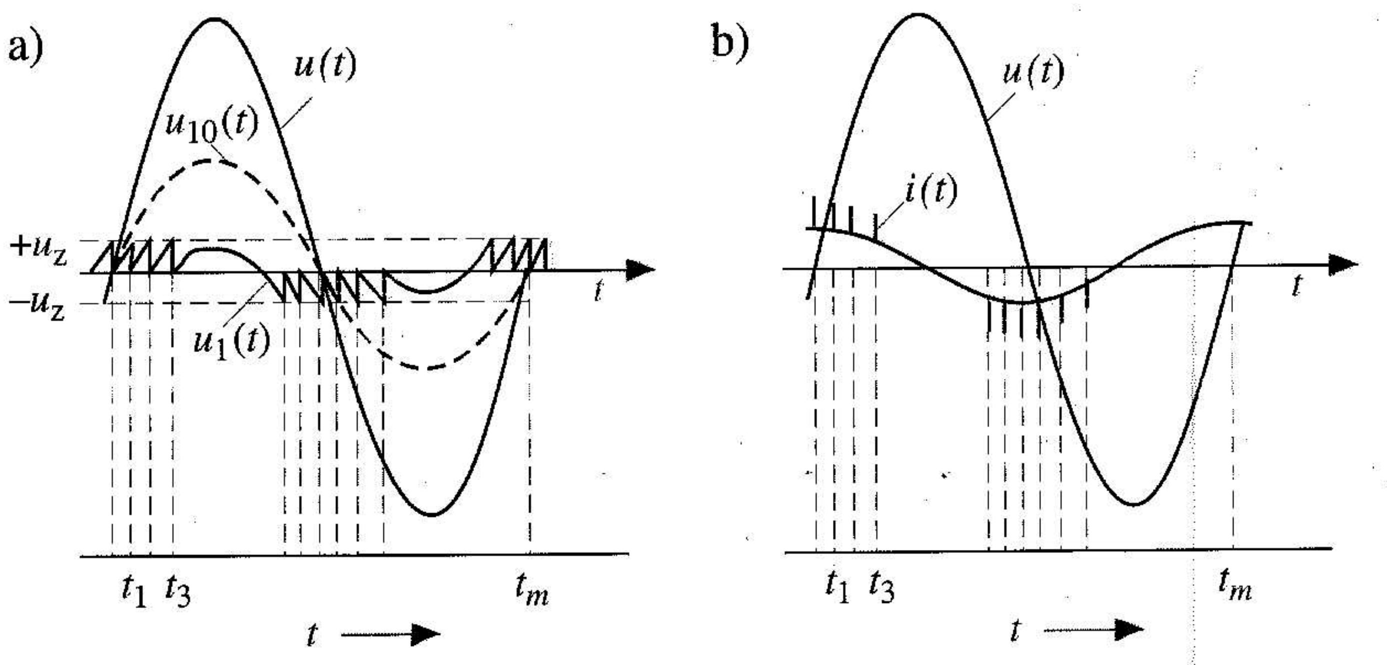


- a) object under test with void
- b) equivalent circuit scheme

Small void: Ct ≅ >>C3 >> C1 >> C2

u_{10} = C2 / (C1+ C2) u(t)

V and I curves according to classic equivalent circuit (void)



- a) Voltage curve's
- b) current curve’s

q ` = ∫ i(t) dt ≅ (C2 + C3) ΔUt = C2 ΔU1 = C2/C1 Δq1, C2 + C3 ≅ Ct

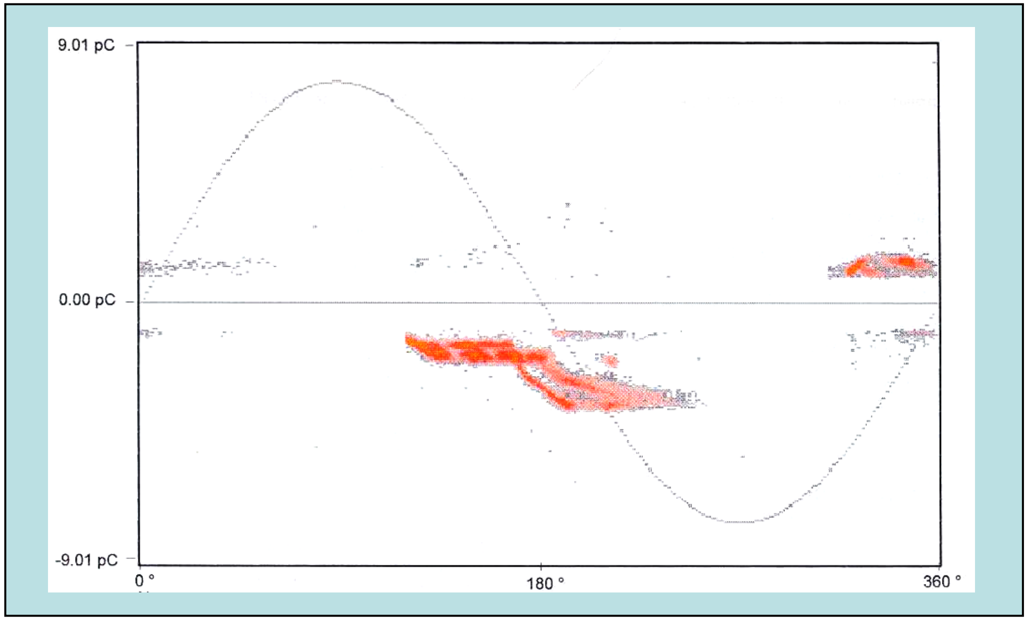
Apparent charge q`

Measureable charge qm

Coupling capacitor will be needed: qm = Ck/(Ct + Ck) q `

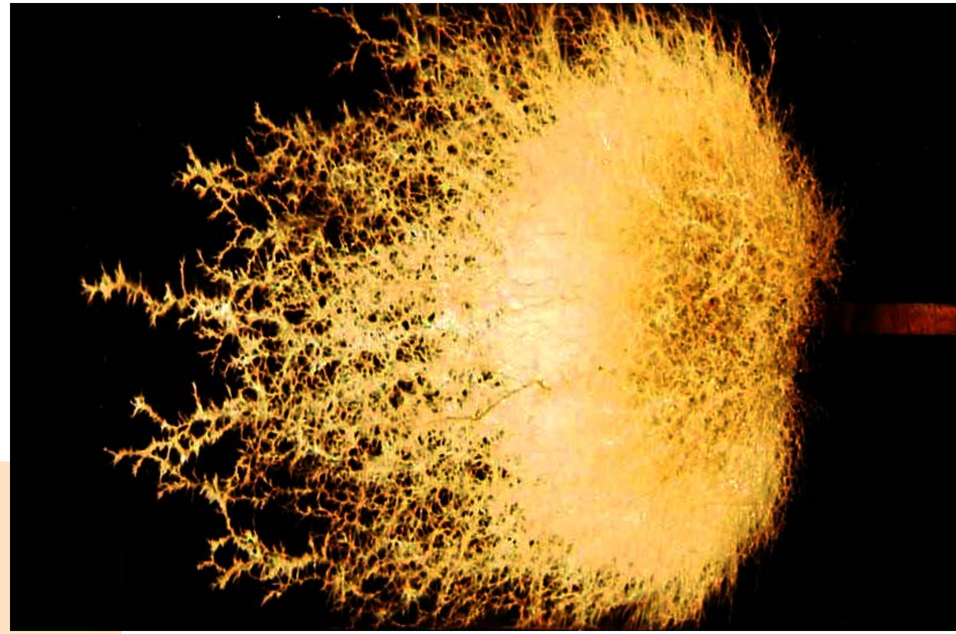
Characteristic of void type PD

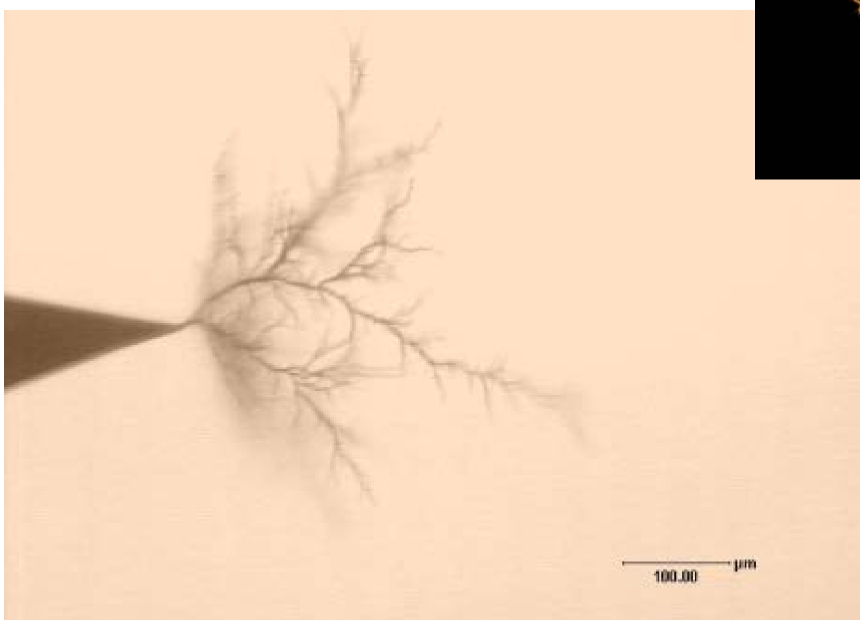
- Pulse- trains of opposite polarity
- number of discharges increases with increasing voltage
- their amplitude remains nearly the same



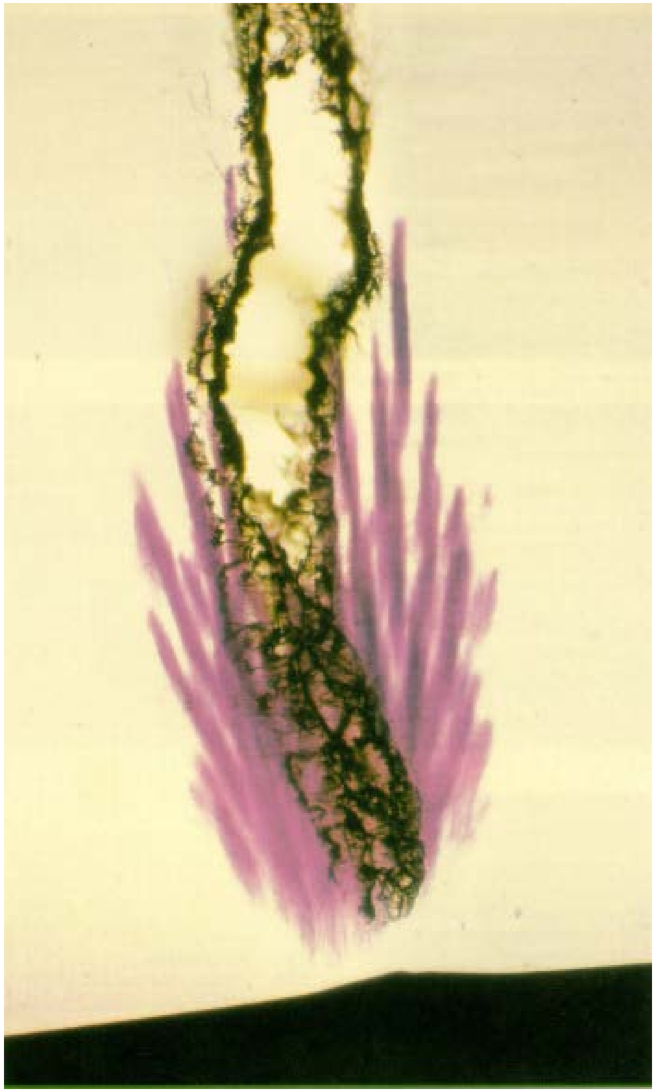
Void in epoxy resin

PD in solid insulation material

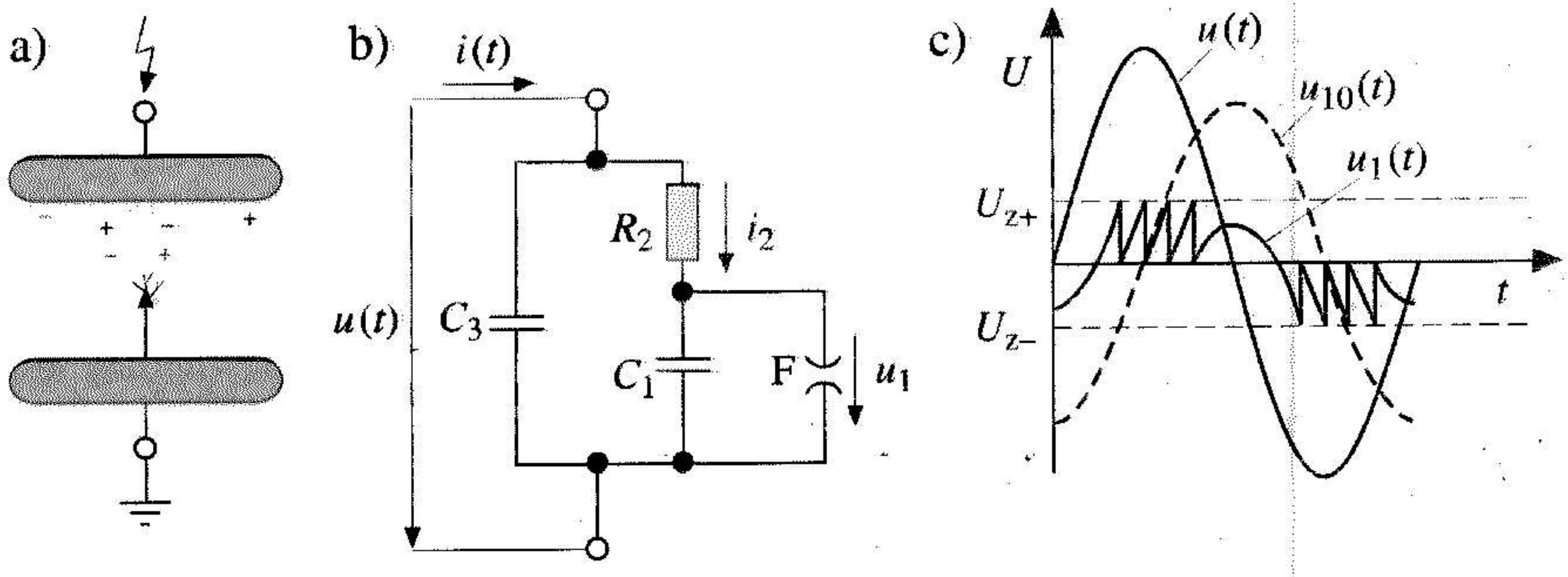




Breakdowns starting at trees



External partial discharge



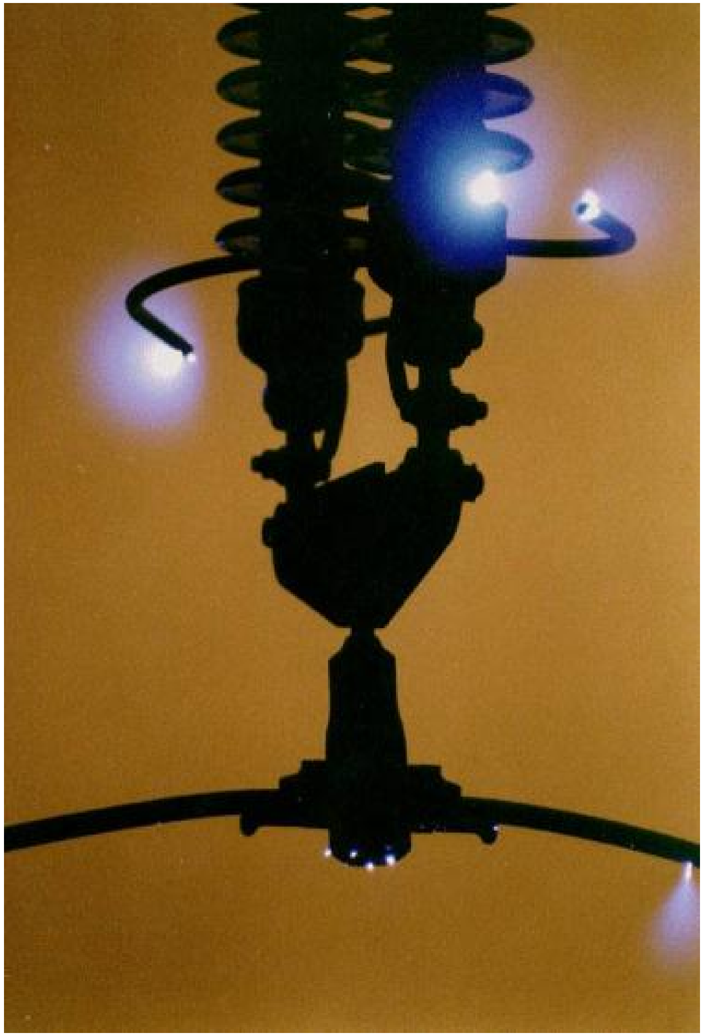
- Needle- plane gap configuration
- C1 capacity of the flashed over sparking gap
- R2 resistance representing the charge carrier cloud around the needle point

$R2 \gg 1/\omega C1$; $i2 = u(t) / R2$

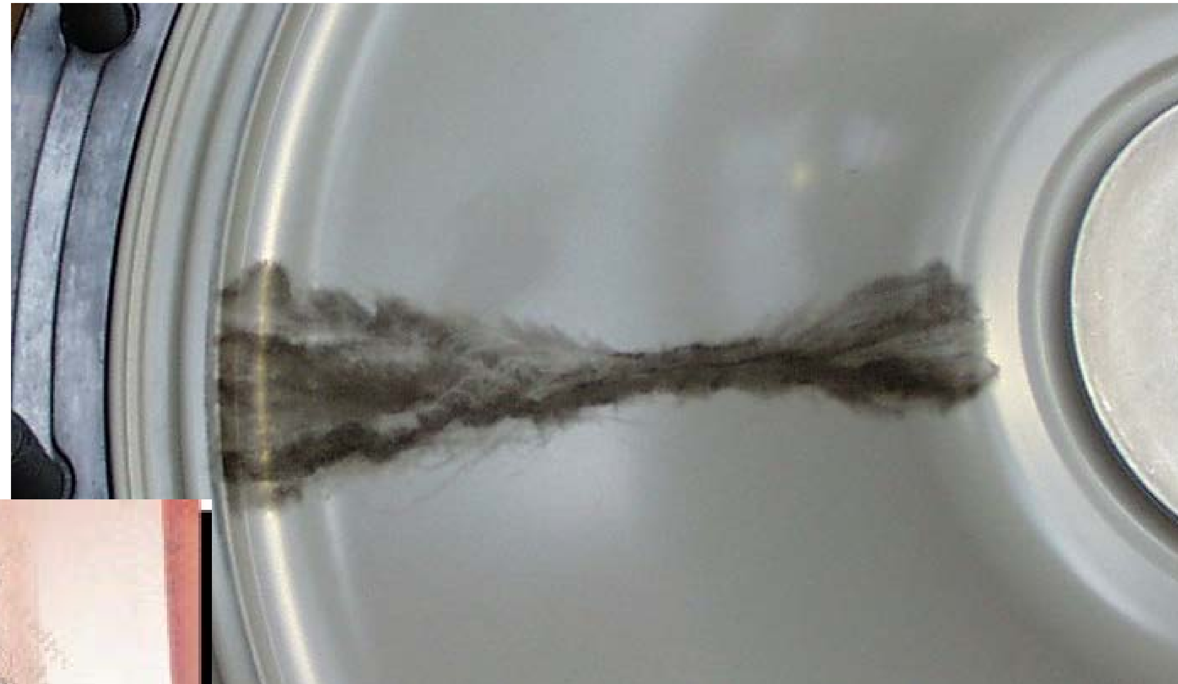
$u10 = \hat{U} / (\omega C1\ R2) \sin(\omega t - \pi/2)$

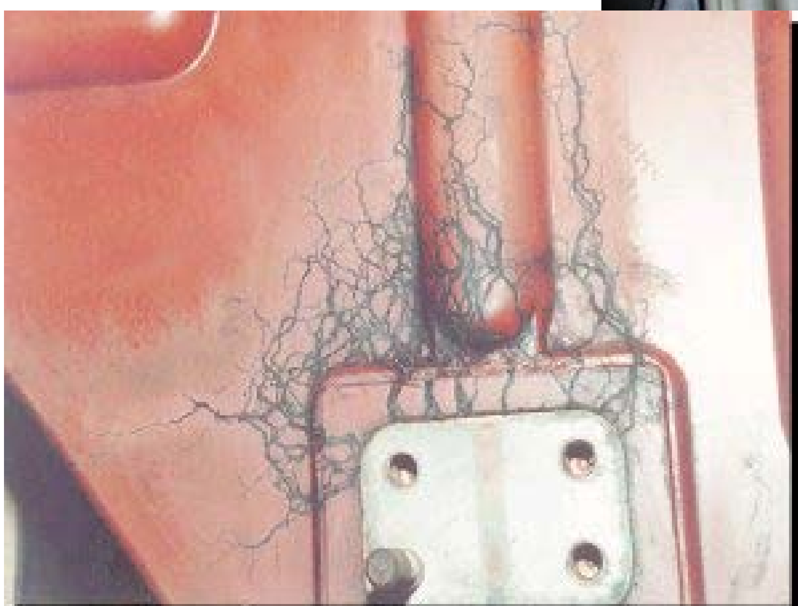
PD impulse will happen in the peak of the voltage wave

Corona discharges

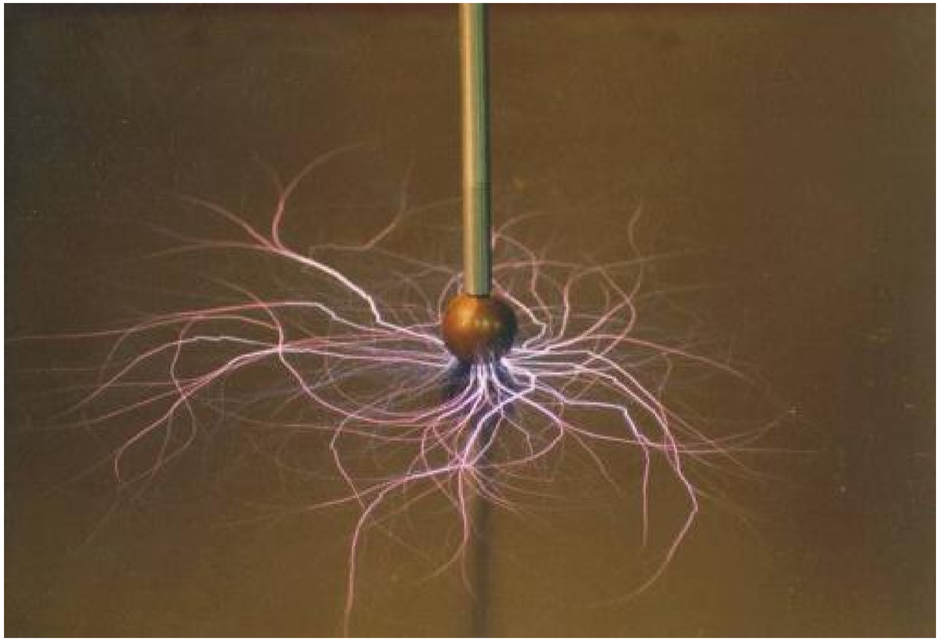


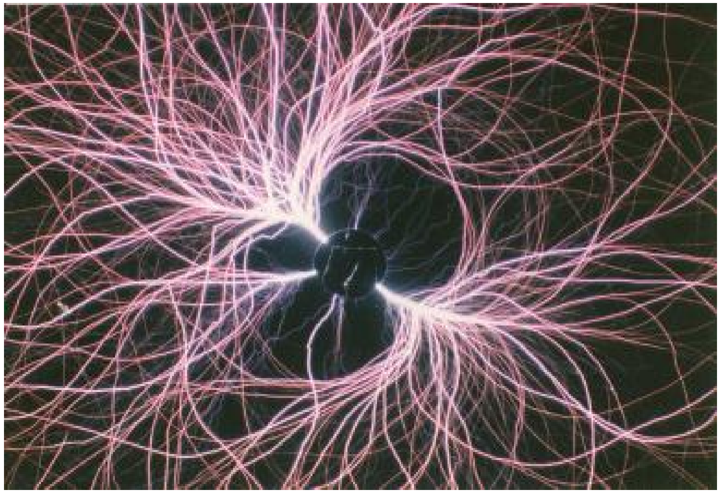
Surface discharges





Surface discharges





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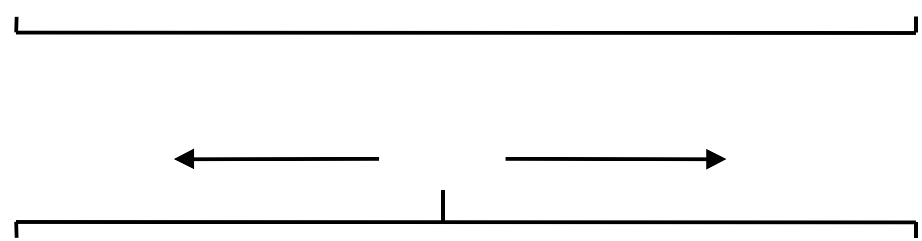
Basics on PD source localization – time of flight

Uhf PD pulses travel at the speed of light inside the GIS and an electromagnetic wave.

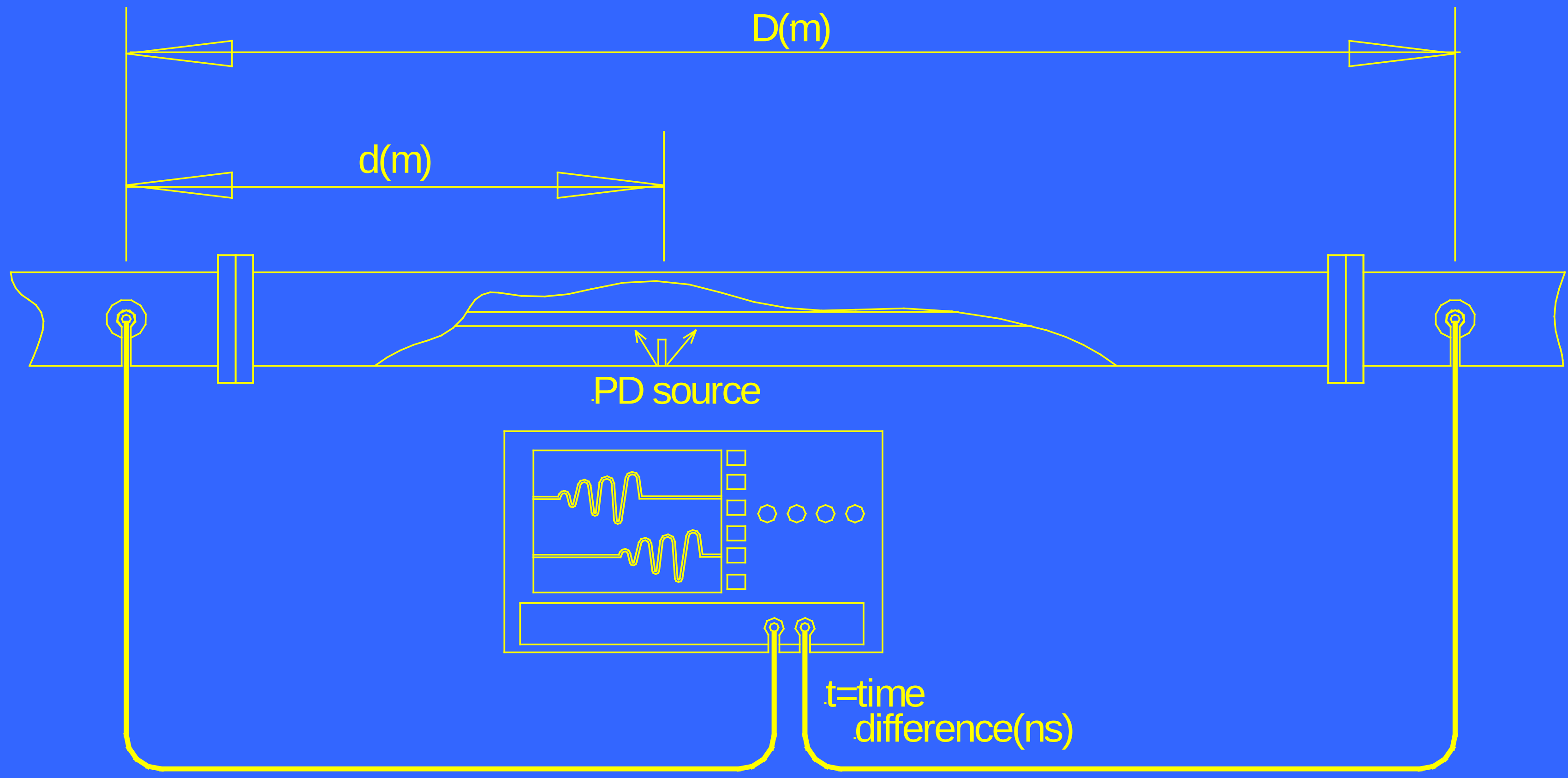
Speed of light =300,000,000 m/s
=300 m/μs
= 0.3 m/ns

This means it travels 1m every 3.3ns.

The pulse travels in both directions along the GIS away from the PD

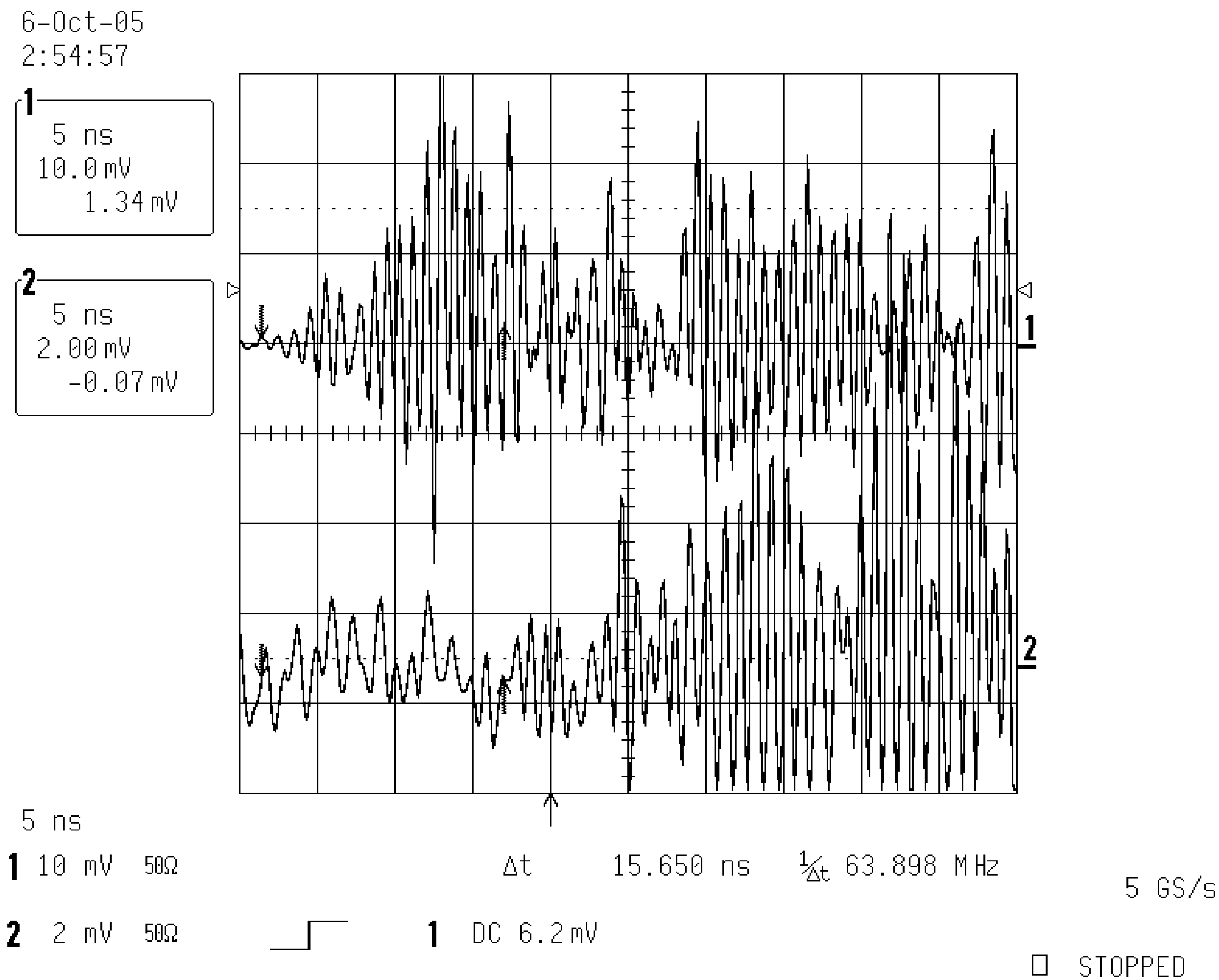


Setup for PD localization

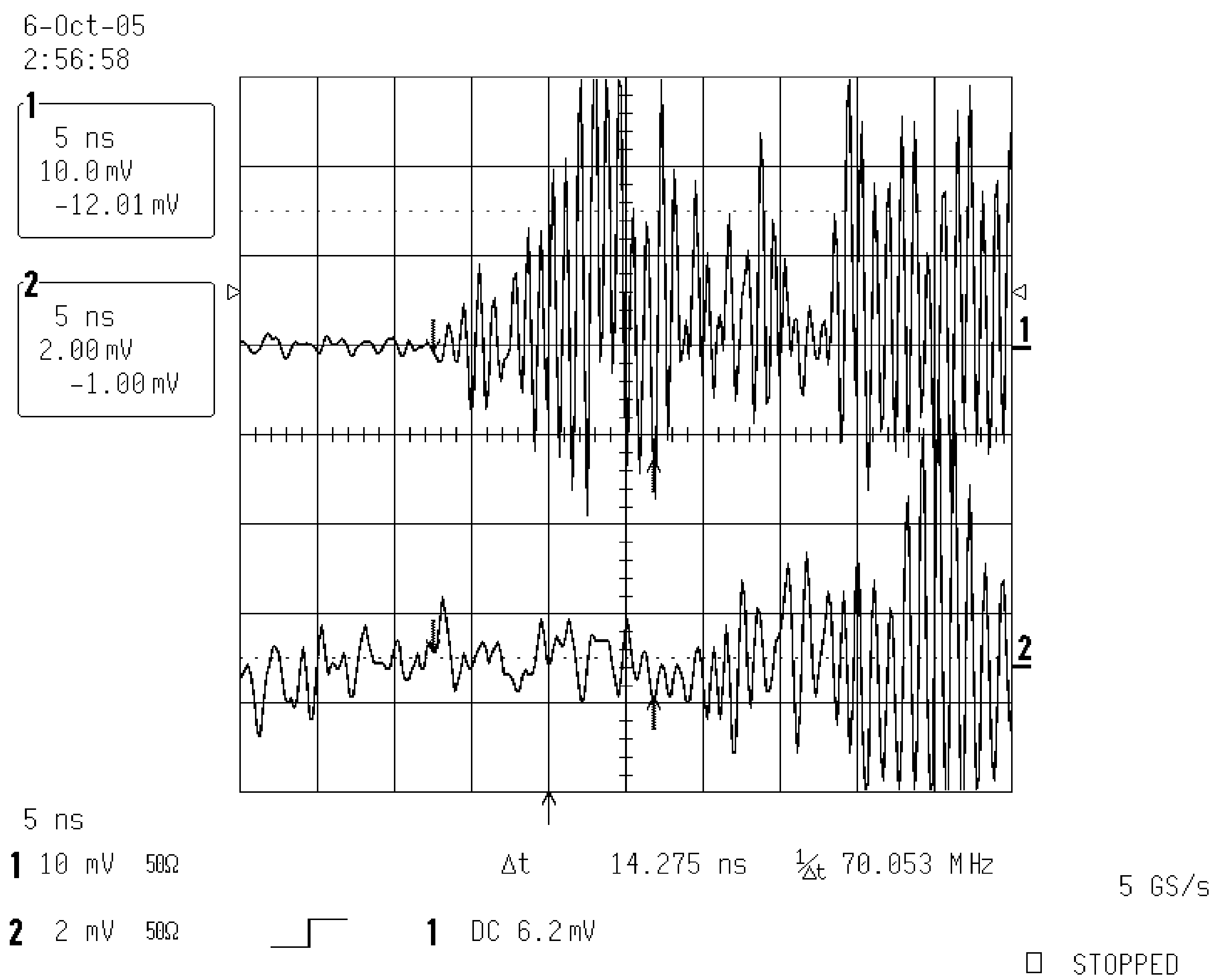


d=(D-0.3t)/2 metres

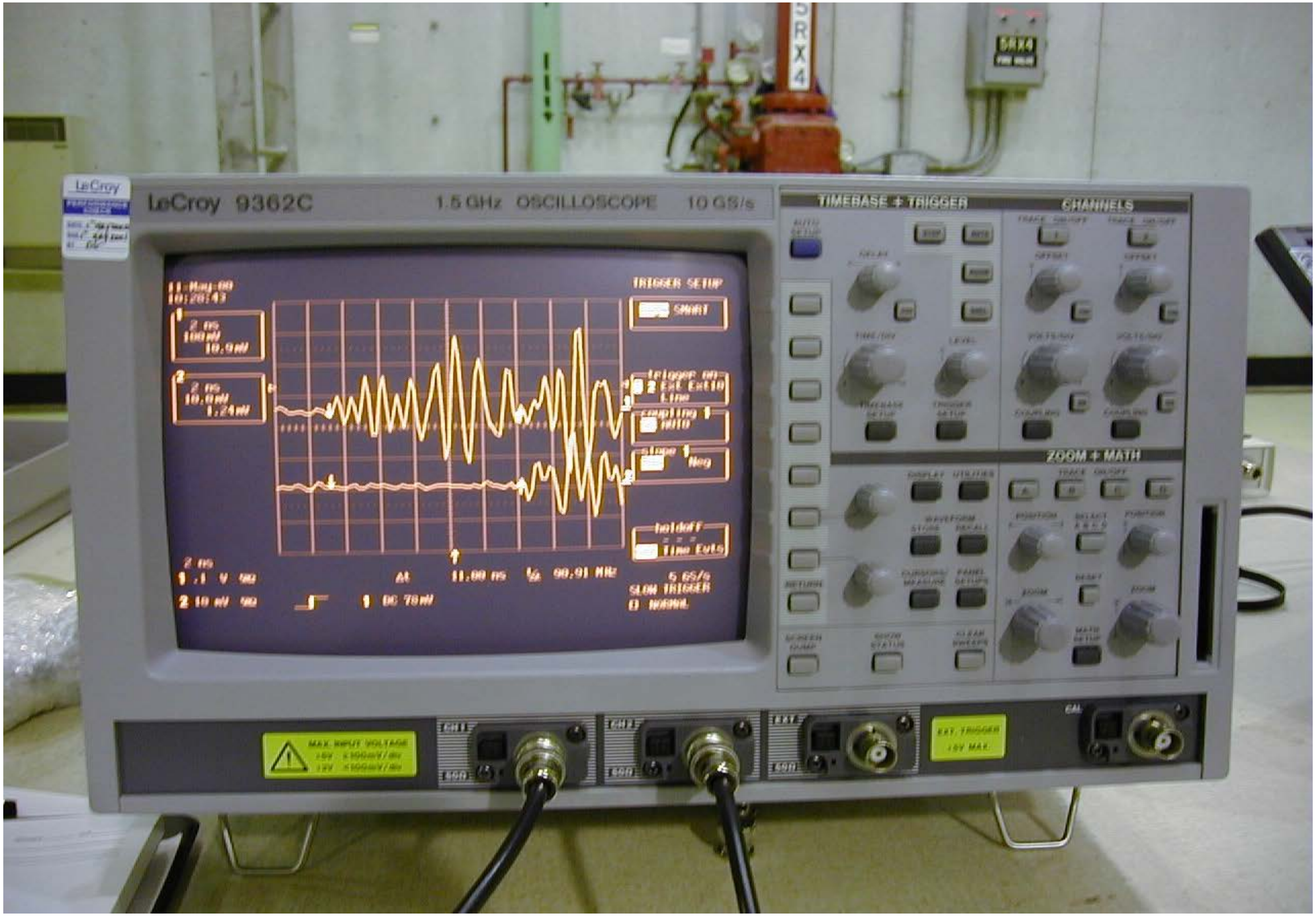
Example for time of flight measurement



Example for time of flight measurement



Real time of flight signal on a scope



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GIS PD case studies

Over 9 years (1996 – 2004), outages taken to remove 55 defects.

No. of monitored bay-years	No. of in–service breakdowns	No. of in-service breakdowns prevented	No. of bkdns prevented per 100 bay-years	No. of bkdns prevented per 100 coupler-years
1250	2	55	4.4	1.47

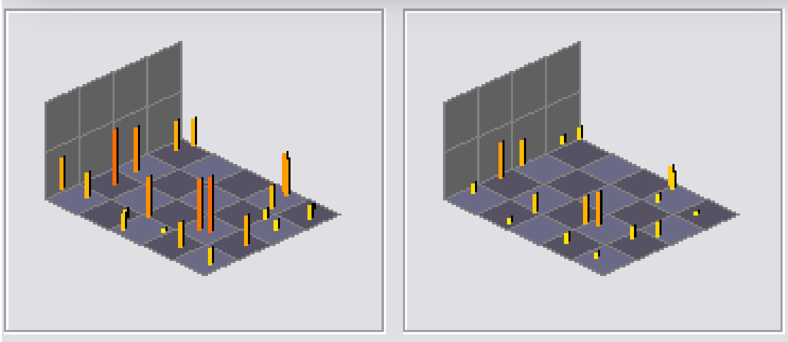
Additional benefit of PD monitoring:

PDM used during HV commissioning on 22 new GIS detected 35 defects while voltage raised to test level…. excellent system for ‘cleaning up’ the GIS and transformers before going into service.

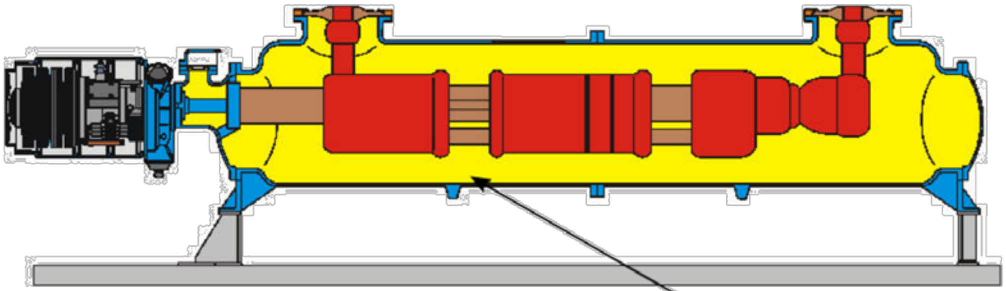
GIS PD case studies

Examples from our experiences

- Ghunan 400KV GIS, Saudi Arabia
  - One of the substation in GCCI link
  - During conditioning at 130KV, PD activity was observed in circuit breaker
  - When the CB was opened a metallic particle (1-2mm in length) was found
  - Fault detected, and located by Qualitrol PDM system and services
  - Saved utility from a faulty installation



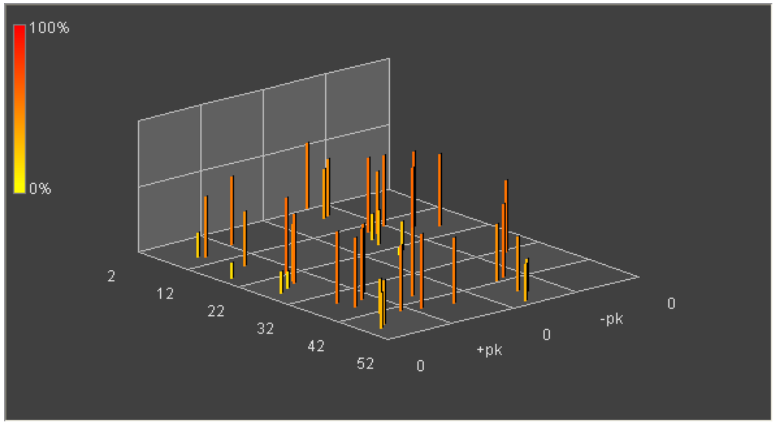
PDM system output: Single Cycle Display



GIS PD case studies

Examples from our experiences

- Al Jasra 400KV GIS, Bahrain
  - One of the substation in GCCI link
  - PD activity was observed during operation
  - Fault detected, and located by Qualitrol PDM system and services
  - Investigation indicated surge arrestor was the source of the signal
  - Saved utility from potential outages and loss of



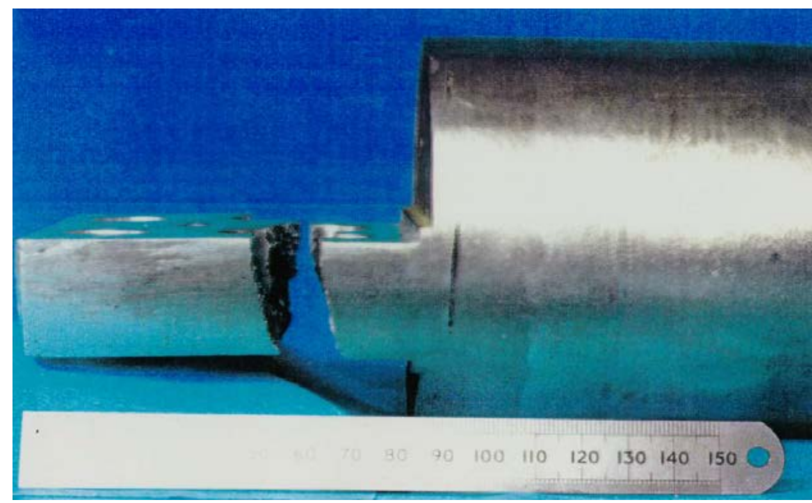
PDM system output: Single Cycle Display

GIS PD case studies

Examples from our experiences

- Nuclear Power Plant, UK
  - Net electrical output: 1190 MW
  - Palm Joint Fault (1994)
  - Stress cone failure (in 2012)
  - Fault detected by Qualitrol PDM system and located prior to flashover
  - Saved potential loss of £250K per day for the utility (due to the loss of power supply)

Stress Cone Fault (2012)



Palm Joint Fault - 1994

Further on an online partial discharge system that has been in operation since 2001 will be described and some of the 11 issues, which were discovered before they had a chance to cause serious damages, will be discussed.

Itaipu Hydro Electrical Power plant

History:

Joint project between Paraguay and Brazil in Foz do Iguaçu and the world largest generator of renewable clean energy. The power plant started its energy production 1984 and the last 2 of the 18 turbines started to work 1991. In 2004 the plant was extended by 2 units (20 units now in total)

Facts and Figures:

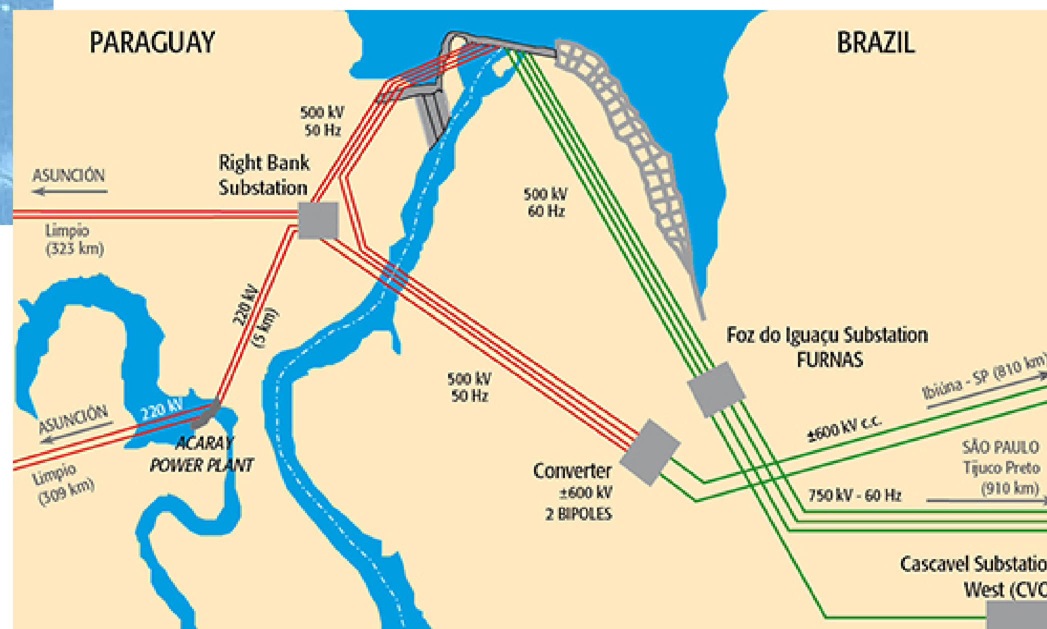
Installed Capacity before 2004: 12.600 MW and after extension 14.000 MW

Production 2012: 98.2 Million MWh (new world record)

Itaipu Hydro Electrical Power plant

Location:

Situated on the border between Brazil and Paraguay, close to the Argentinean boarder.



Three substations (2 GIS substations, 50 and 60Hz installed in the power house and one conventional – Right Bank)

Itaipu Hydro Electrical Power plant

Gas insulated substation (GIS):

There are two GIS installed (50 and 60Hz) with a total busbar length of approximately 1km.
Itaipu has 154 ground switches, which means 462 monitoring points available.

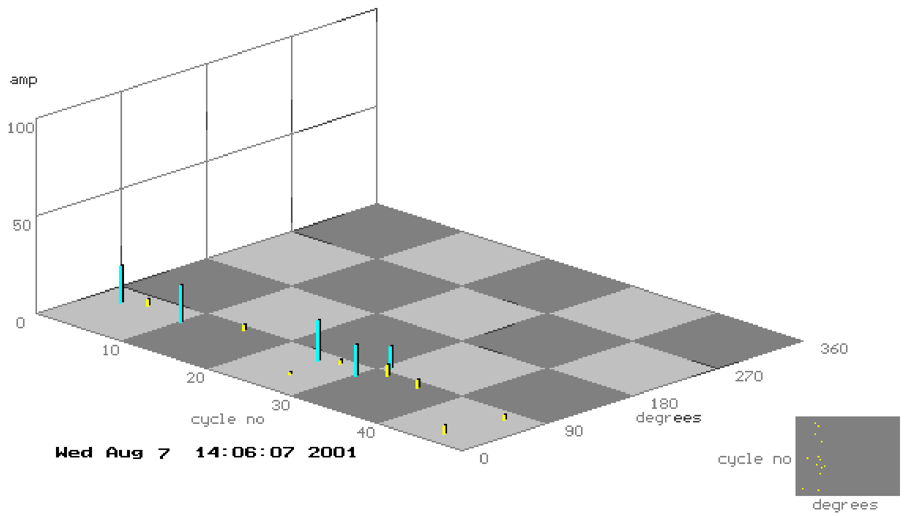
Itaipu Hydro Electrical Power plant

Partial Discharge Monitoring System:

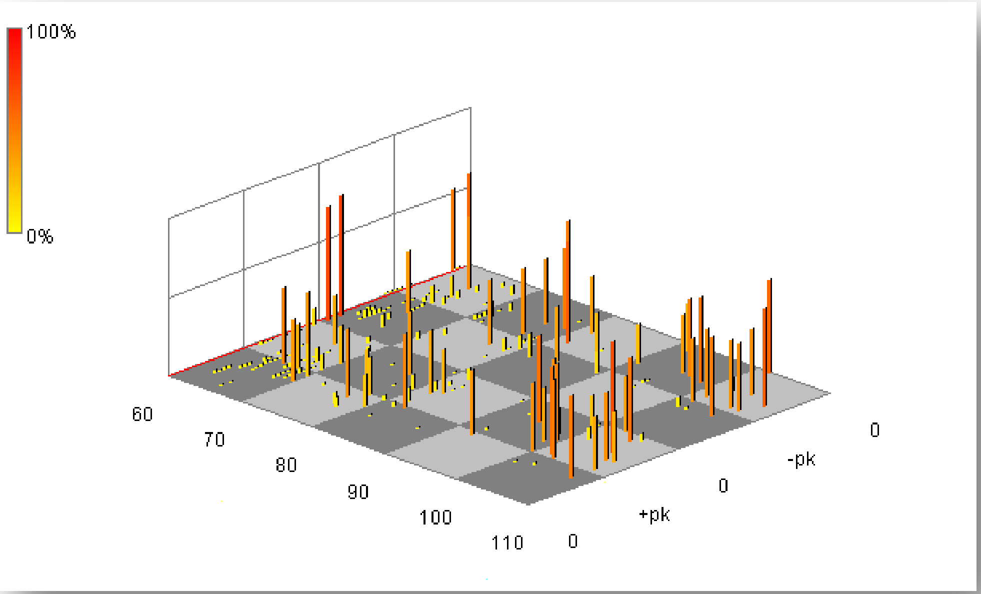
Currently Itaipu has installed 144 OCU's, 432 individual points monitoring the couplers on the ground switches, more 16 OCU's were commissioned on 17/11/2009 monitoring the output line bays connected to couplers specially developed by DMS installed externally on the support insulators.

Today the total number of monitored points is (144 +16) x3 = 480

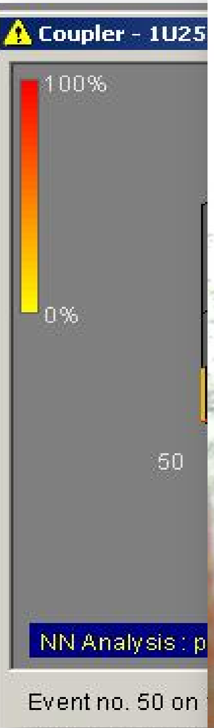
I) Breaker 85L02 S phase
Corona per particle in the housing

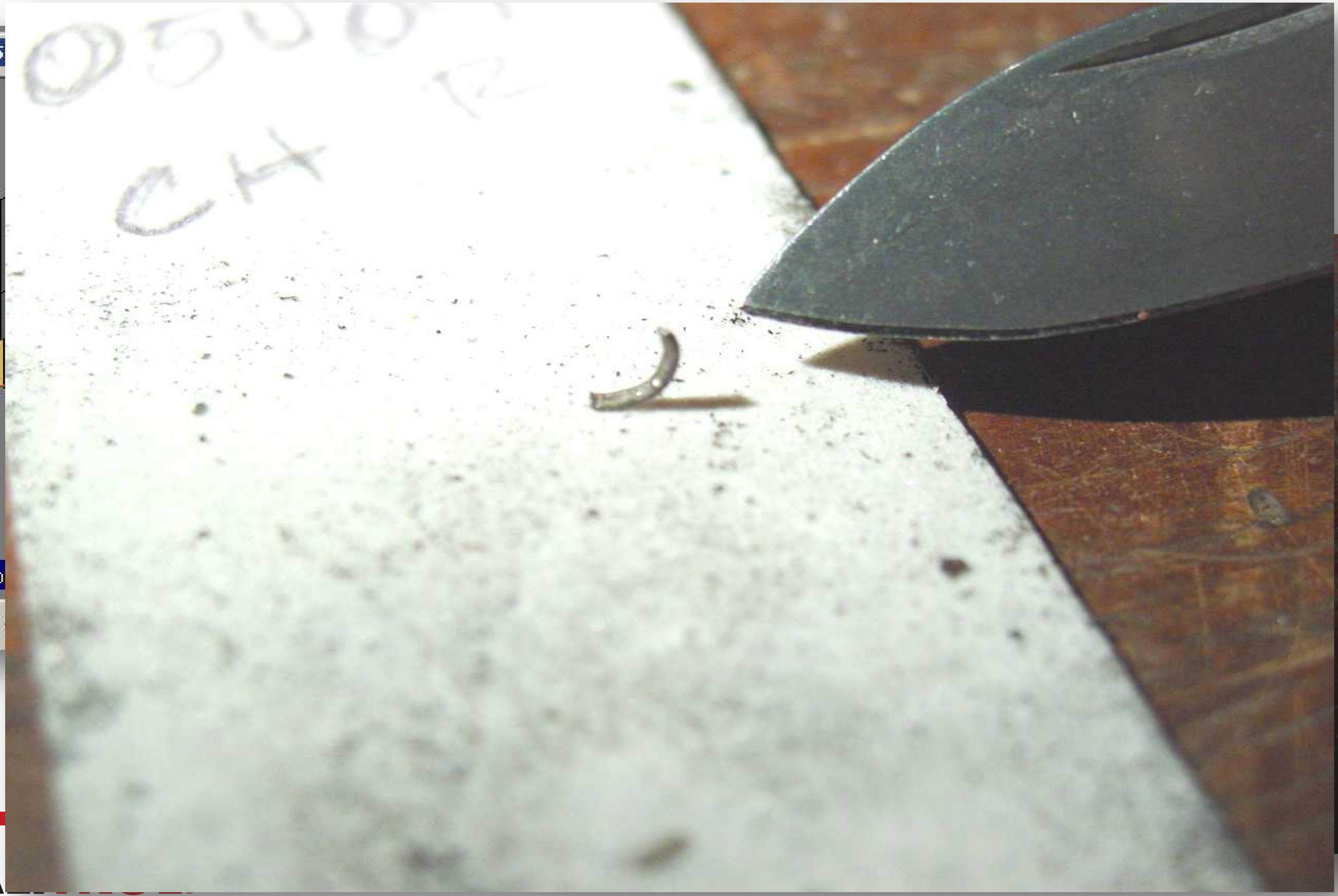


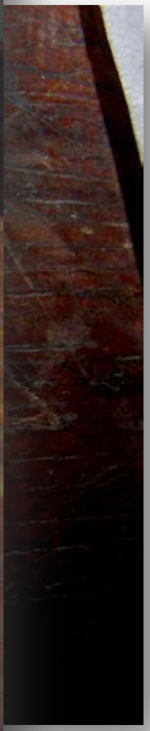
III) Breaker 86LI2 S phase
Particles detected after operation



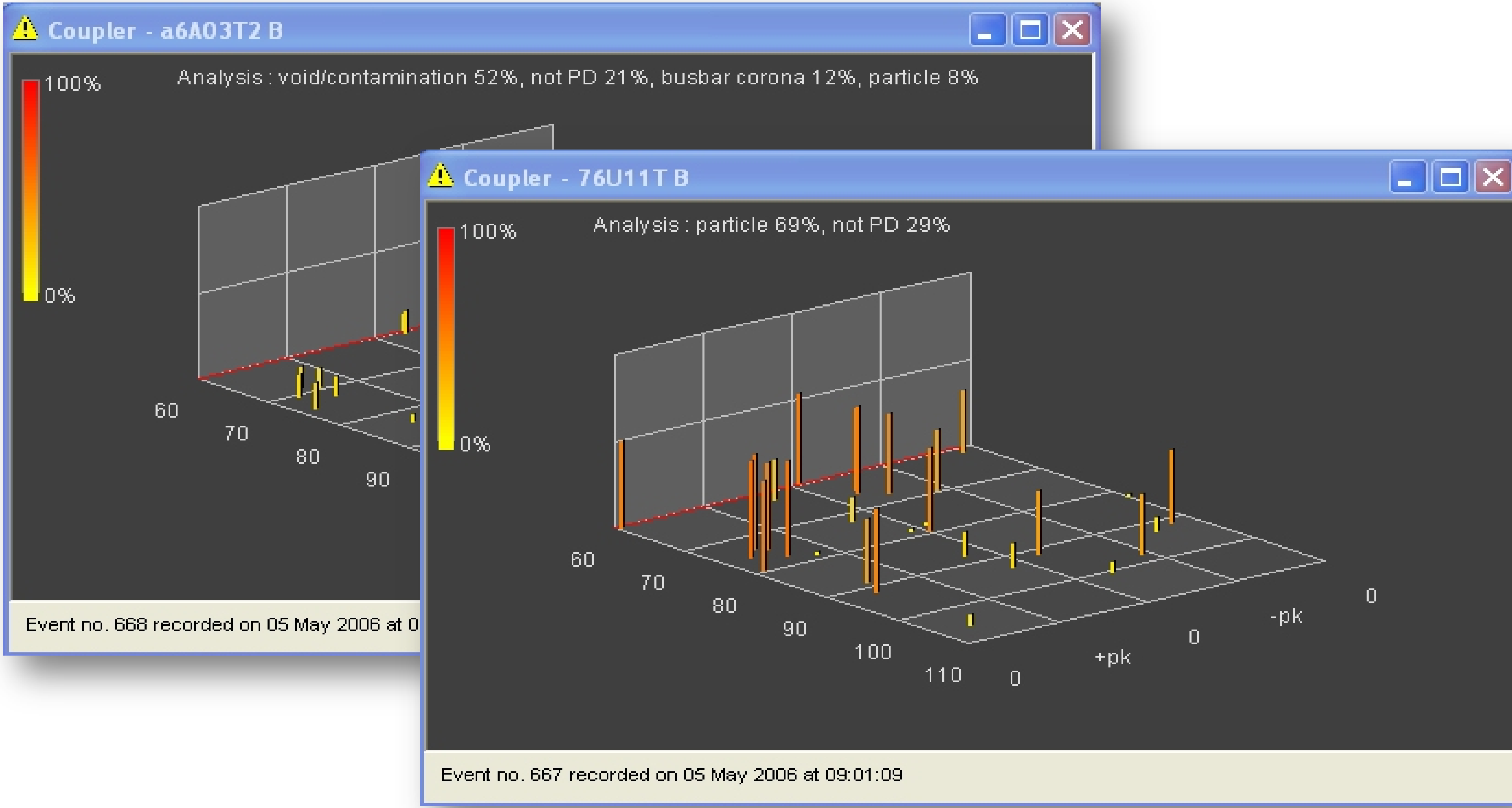
IV) Breaker 05U09 R phase particles

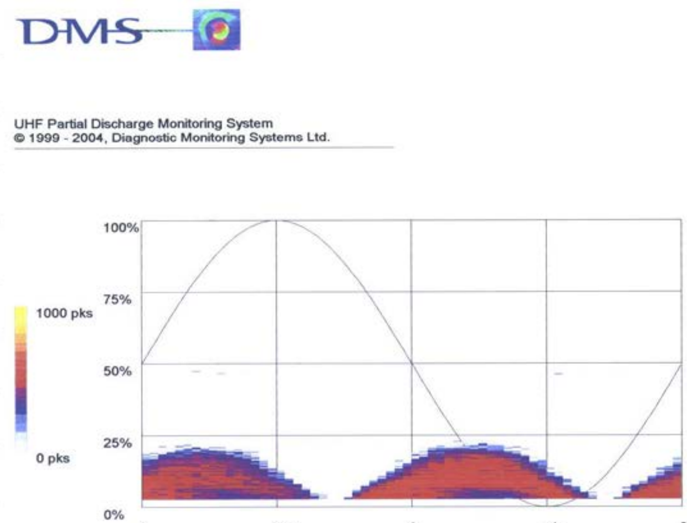






V) Surge Arrestor A34-T1 Phase T




DMS
UHF Partial Discharge Monitoring System
© 1999 - 2004, Diagnostic Monitoring Systems Ltd.
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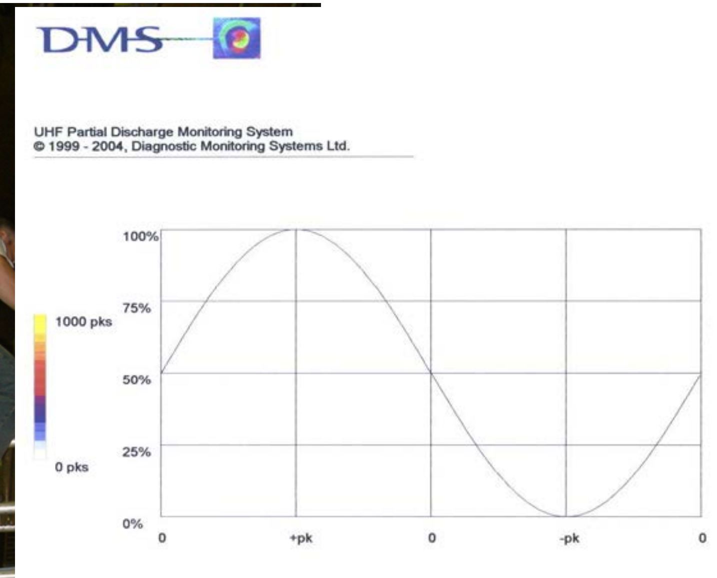
DMS
UHF Partial Discharge Monitoring System
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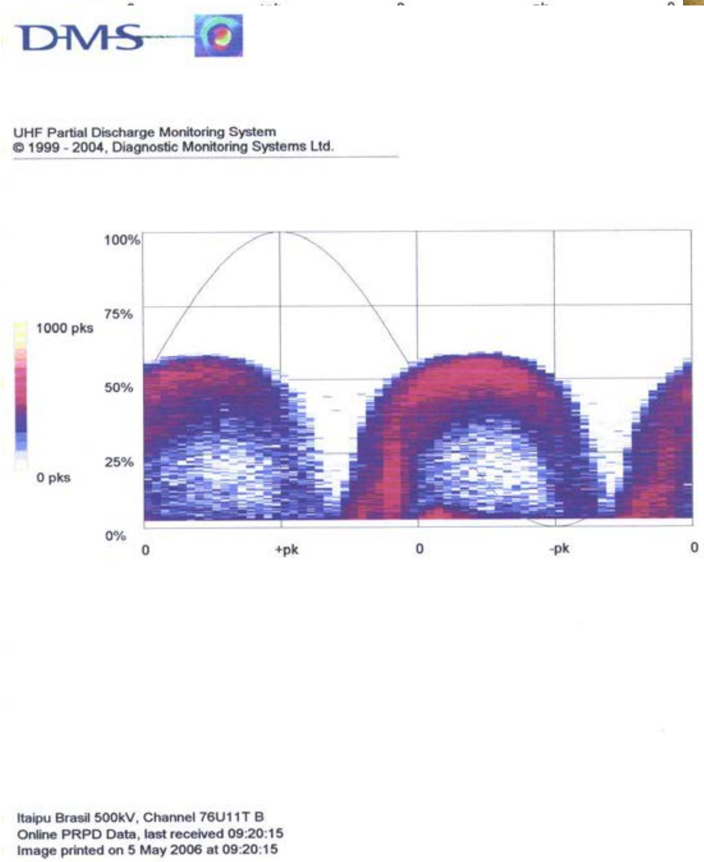
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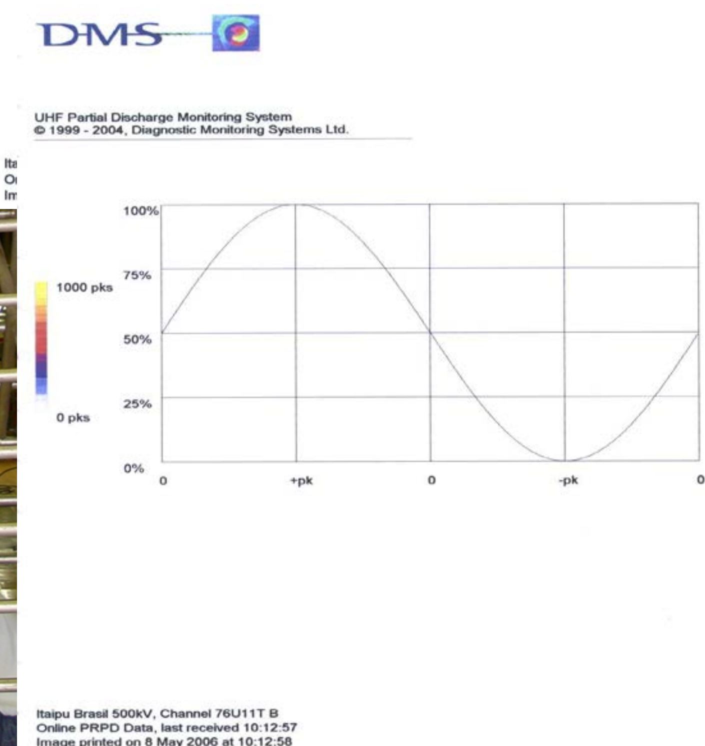
Itaipu Brasil 500kV, Channel 76U11T B
Online PRPD Data, last received 09:20:15
Image printed on 5 May 2006 at 09:20:15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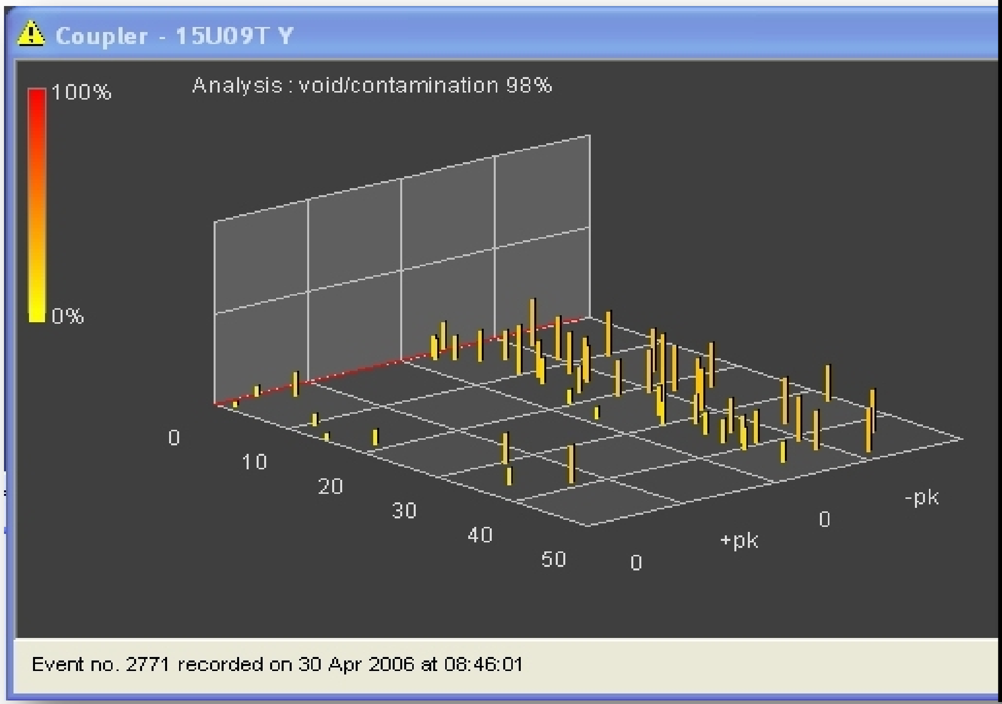
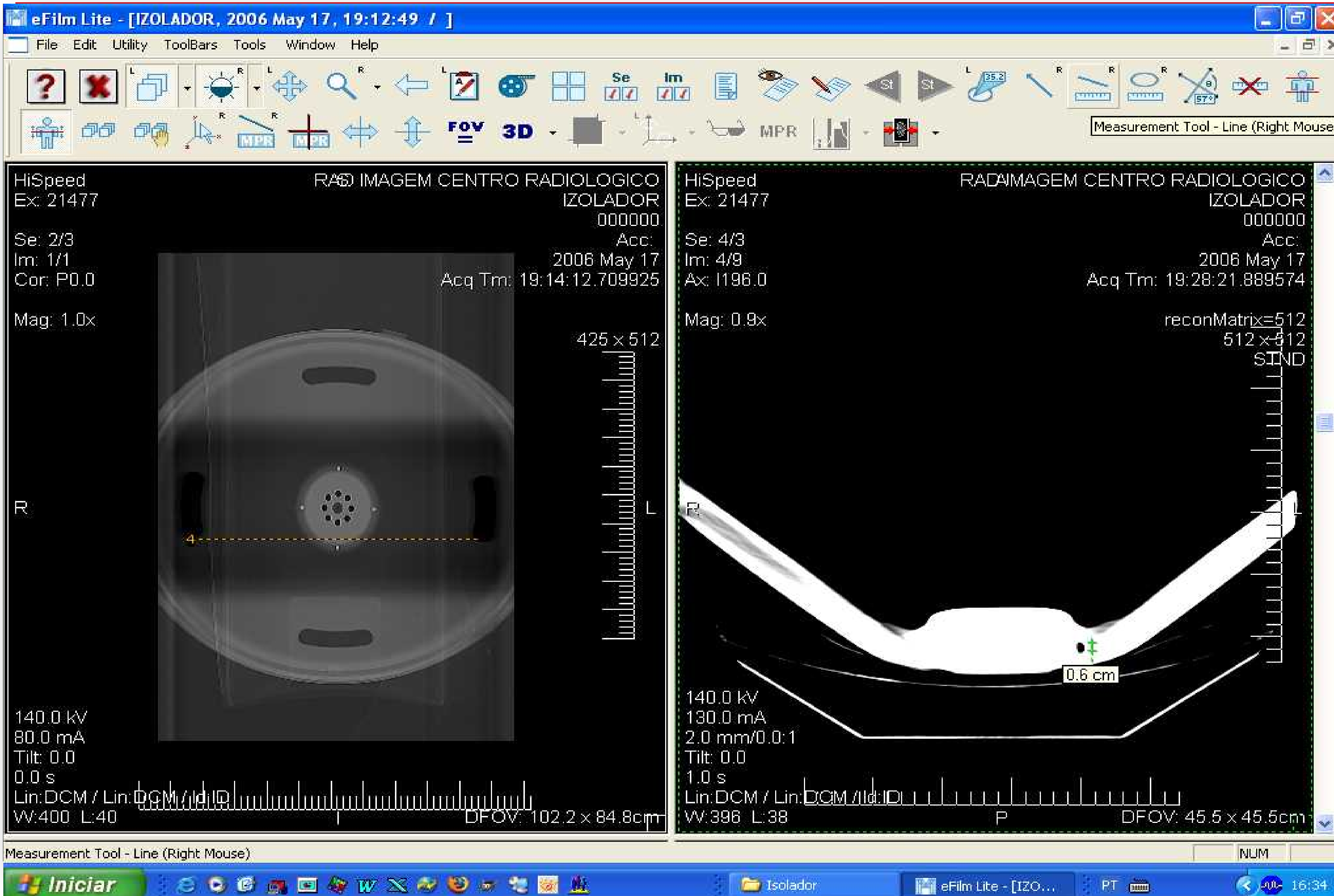
Itaipu Brasil 500kV, Channel 76U11T B
Online PRPD Data, last received 10:12:57
Image printed on 8 May 2006 at 10:12:58

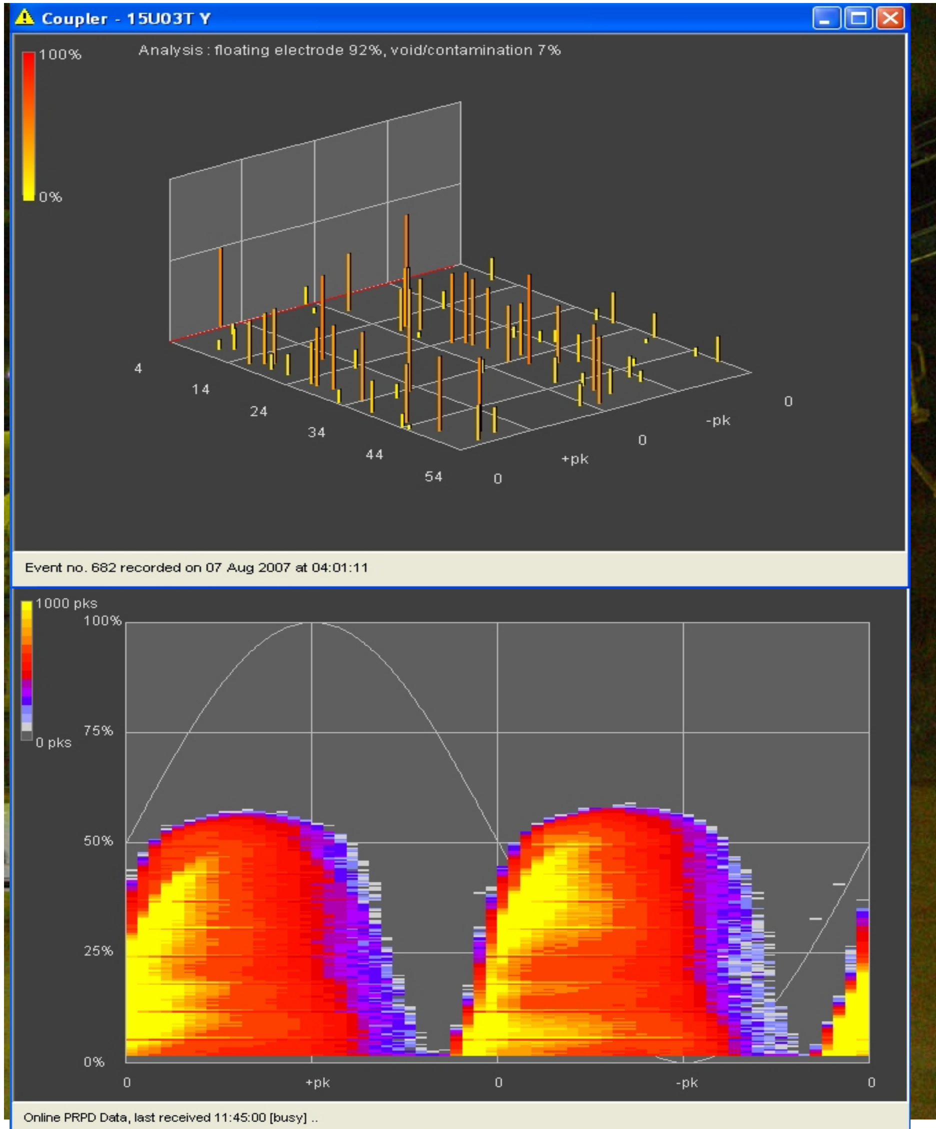
VI) Barrier (Disconnector Switch 55U9A) Bubble (void) in the resin epoxy / support insulator

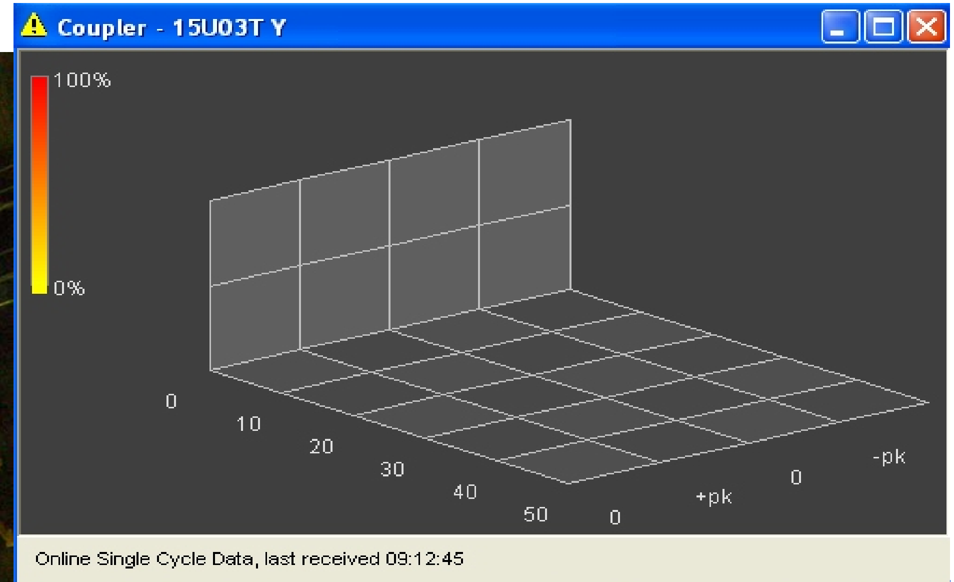


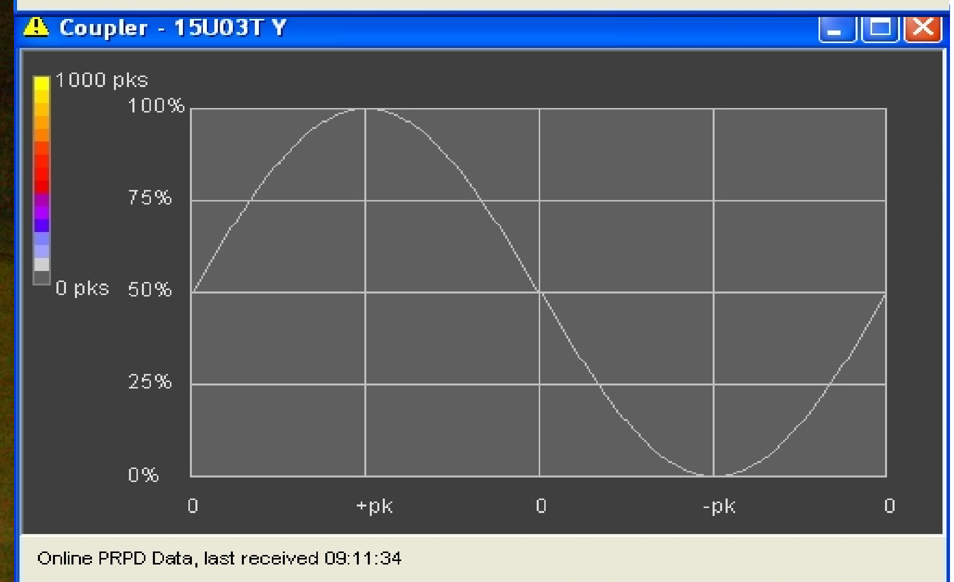
Further case studies



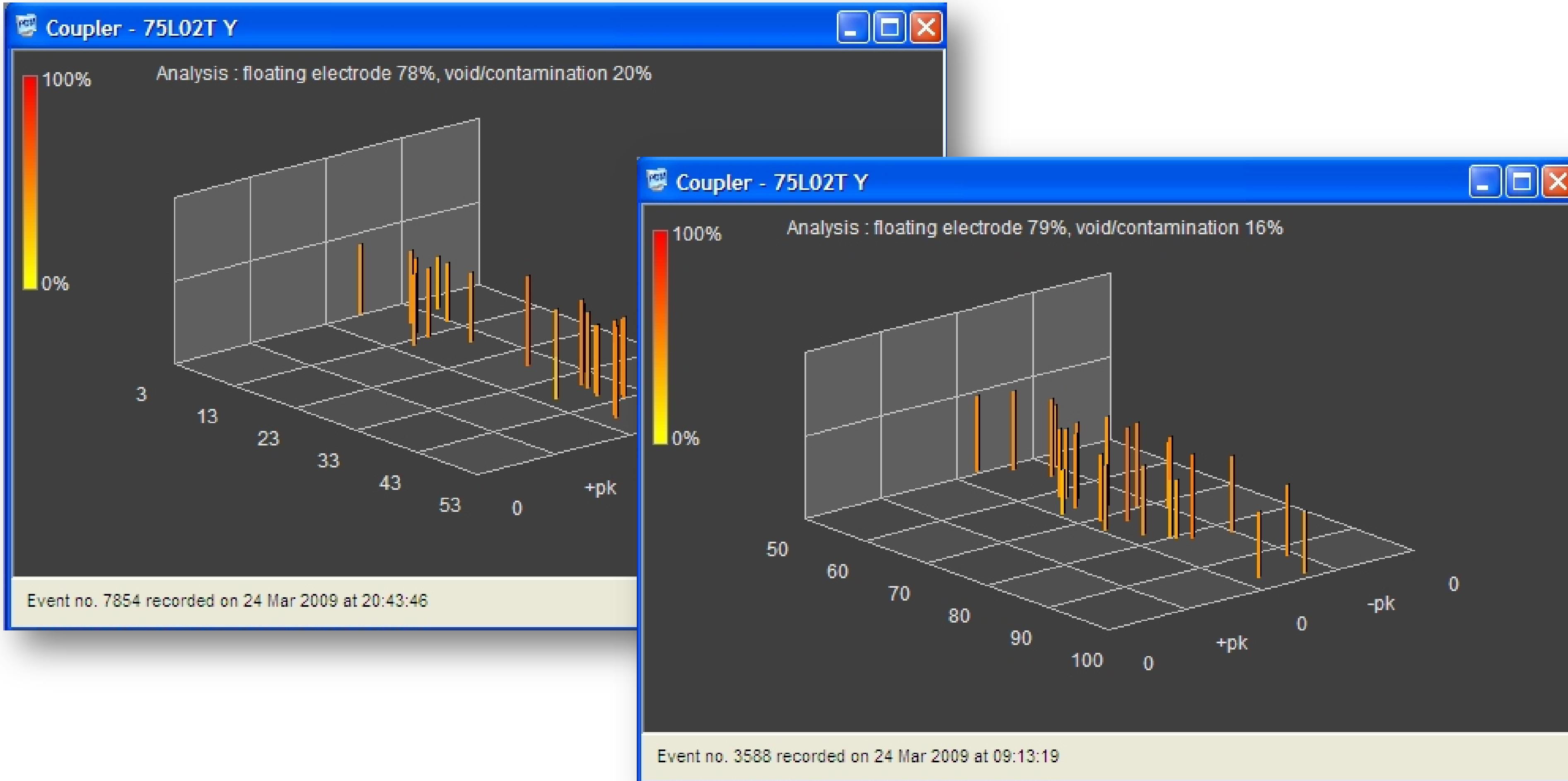
VII) Surge Arrestor A10 T1-S phase S



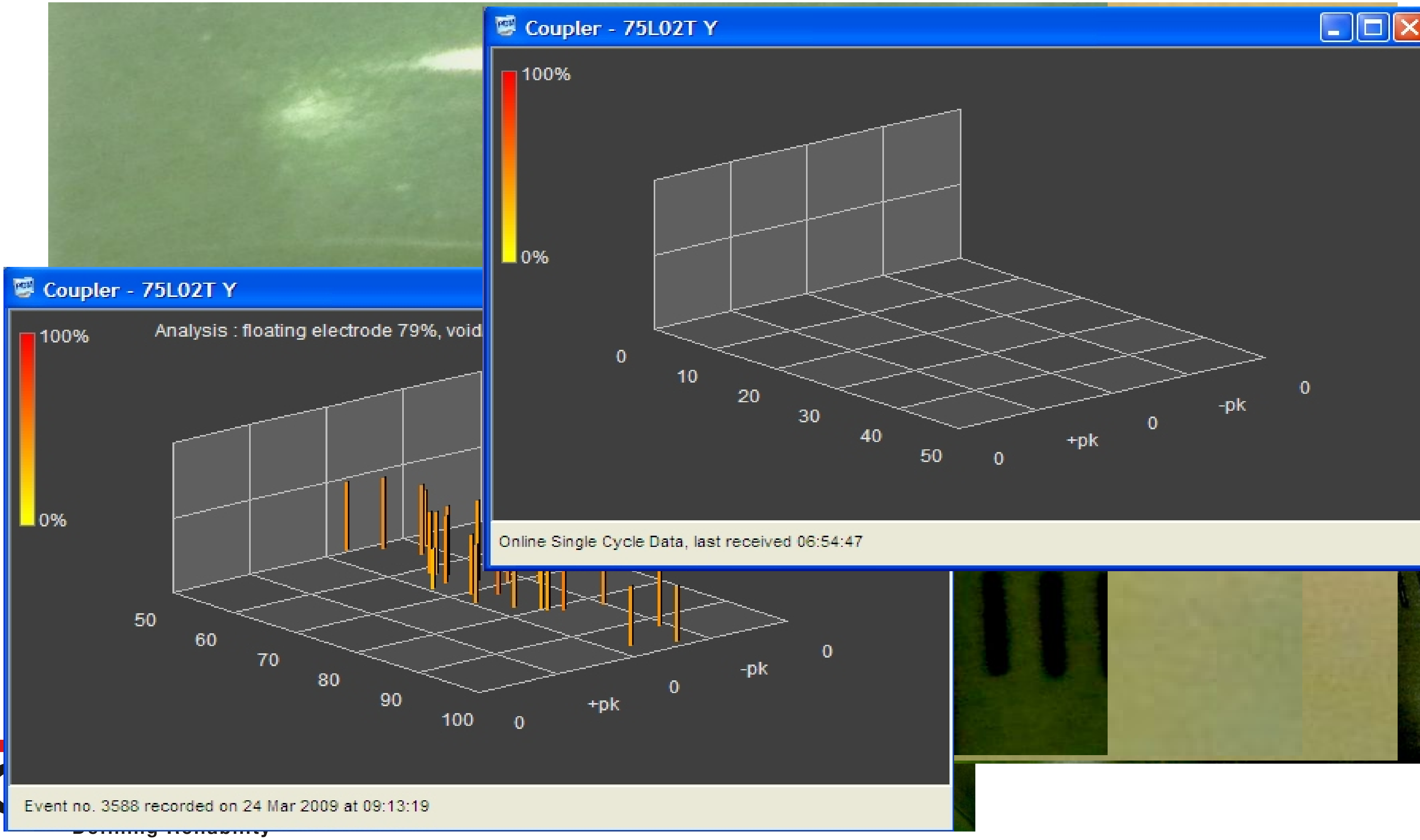




VIII) Conductor on line 2, output bus phase S
Floating electrode



VIII) conductor line 2 output phase S
Floating electrode



Thank you

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