PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Demonstration of HVDC Circuit Breaker and HVDC GIS

HVDC GIS technology demonstrator

Work Package 15

Demo HVDC Switchgear, Arnhem, Thursday, 27th February, 2020

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691714.

How to reduce the size of platforms with HVDC GIS

Uwe Riechert, ABB Power Grids Switzerland, WP15 leader

Testing of HVDC GIS

Hong He, KEMA Labs, Netherlands

Michael Gatzsche, ABB Power Grids Switzerland

Alternative Partial Discharge Monitoring Techniques for HVDC GIS

Fabio Andres Muñoz, Delft University, Netherlands

SF_6 alternative gases for HVDC GIS: Focus on PD characteristics and monitoring

Thanh Vu, SuperGrid Institute, France

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ABB HVDC GIS demonstrator visit 27th February 2020

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Demonstration of HVDC Circuit Breaker and HVDC GIS

HVDC GIS technology demonstrator
How to reduce the size of platforms with HVDC GIS?

ABB Power Grids Switzerland Ltd ● Uwe Riechert ● WP15 leader

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HVAC GIS

Using **pressurized gas** instead of ambient air for insulation (sulfur hexafluoride or eco-efficient alternatives)

Massive **space savings** (up to 90 %)

Very **robust** against environmental impacts

Alternating Current (AC): GIS introduced in 1967, today: proven technology with **100 000+ GIS bays** in operation

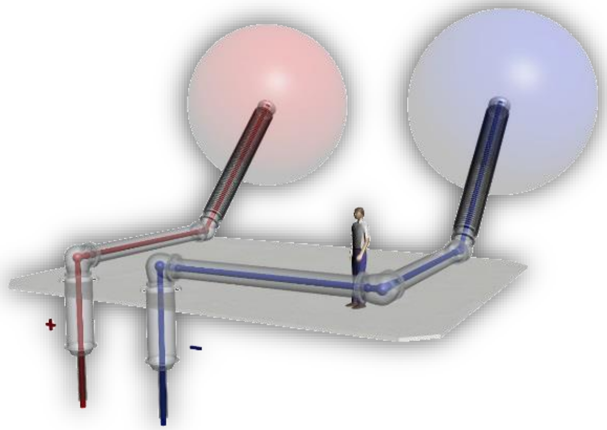
Objectives: HVDC GIS

HVDC GIS

A DC-GIS installation can be built with a much **higher degree of compactness** and significantly **lower sensitivity to ambient factors** than with air-insulated switchgear (AIS).

The most obvious cost-saving potential can be found on **off-shore converter platforms** where the required air-clearance for AIS leads to much larger and heavier off-shore structures.

By using DC-GIS, the **volumetric space** of the switchgear installation can be **drastically reduced** e.g. by 70%- 90%.



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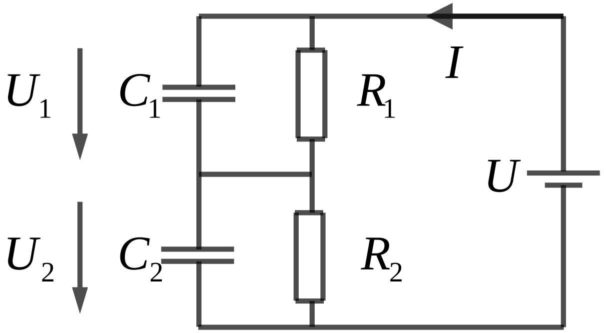
Basics

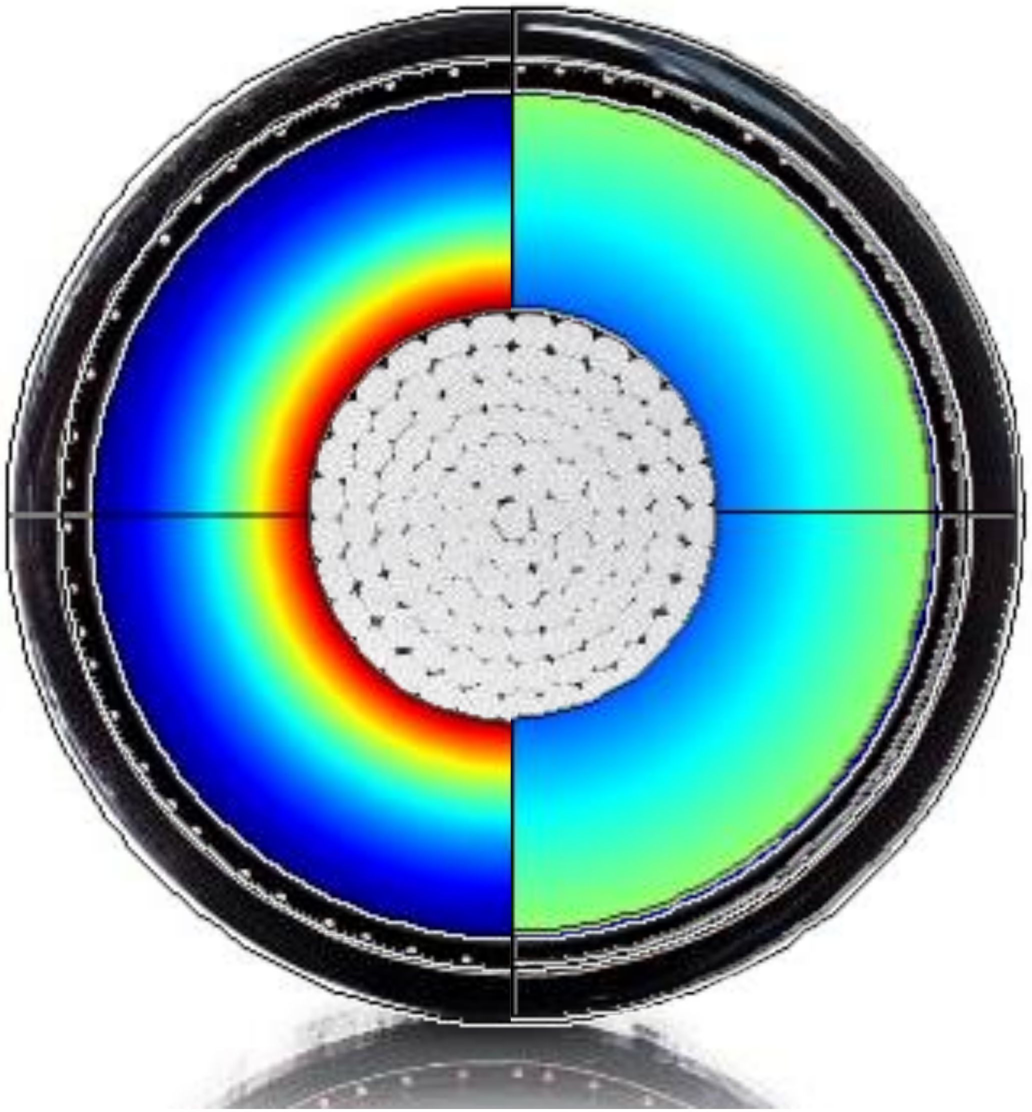
Basics - Cable



$$I = \frac{U}{R} + C\frac{d(U)}{dt}$$

$$\tau = RC = \frac{\varepsilon_0 \varepsilon_r}{\sigma}$$

$t = 0$ ("AC") $\qquad t \to \infty$ ("DC")



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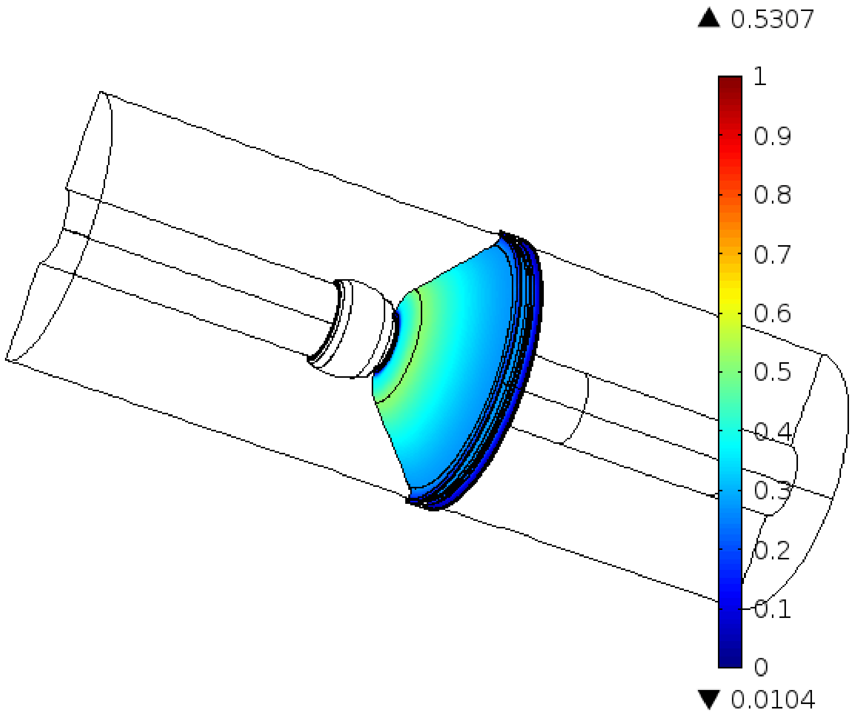
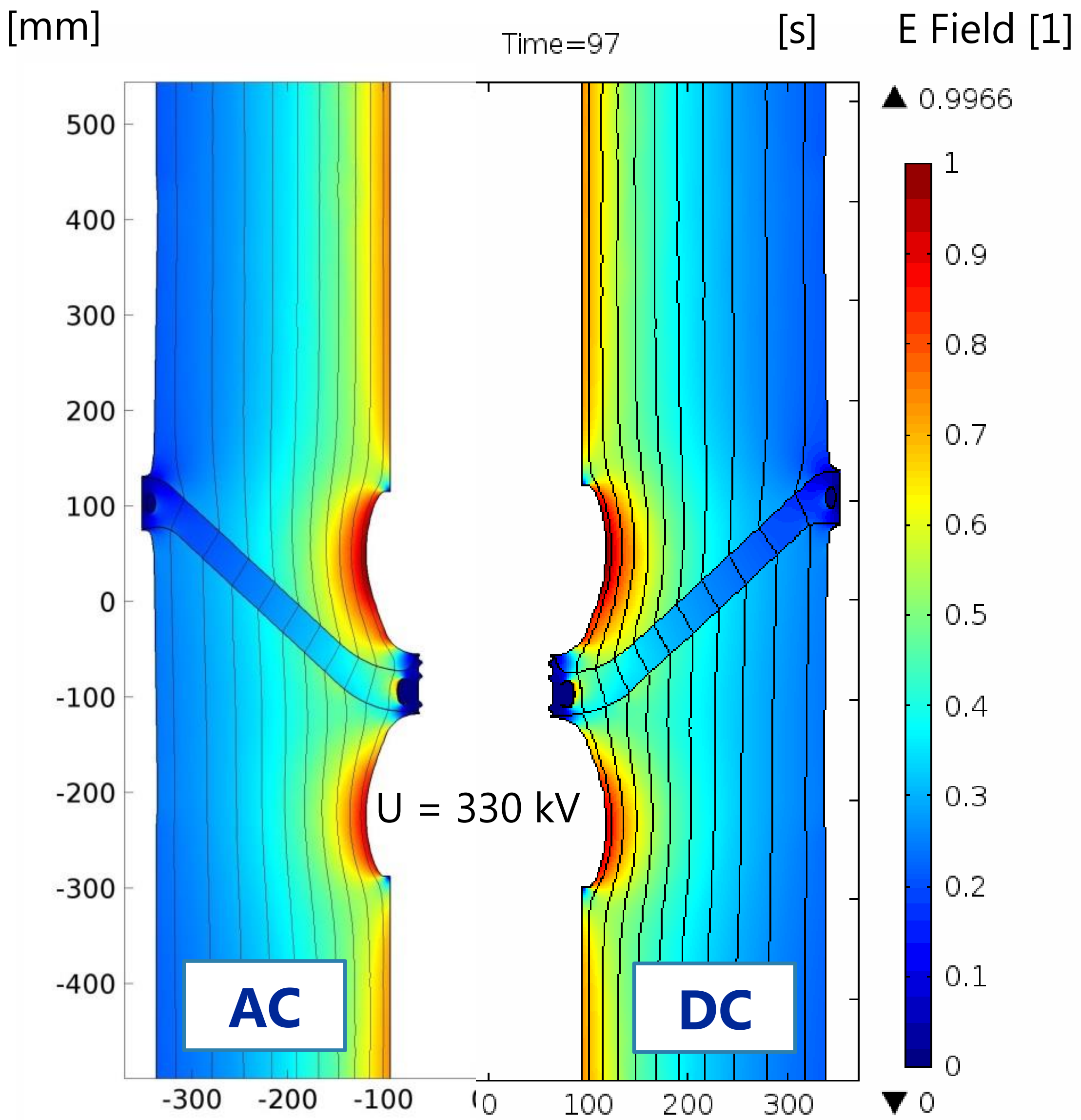
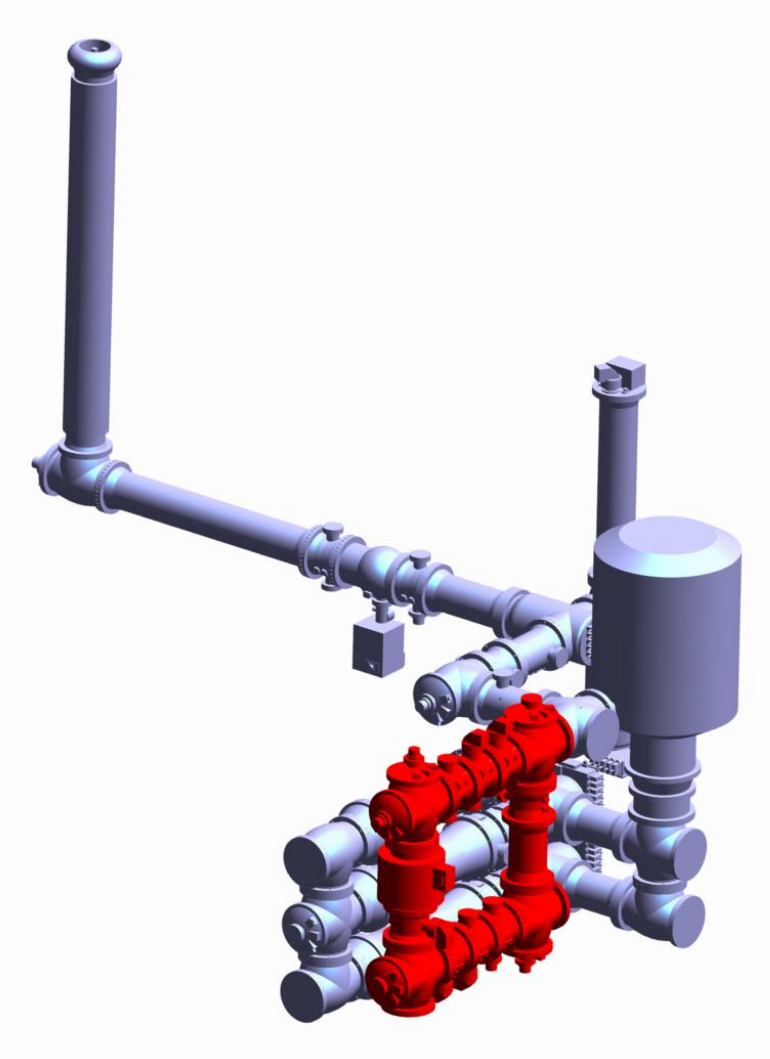
HVDC gas insulated system technology demonstrator

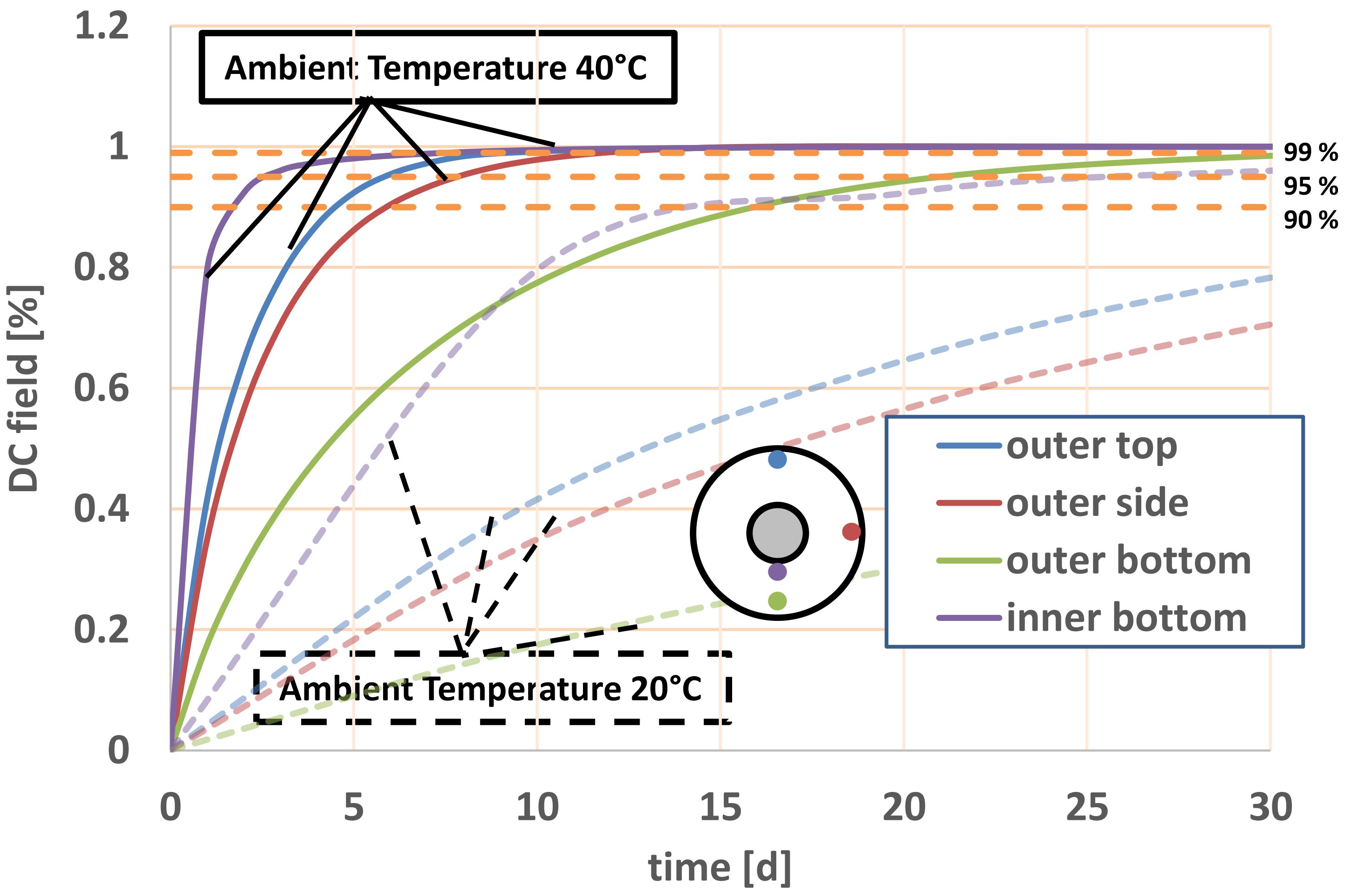




This project has received funding from the European Union's Horizon 2020 research and innovation programme ur

HVDC GIS - Verification Test for Insulators





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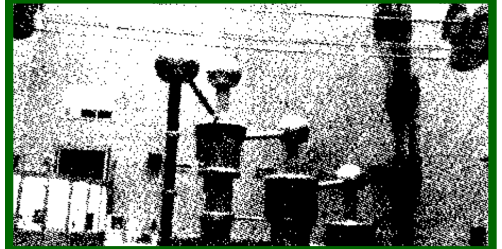
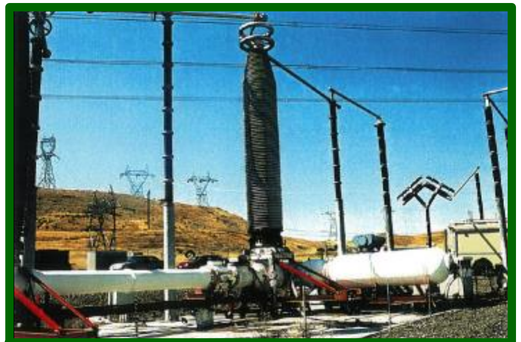
20 years experiences

First 150 kV GIS
Gotland 2



First research

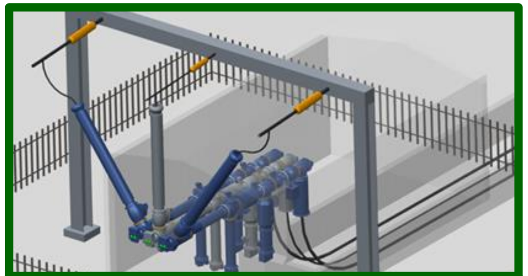
150 kV GIS
Gotland 3



First long-term test
BPA (USA)-ABB

First long-term test
(Japan)

First 250 (500) kV GIS
KII – link (Japan)



New generation
(CH)

New generation
(DE)

New generation
(Japan)

1980 1983 1987 1990 1995 2000 2013 2014 2018

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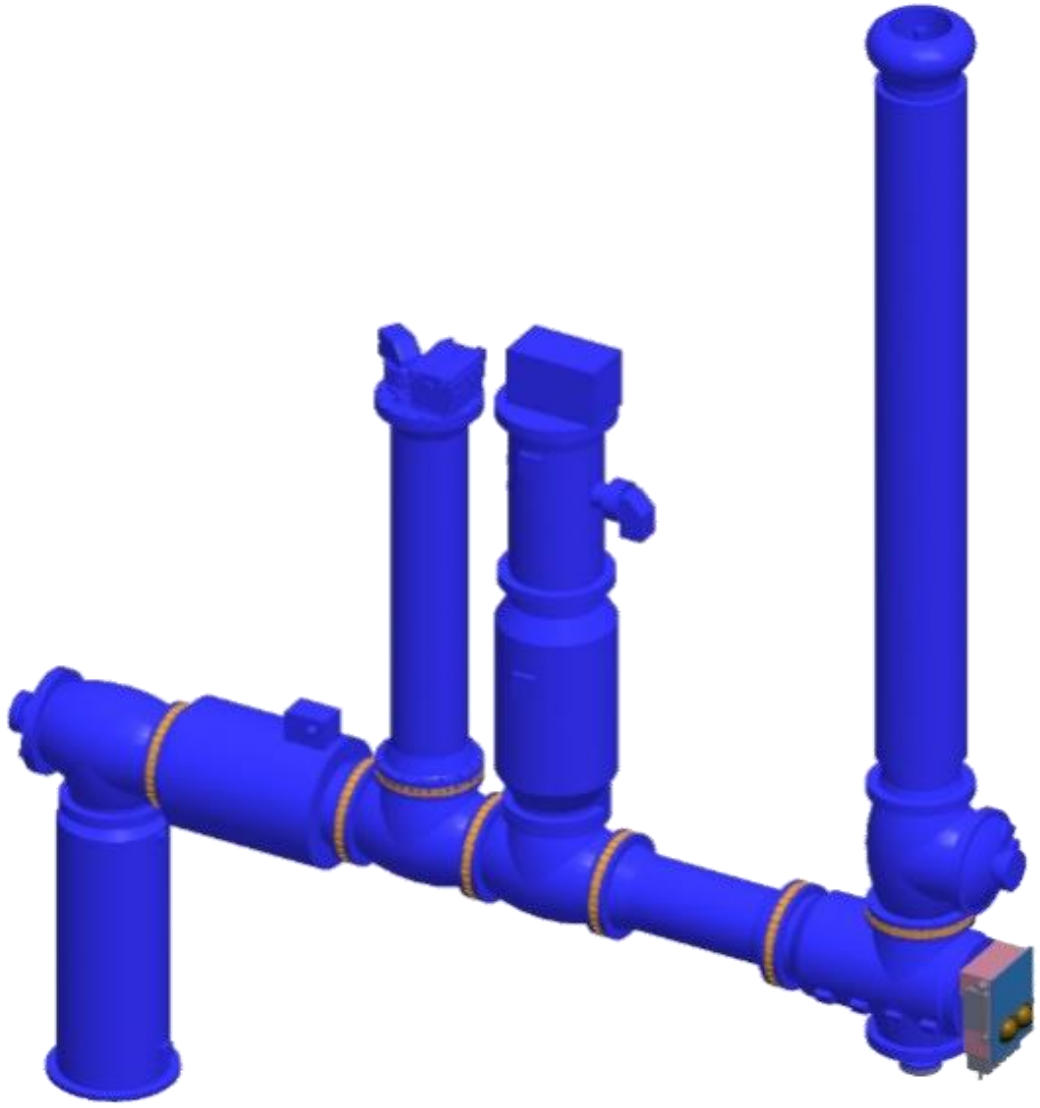
Objectives: Components

HVDC GIS

The HVDC-GIS technology spans a number of switchgear components, e.g.:

- Bus-ducts and high voltage DC conductors
- Disconnect- and earthing switches
- Bushings and cable terminations
- Current- and voltage measurement sensors
- Surge arresters



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Objectives

- To increase the **Technology Readiness Level (TRL) from 6 to 8** for HVDC GIS equipment
- To develop **recommendations for specifying** gas-insulated (GIS) HVDC systems
- To develop **testing requirements, procedures and methods** based on simulation analysis, real HVDC onshore and offshore experiences, and also based on Cigré work
- To carry out **long term testing of full power HVDC GIS** according to developed test requirements/procedures and using developed monitoring and diagnostic methods
- To **develop monitoring and diagnostic methods** for HVDC GIS to ensure a safe operation,
- To **evaluate performance of SF_6 alternatives**
- Use results to improve models and develop **understanding of failure modes**

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WP structure

Kick-off meeting

ABB

DNV·GL

sse

KEMA Labs

SuperGrid Institute

TenneT Taking power further

TU Delft

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Task Structure

WP15 – HVDC GIS technology demonstrator

WP1

WP4

Task 15.1: SHE Transmission
Defining specifications and long term testing requirements

Task 15.2: TU Delft
Develop monitoring and diagnostic method and applicability of SF_6 alternatives

Task 15.3: DNV-GL
Long term testing of the DC GIS equipment

Task 15.4: ABB
Initiation of standardization activities for HVDC GIS design, testing and application

WP11

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Deliverables

- D15.1 : Document on recommendations for specifying DC GIS systems
- D15.2 : Document on test requirements, procedures and methods
- D15.3 : Report on DC GIS diagnostic and monitoring tools and methods
- D15.4 : Anonymized test reports on tests carried out
- D15.5 : Report of diagnostic analysis and condition assessment
- D15.6 : White- and position papers on pre-standardization of DC GIS testing
- D15.7 : Report on characteristics of PD Alternative gas: comparison with SF6
- D15.8 : Report on long term monitoring of DC GIS with defects

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Any Questions?

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PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

PROMOTioN WP15
320 kV HVDC GIS Prototype Installation Test

Arnhem, 27-02-2020

Hong He – KEMA Labs
Michael Gatzsche – ABB Power Grids

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

CONTENT

- What is the Prototype Installation Test?
- Test Object
- Test Program
- Test Progress and Results

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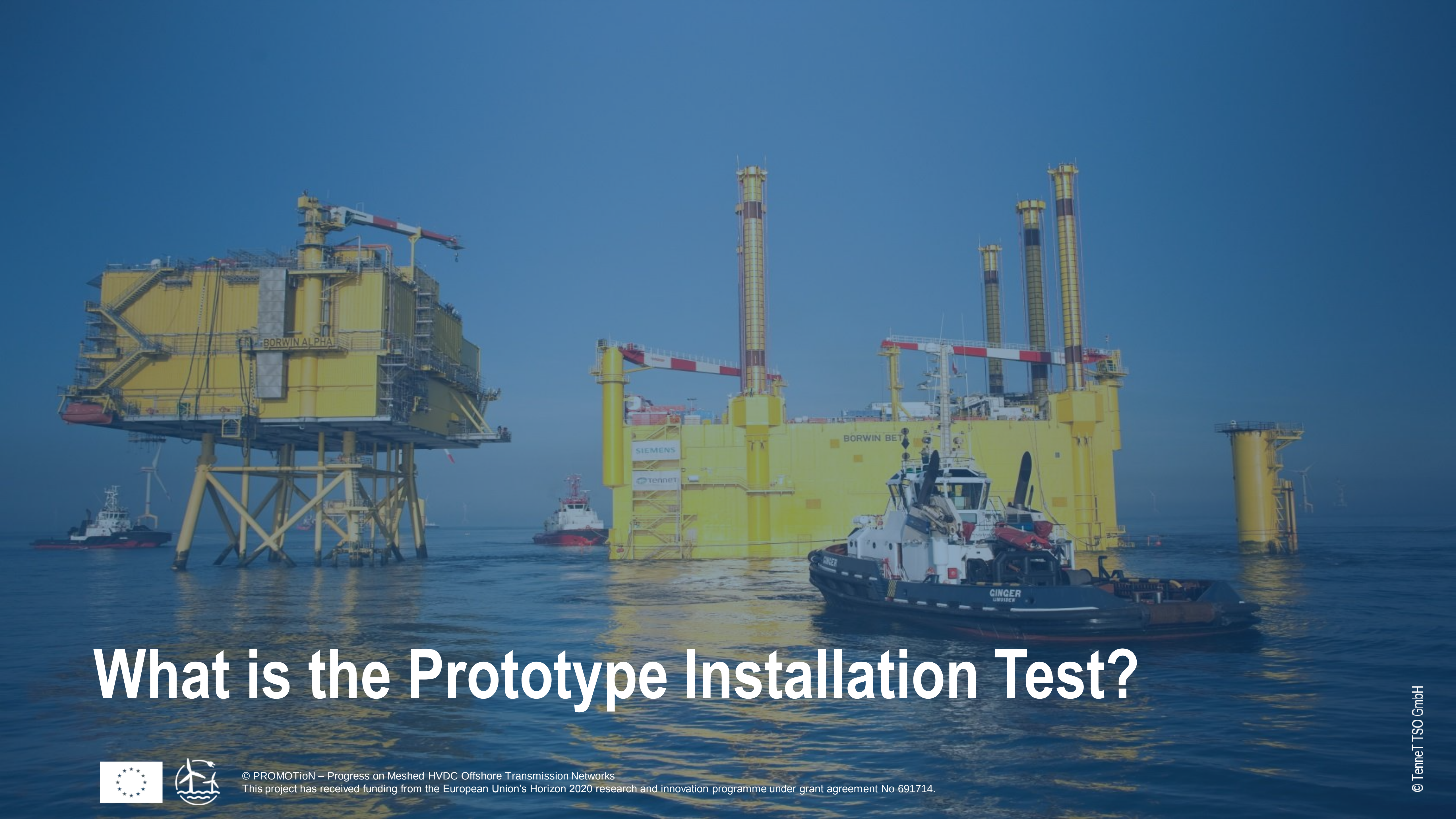

What is the Prototype Installation Test?

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Introduction

- Development tests
- Type tests
- Routine tests
- On-site tests

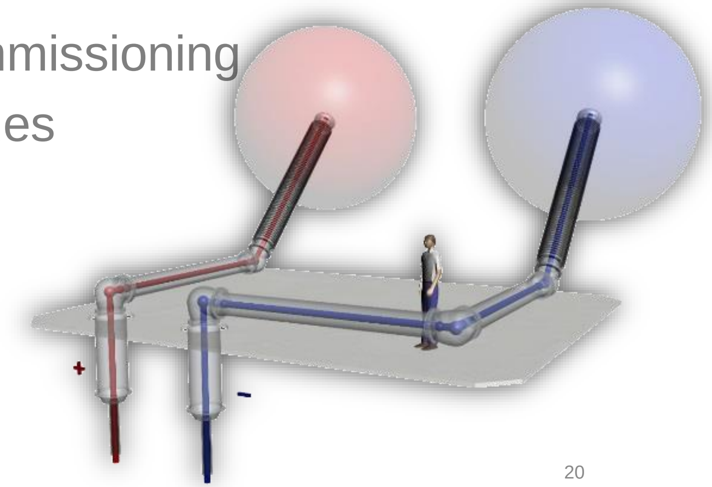
- Prototype installation test

➢ full scale
➢ long-term (> 1 year)
➢ representative stresses (electrical, thermal, mechanical)
➢ optional test

- Role of Prototype installation test

➢ Increase Technology Readiness Level (TRL 6 → 8) by full scale demonstration in independent lab

➢ verify the overall performance:
  - production
  - Installation and commissioning
  - Operation for decades



Test Object

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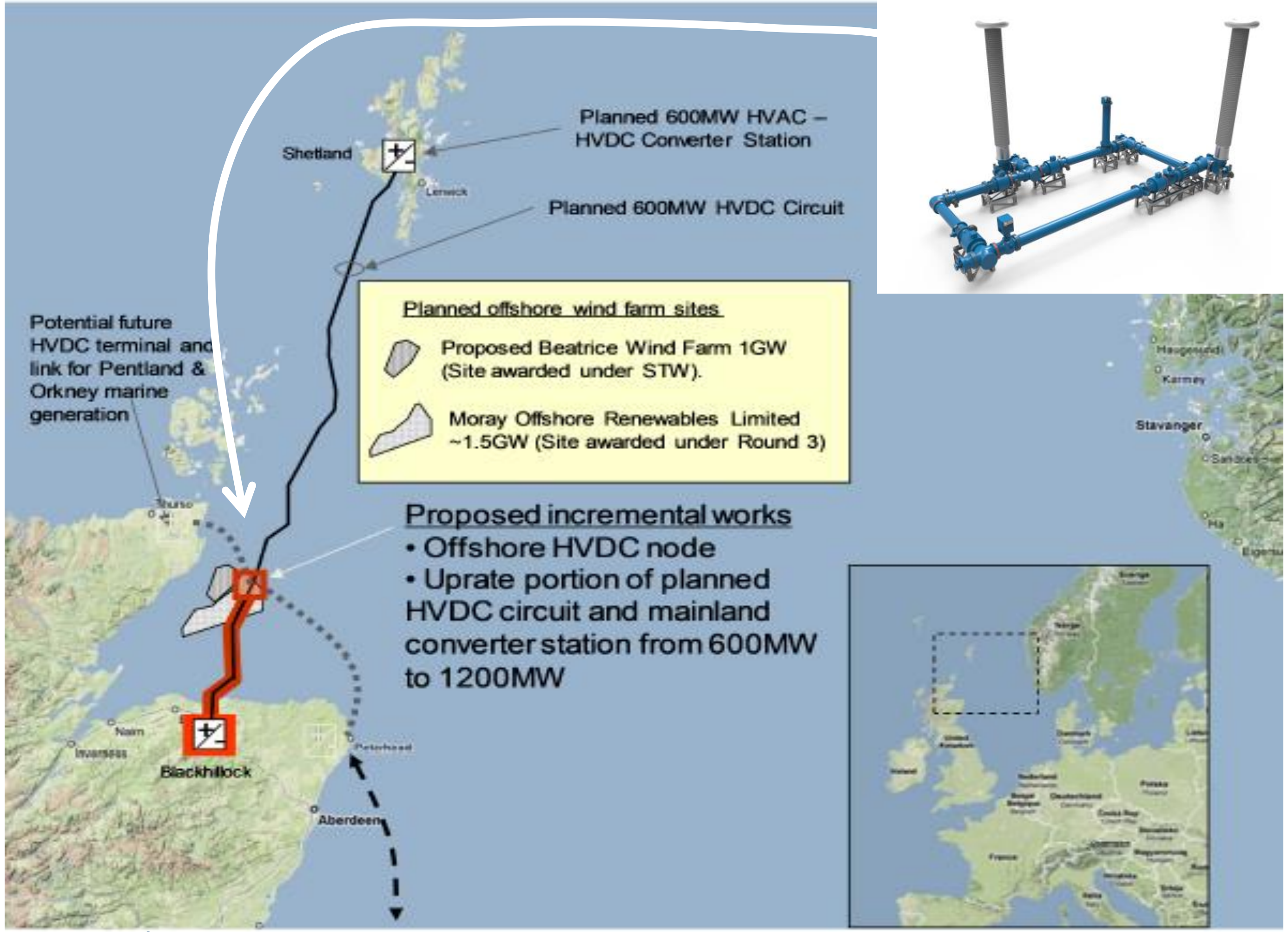
Prototype installation test

Test Object

ABB 320 kV HVDC GIS Ratings: Base for Specification & Ratings



Nominal DC voltage U_n	± 320	kV_{dc}
Rated DC voltage U_r	± 350	kV_{dc}
Rated superimposed LI withstand voltage U_P / U_r		
Lightning impulse voltage	± 1050	kV
DC voltage	± 350	kV_{dc}
Rated superimposed SI withstand voltage U_S / U_r		
Switching impulse voltage	± 950	kV
DC voltage	± 350	kV_{dc}
Rated DC withstand voltage to earth U_w	± 610	kV_{dc}
Rated normal current I_r	4000	A_{dc}
Rated peak withstand current	160	kA
Rated short-time withstand current	64	kA
Rated duration of short-circuit	1	s
Ambient temperature range	-30/+40	°C

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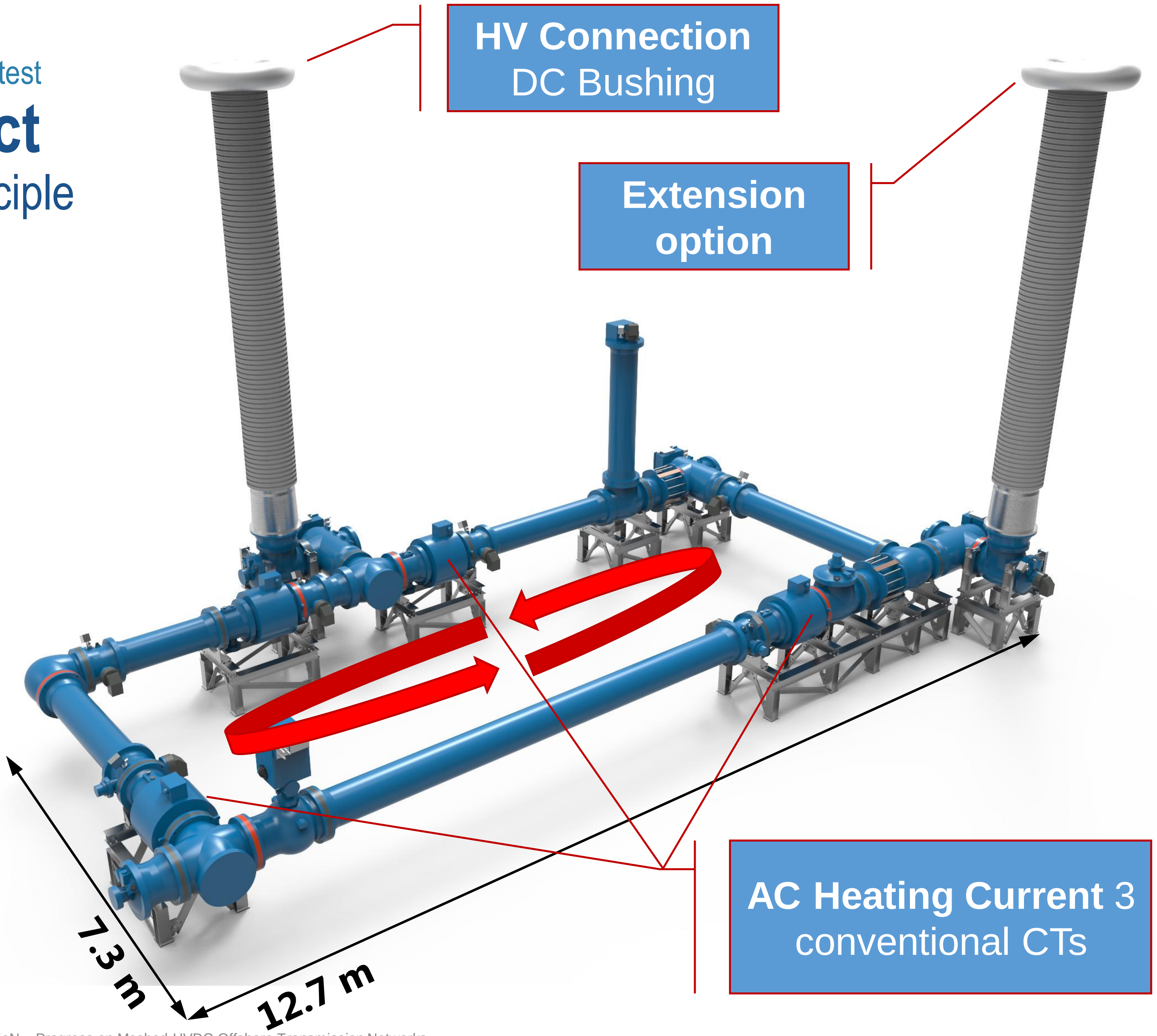
Prototype installation test

Test Object

Test Pole Principle



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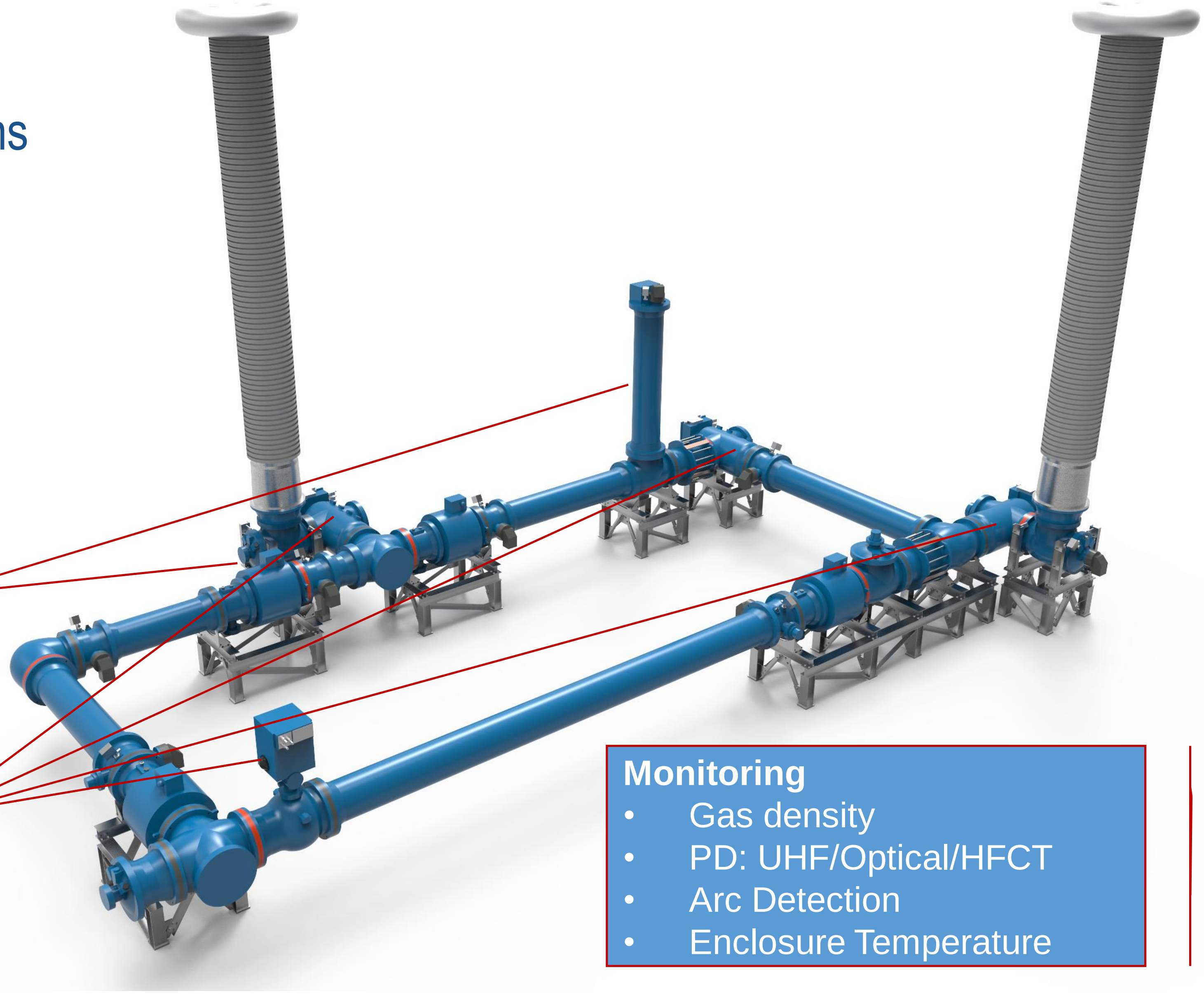
Test Object

Components and Monitoring Systems

Ring
- 8 gas compartments
- 31 m busbar
  (straight, L, T, X elements, dismanteling unit)
- Partition Insulator: 8 pcs.
- Support Insulator: 14 pcs.

GIS Instrument Transformers
- Voltage: RC-divider
- DC/AC: Zero-Flux Sensor

Switching Devices
- 3 disconnector and earthing switches
- Fast-acting earthing switch



Monitoring
- Gas density
- PD: UHF/Optical/HFCT
- Arc Detection
- Enclosure Temperature

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Test Program

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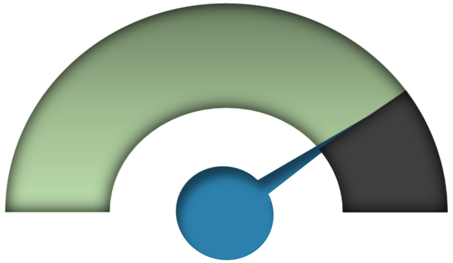
Prototype installation test

Test progress



80 %

Pre-tests → ZL + HL 6 x 60 days → LC 2 x 15 days → Subsequent tests

Thermal cycle
LI / SI
DC/AC PD
SIM LI/SI
Polarity reversal
(120-2-120-2-45 min)

1 x ZL: – U_T
1 x HL: – U_T
1 x ZL: + U_T
1 x HL: + U_T
1 x HL: – U_T
1 x HL: + U_T

1 x LC: + U_T
1 x LC: – U_T

DC PD
LI / SI
AC PD

SIM: U_r / ± LI/SI & 10 CO & AC PD

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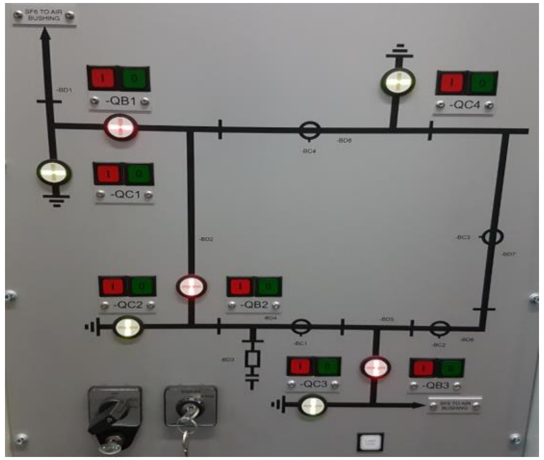
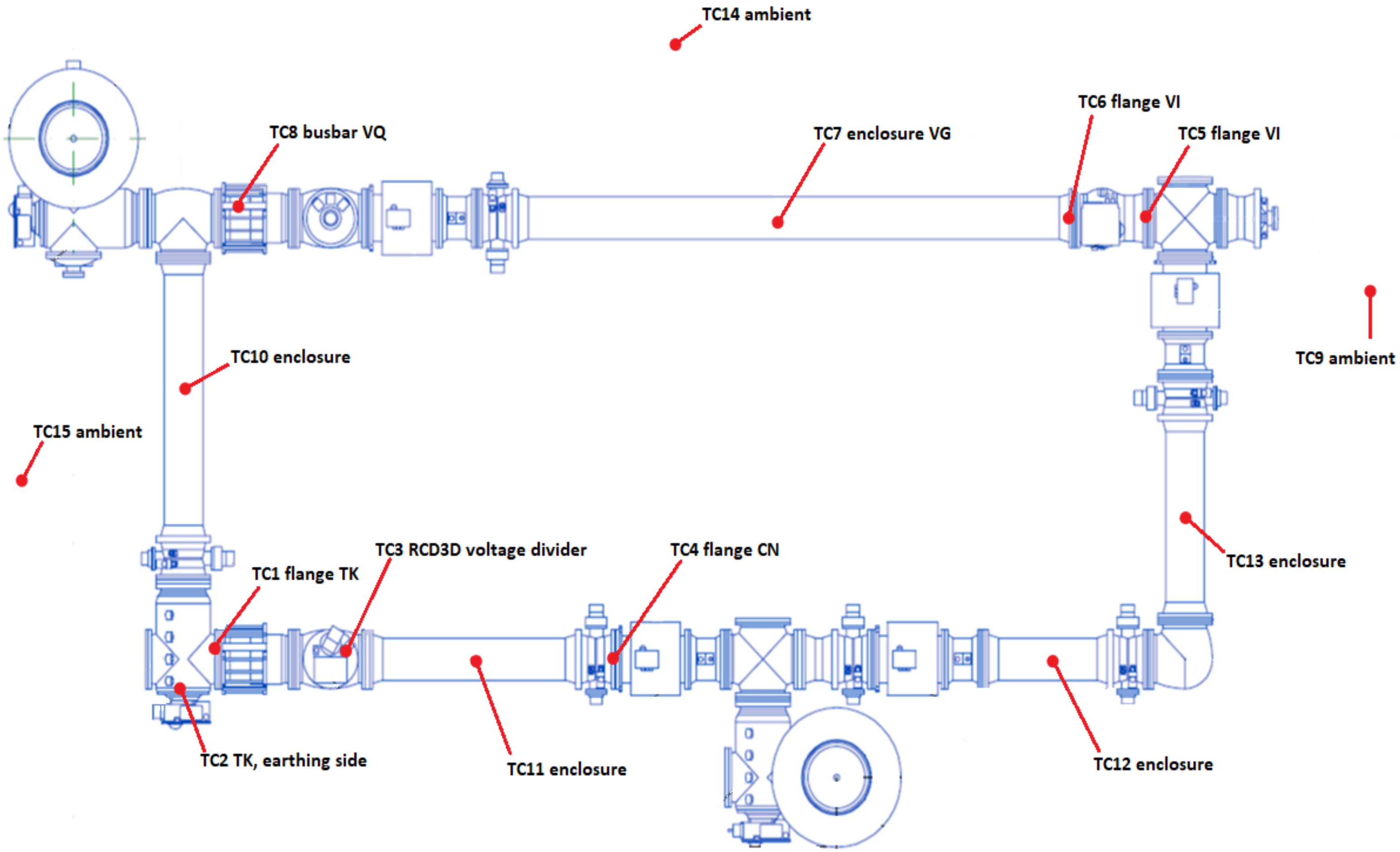
Test results – Monitoring system

Monitoring

- Gas pressure
- PD sensors
- Arc Detection
- Enclosure Temperature
- U, I, T control/record system
- Disconnectors/switches panel





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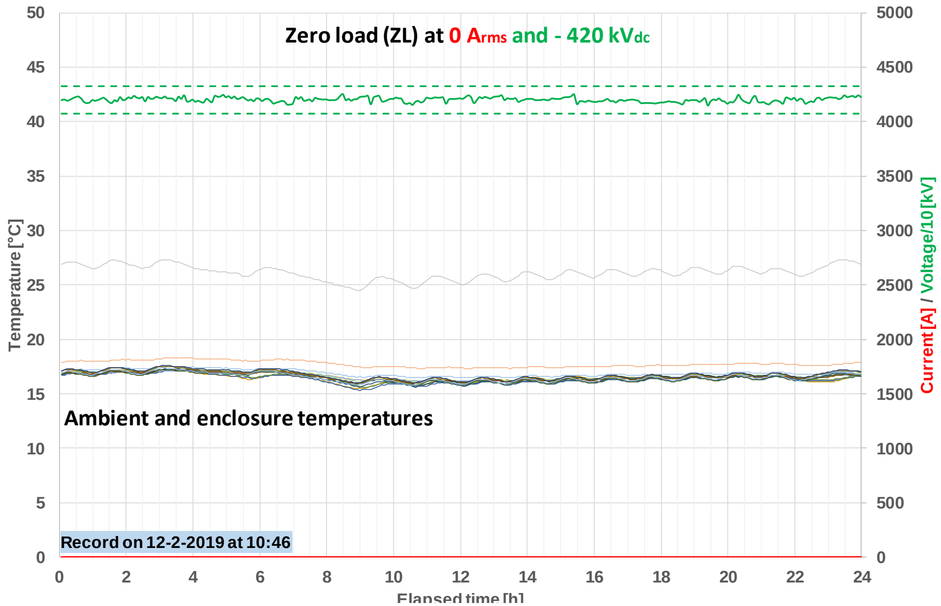
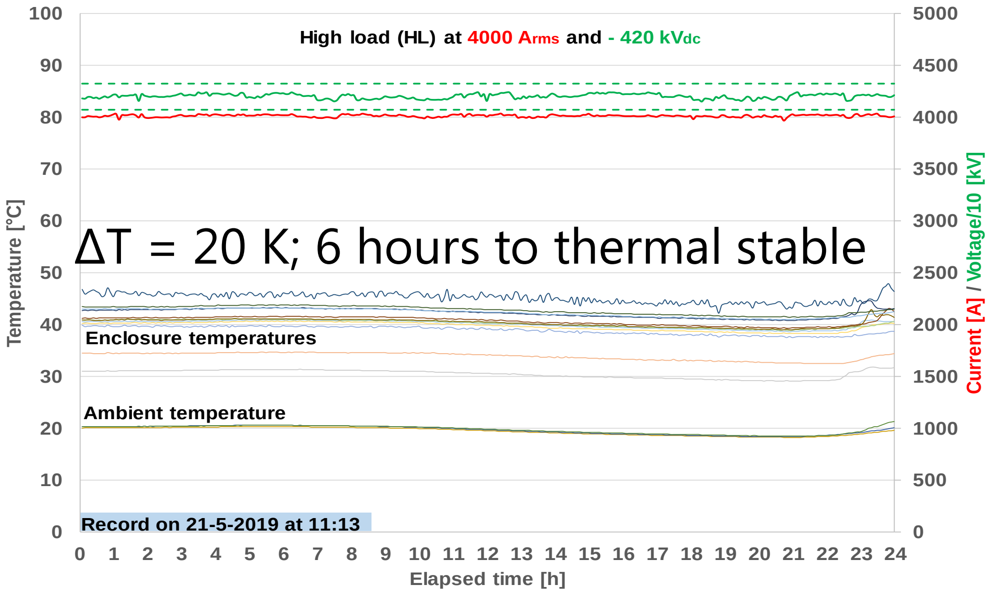
Prototype installation test

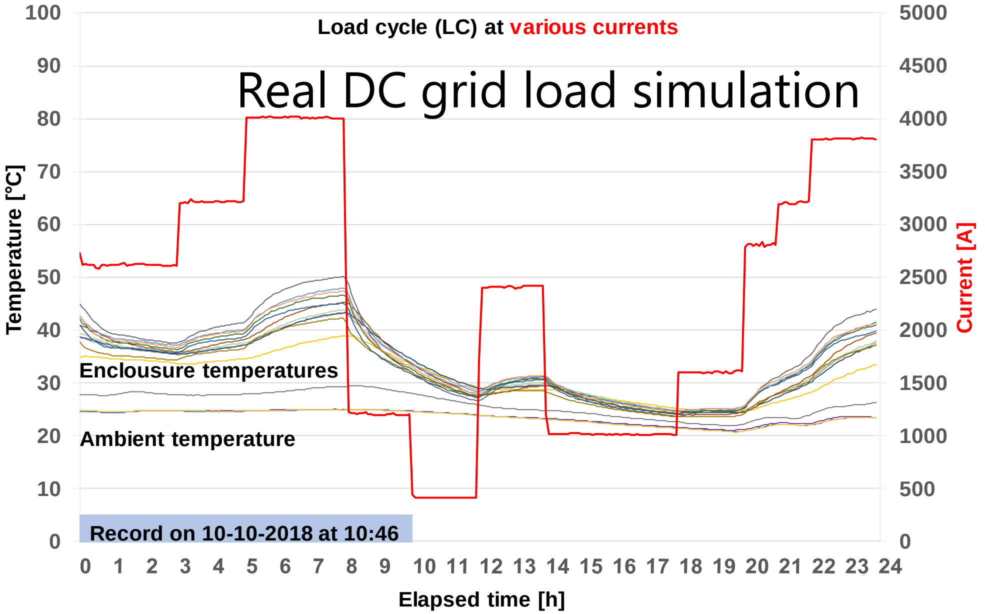
Three types of loads

- ΔT = 20 ± 1 K

($T_{\text{average surface of enclosure}} - T_{\text{average ambient}}$)







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Test Progress and Results

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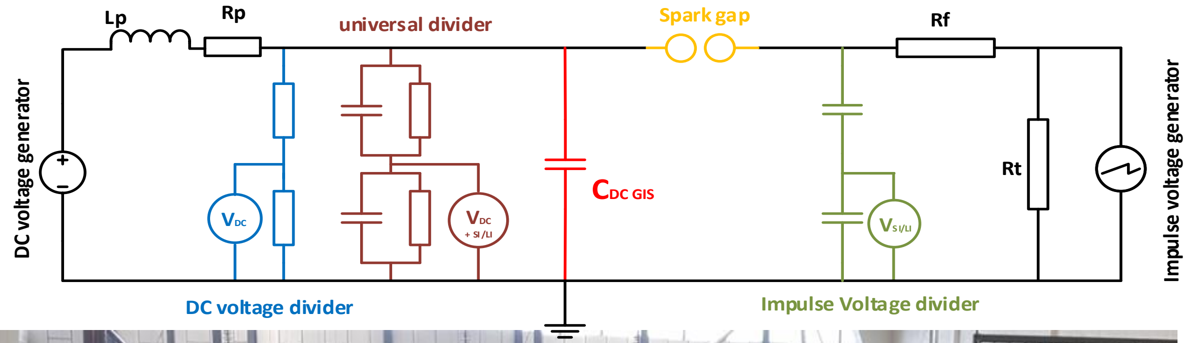
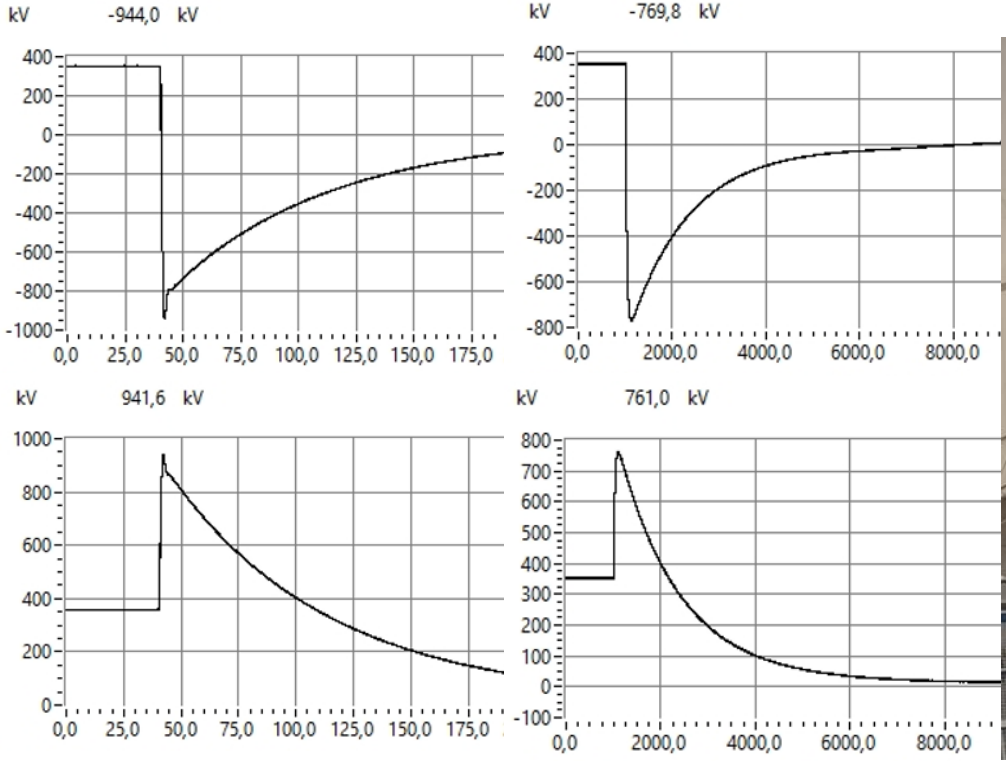
Test results - SIM

- Spark gap method
- DC 350 kV + LI 940 kV / SI 760 kV





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Prototype installation test

SIM: Spark gap method

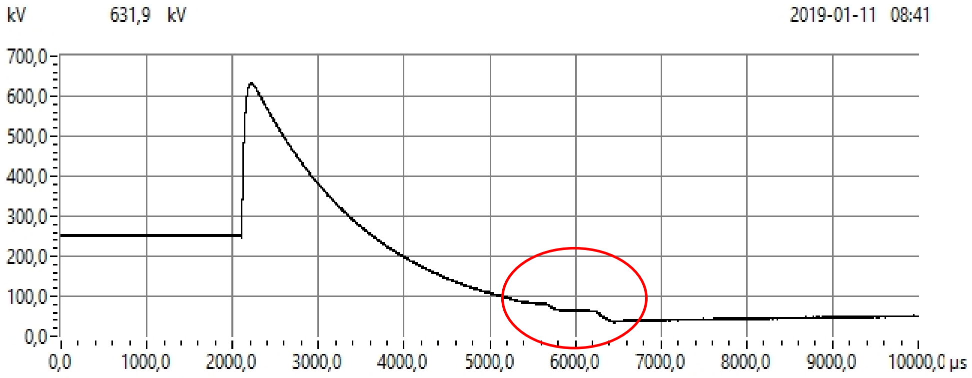

Fig. 20: DC +250 kV SI +65%

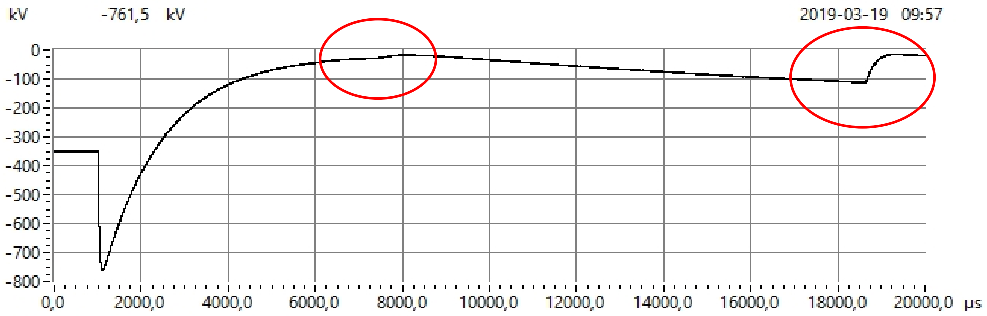

Fig. 13: 72129113 DC -350 kV, -100% of test voltage

- An effective solution
- Extinction and reignition effects
- Equipped both spheres with trigger units might be a solution

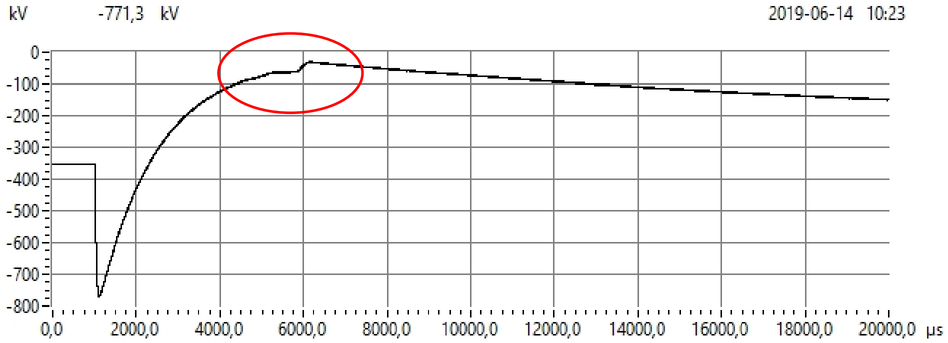

Fig. 12: DC - 350 kV, -SI 100%

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Test results

- Pre-tests ➔ all passed
  - AC PD measurement
  - DC PD measurement
  - LI and SI
  - Polarity reversal tests
- Long term load cycle voltage tests ➔ all passed
  - 2 x ZL
  - 3 x HL

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Thank you!

PROMOTioN WP15

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PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Alternative Partial Discharge Monitoring Technique for HVDC GIS.

Delft University of Technology
Fabio Muñoz.

Arnhem, The Netherlands

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Content

- Introduction.
- The UHF system for PD measurements.
- New alternative measuring system.
- Conclusions.

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Introduction

- PD measurements are used worldwide by GIS manufactures utilities for detection of incipient defects in the insulation system of GIS.

Introduction

HIGH FREQUENCY.
GIS acts as a Faraday Cage
Low background noise.
Highly attenuated and distorted.

LOW FREQUENCY.
Less attenuation and distortion.
Propagation according to the transmission line theory.

NOISE
External disturbances

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The UHF system for PD measurements.

For PD measurements, the ultra-high frequency (UHF) method is the most extensively used in GIS

- Less affected by the noise.
- Based on capacitive couplers (300 MHz to 3GHz).
- The standard for on-line monitoring in AC GIS.
- A solid practice that is being transferred to DC GIS.

But,

- It suffers significant attenuation and distortion.
- In the UHF range there is not a direct correlation with the signal measured and the charge of the PD.

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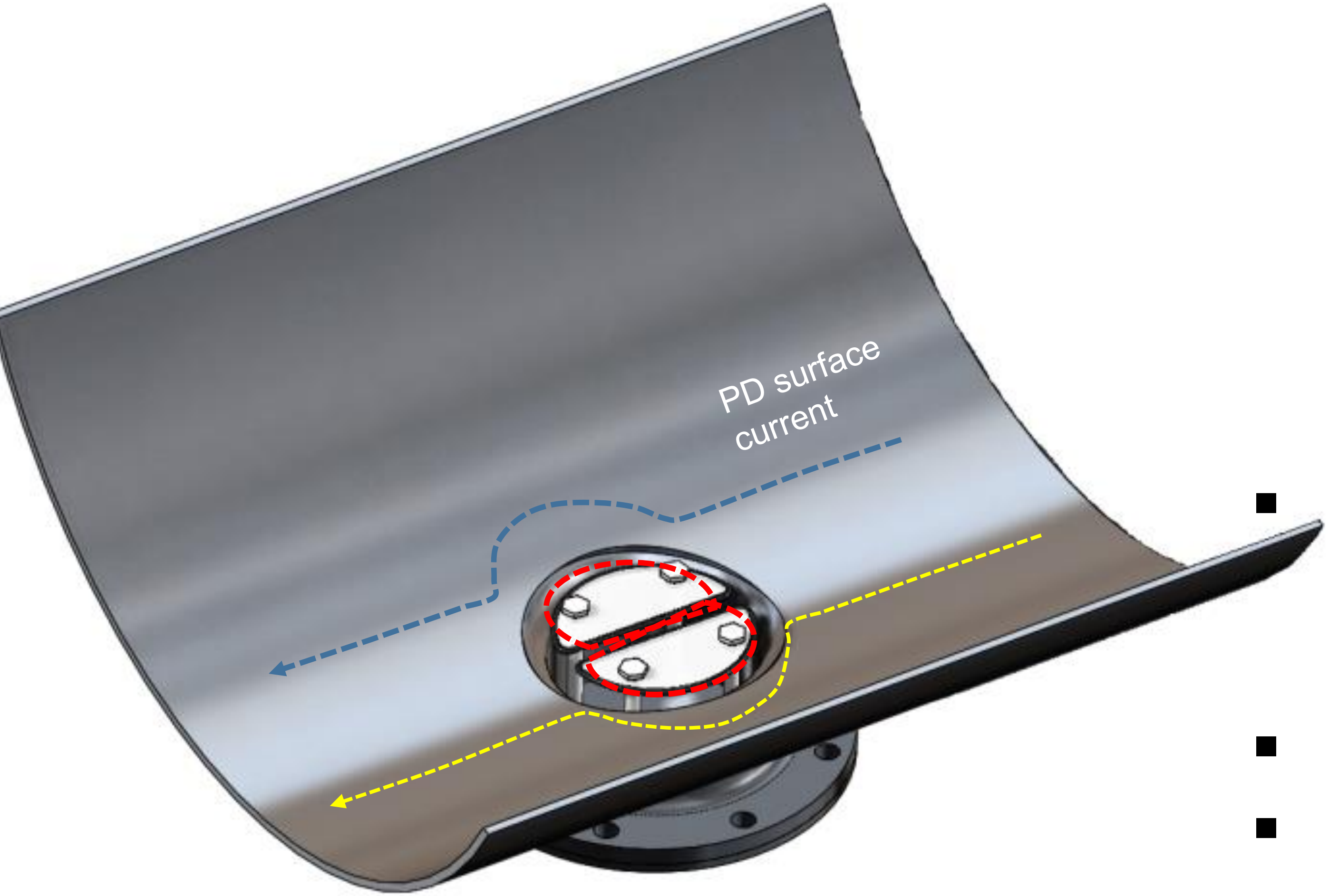
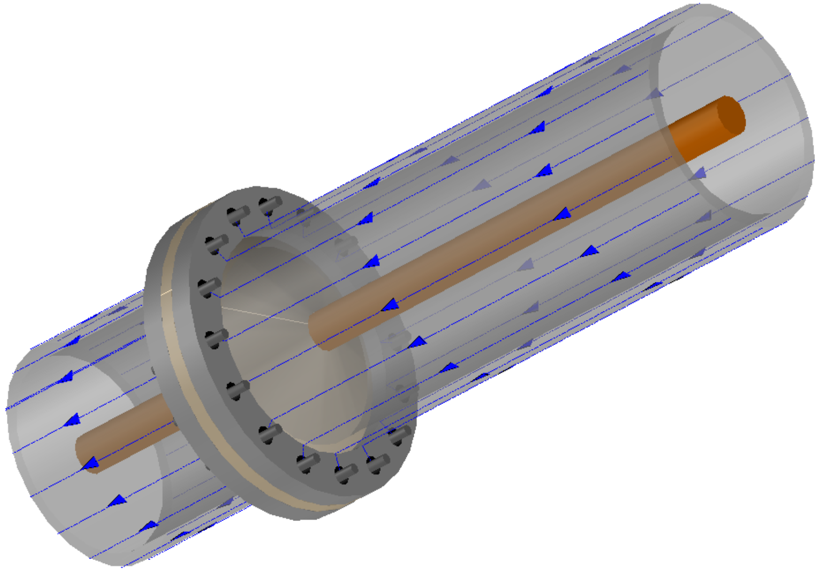
New alternative measuring system.





- The PD produces a current at the low-frequency range (kHz – hundreds of MHz).
- It travels like in a transmission line.
- It suffers less attenuation and distortion.

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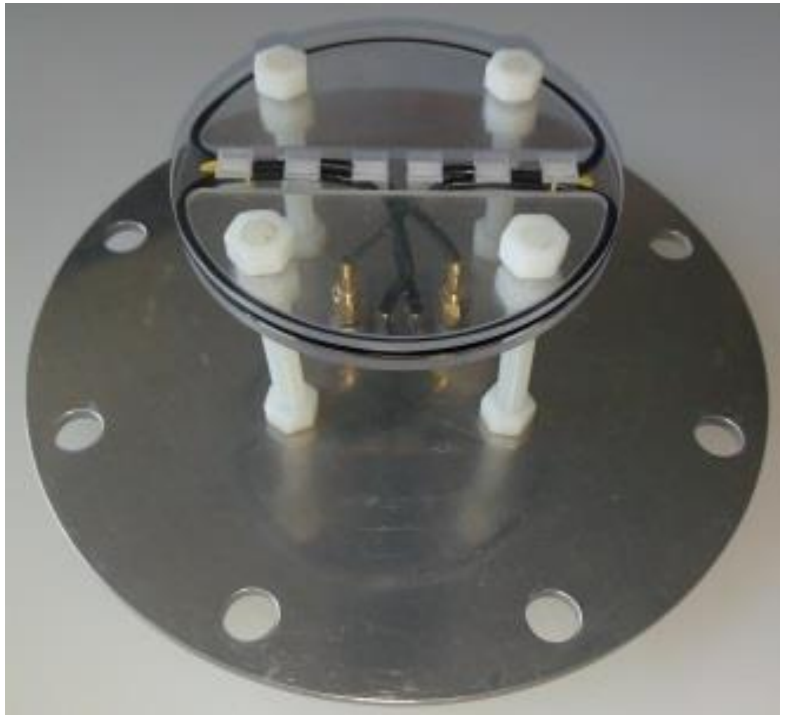
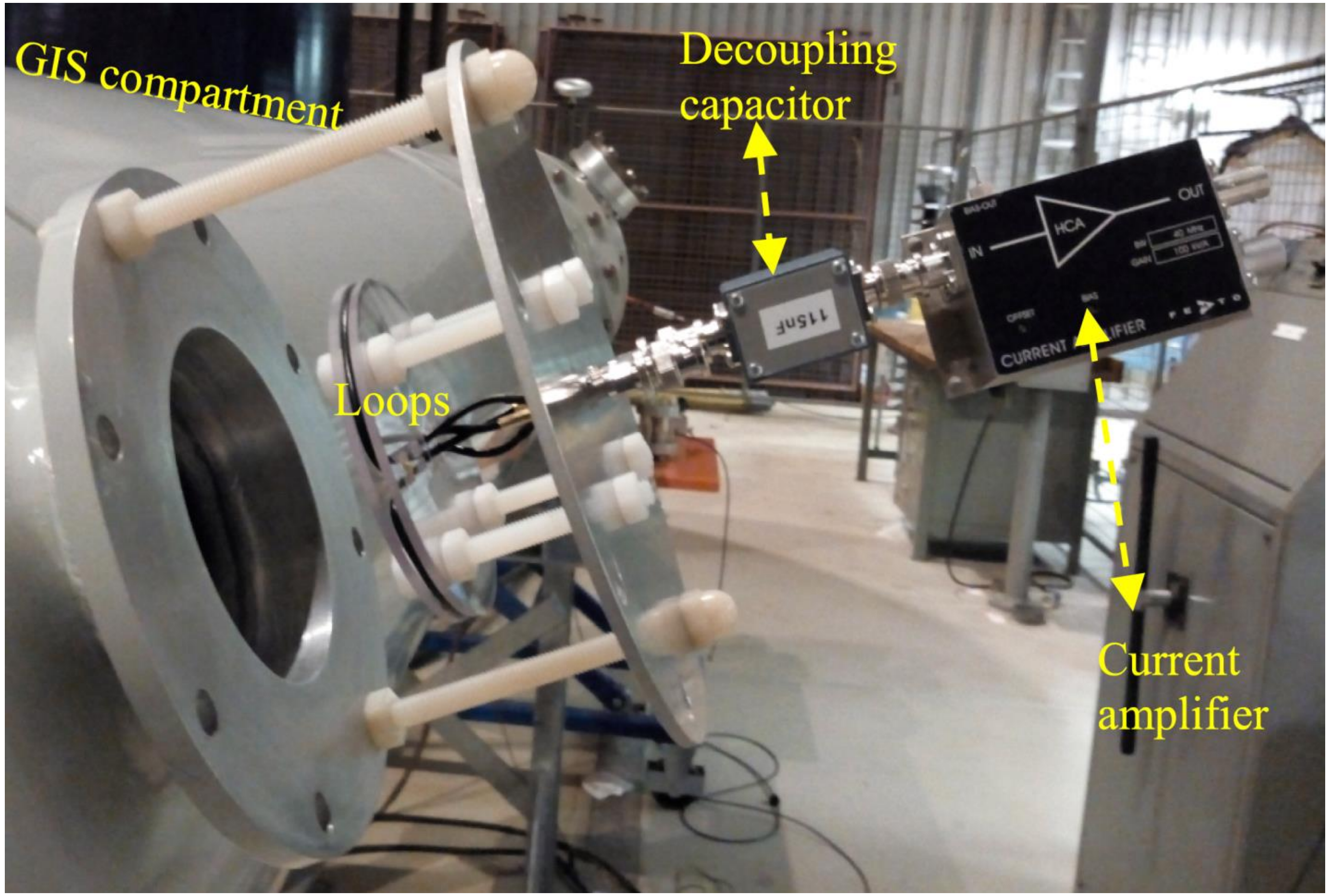
Magnetic antenna

- Low-frequency range.





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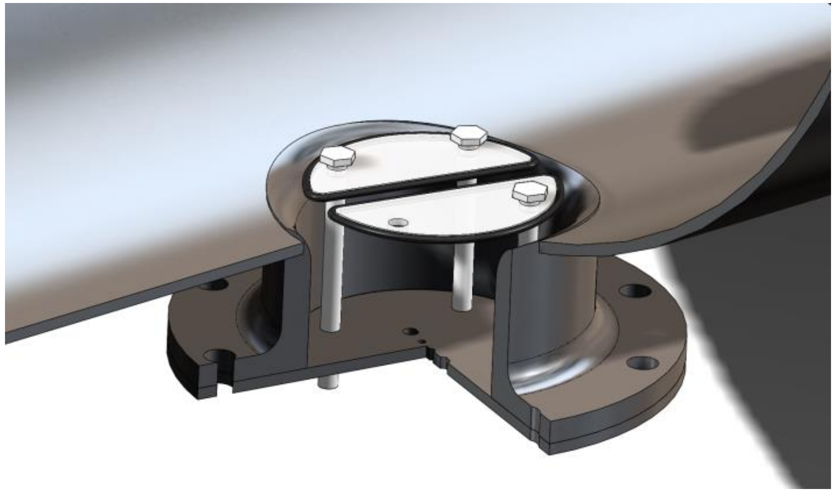
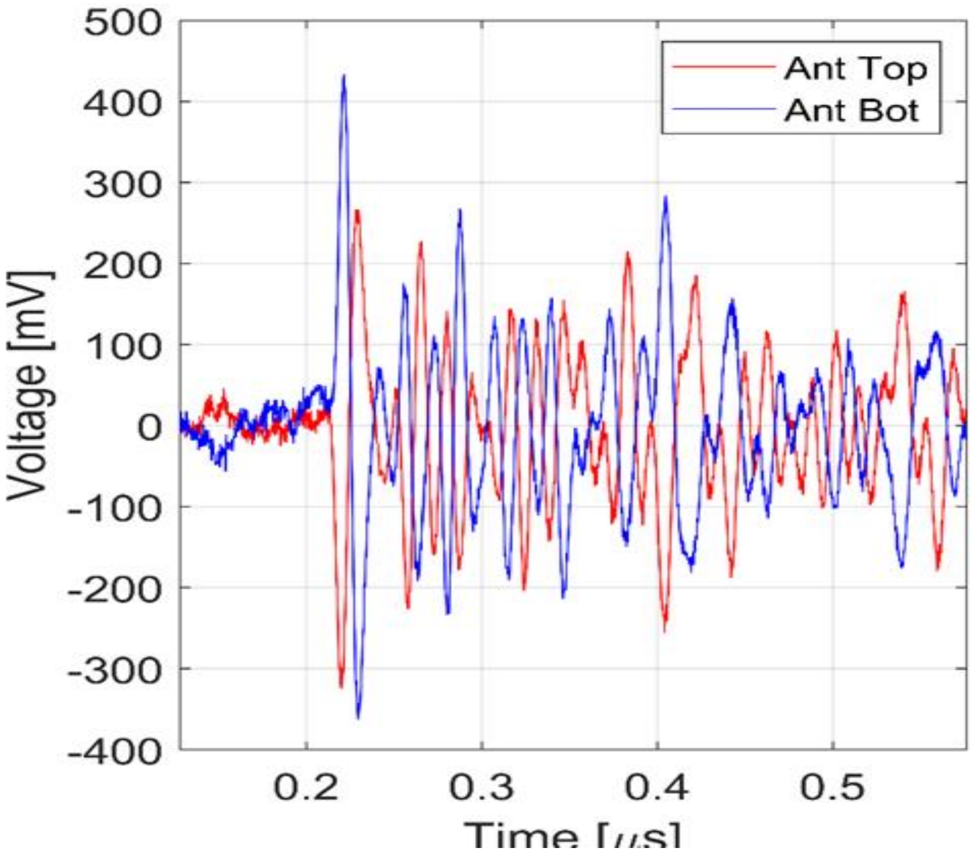
Magnetic antenna.

- Mirror-like symmetry
- Same magnitude.
- Opposite polarity.
- The signals appear around the same time.





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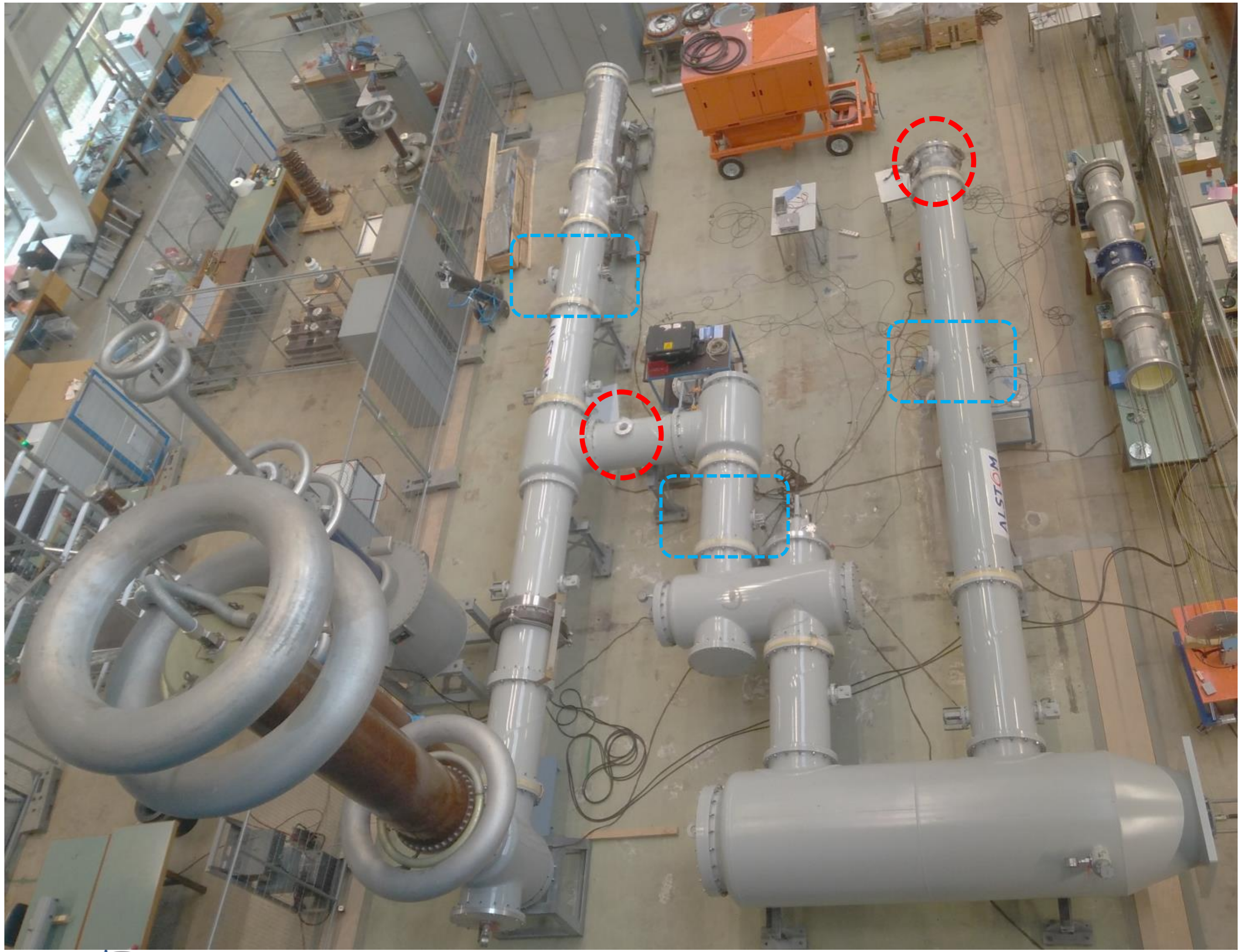
Measuring system.



- Three magnetic antennas deployed in the GIS.
- Two compartments were used to produce PD (corona).
- HVDC -15kV.

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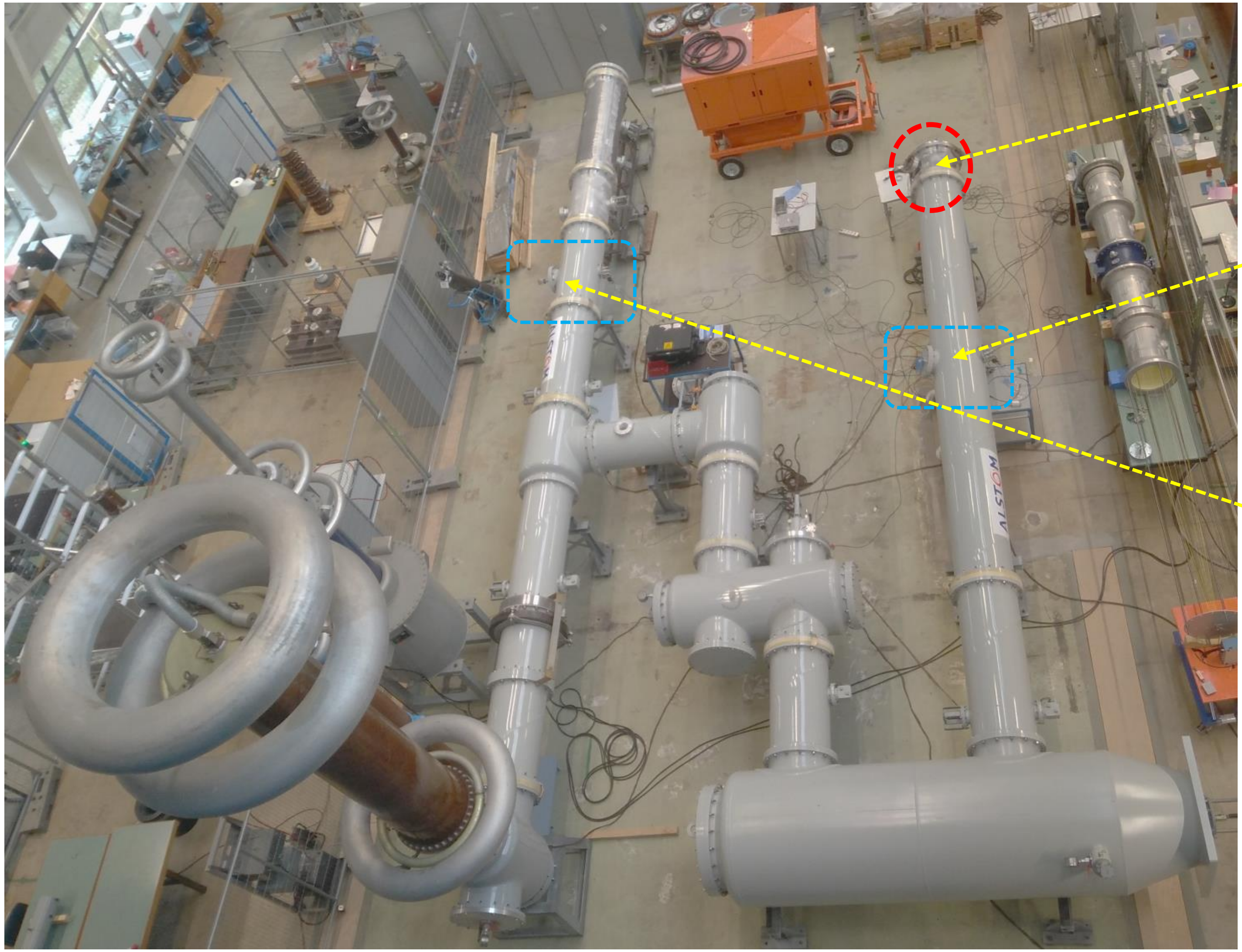
Sensitivity.



- PD source
- Above 5 pC PD are detectable in the closest antenna. (3 m)
- Above 15pC is detectable in the farthest antenna. (21m)

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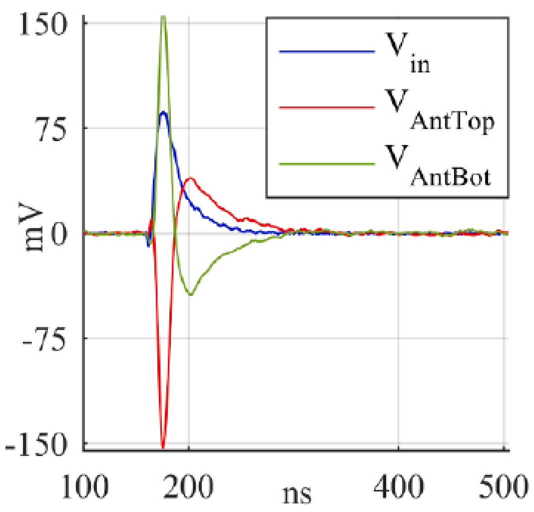
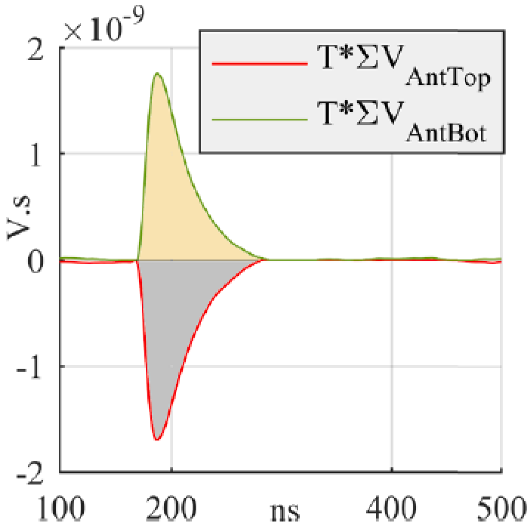
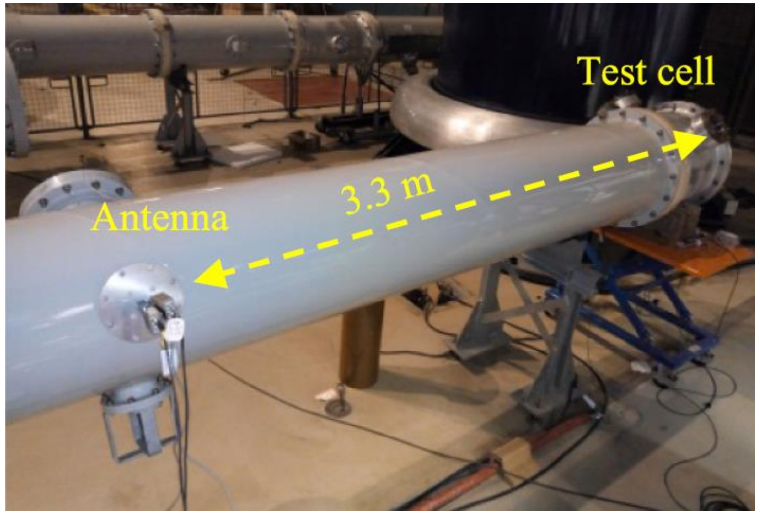
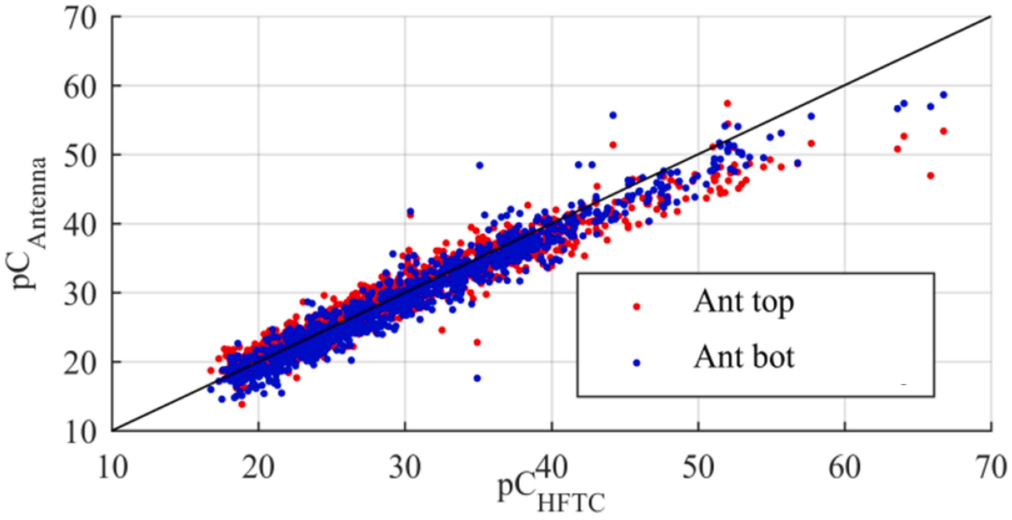
Charge estimation.





$$Q_{HFCT} = K_c Q_{antenna}$$





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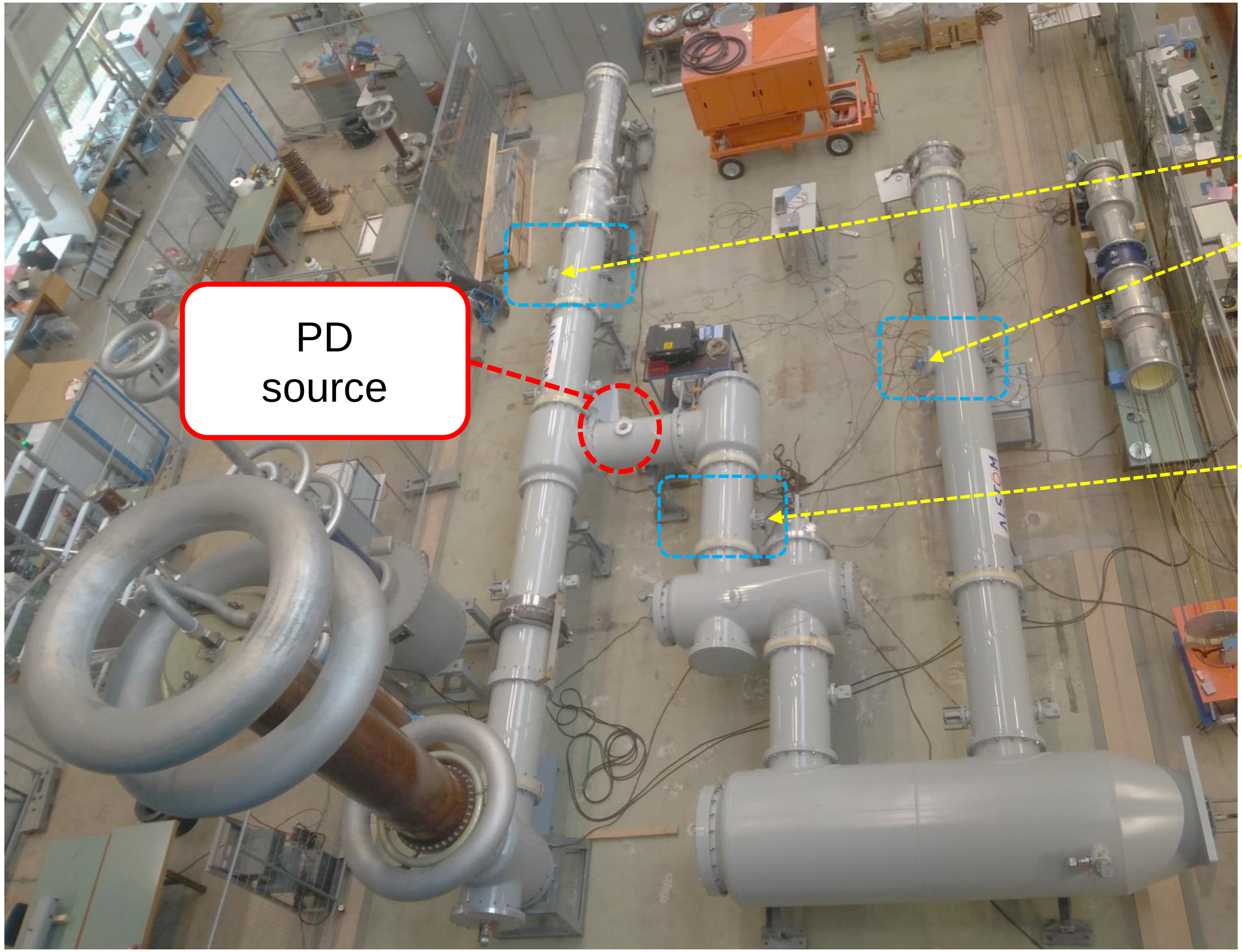
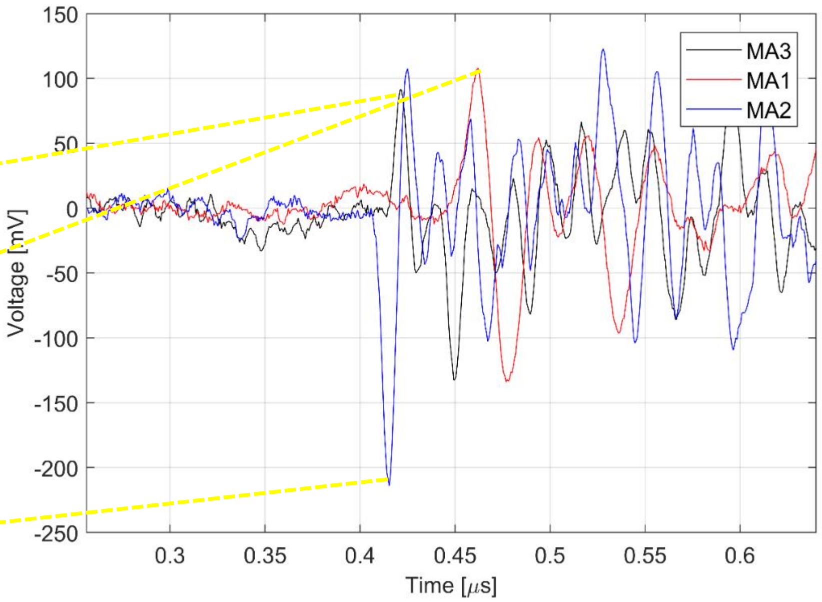
Localization.





- PD source was located using the arrival time between the antennas an average speed of propagation **c**.

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Conclusions

- The measuring system based on magnetic antennas is a feasible option for partial discharge monitoring on HV GIS.
- The magnetic antenna system is able to detect small partial discharges, in the order of 5 pC at 3 m and 15 pC at 21 m distance from the PD source.
- It is possible to estimate the apparent charge of the partial discharges.
- The PD source was located using the arrival time between the antennas.

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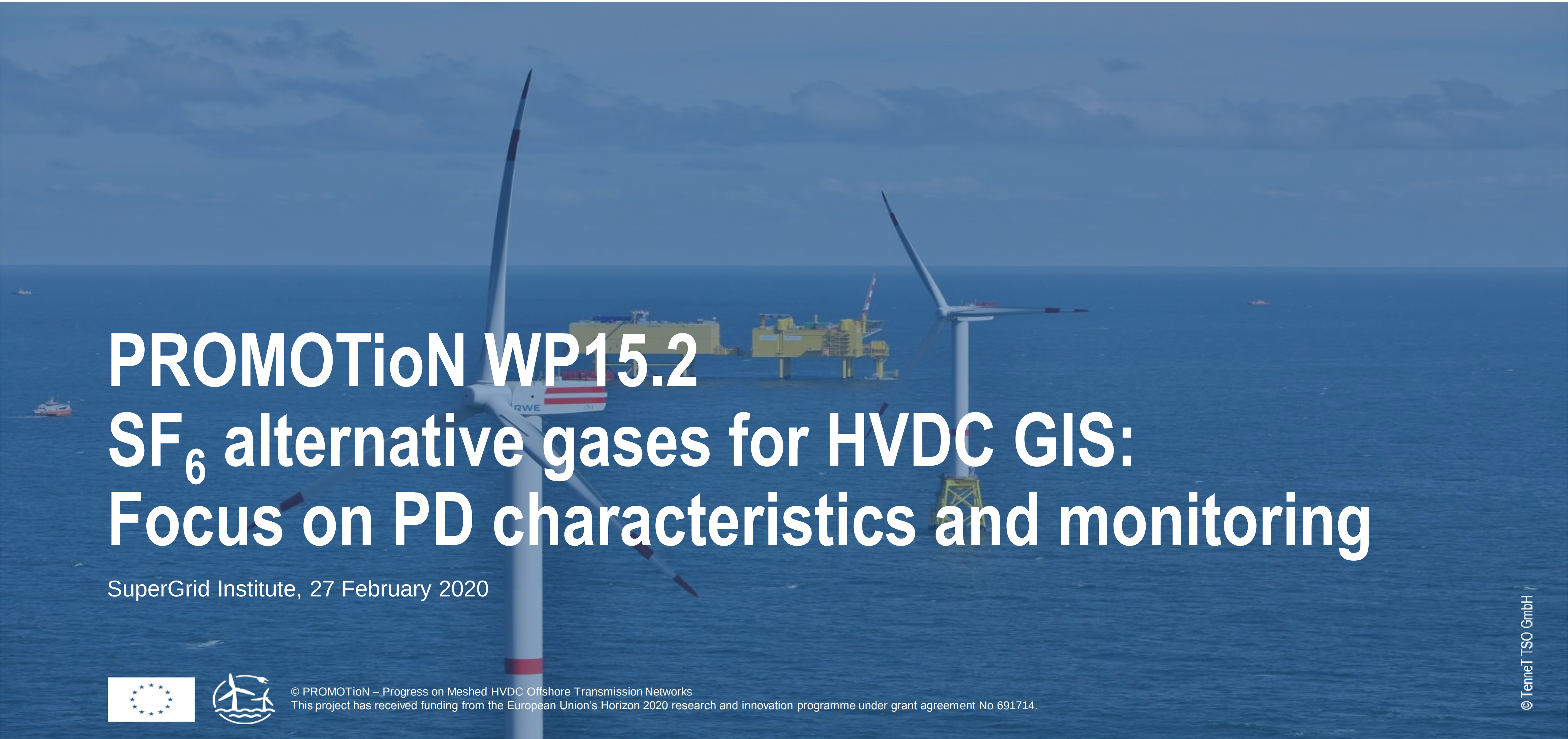
PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS



PROMOTioN WP15.2
SF_6 alternative gases for HVDC GIS: Focus on PD characteristics and monitoring

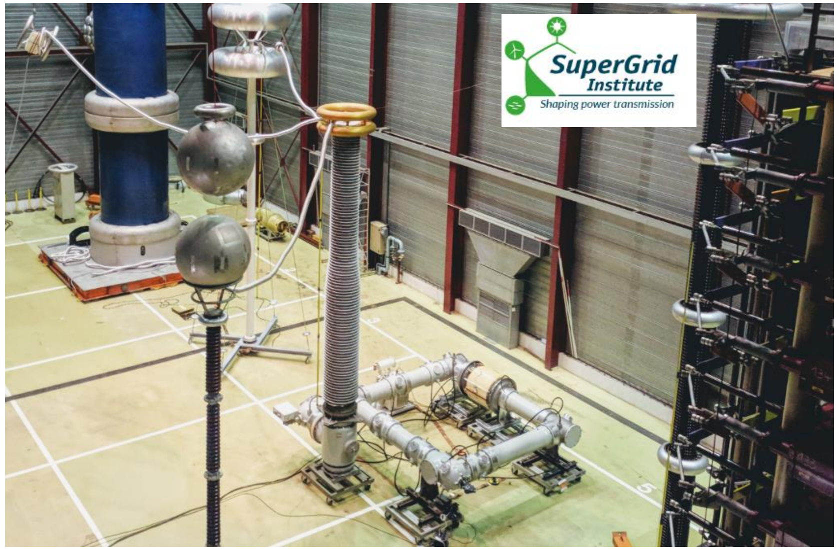
SuperGrid Institute, 27 February 2020

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691714.

- Introduction about HVDC GIS, SF_6 alternative gases and PD measuring sytems
- PD behavior under HVDC
- Effectiveness of PD monitoring systems
- Conclusion & summary

HVDC GIS: current status

- HVAC GIS filled with SF_6 showed very good performance and reliability over time (more than 40 years)
- HVDC GIS filled with SF_6 showed good performance



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SF_6 gas: advantages and disadvantages

- SF_6 is very good dielectric gas
  - High dielectric strength
  - High arc quenching capability
- SF_6 presents very high GWP (23500 times higher than CO_2)

SF_6 should be replaced by new gas with

- At least equivalent dielectric strength
- Equivalent arc quenching capability
- Lower GWP

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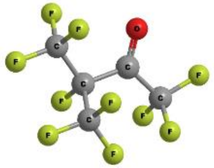
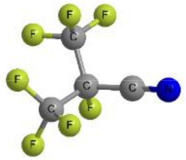
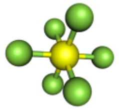
SF_6 alternative gases







Property (at 25°C)	Novec 5110	Novec 4710	SF_6
Molecular Weight (g/mol)	266	195	146
Flash Point (°F)	nonflammable	nonflammable	nonflammable
Boiling Point (°F)	80.4	23.5	-90.9*
Freezing Point (°F)	-166	-180	-59.3
Gas Density at 14.5 psi (lb/ft^3)	0.67	0.49	0.37
Dielectric Strength at 14.5 psi (kV)	18.4 at sat'n	27.5	14.0
Vapor Pressure (psia)	13.6	36.5	312
Atmospheric Lifetime (years)	0.04	30	3200
Global Warming Potential (100-yr ITH, IPCC 2013 method)	< 1	2100	23500
Ozone Depletion Potential (CFC-11 = 1)	0	0	0

SF_6 alternative gases: Lower GWP and higher dielectric strength
Higher boiling point ➔ need to be mixed with buffer gas

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Studied gases

- Different gas mixtures were studied
- Comparison between gases with **equivalent SF_6 dielectric strength**

Gas	Pressure (kPa)		
SF_6	500		
10% FN-CO_2	Novec™4710	CO_2	mixture
	65	585	650
4% FN-CO_2	32	768	800
6.6% FK-Air	Novec™5110	Dry air	mixture
	50	700	750

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HVDC monitoring and diagnostic method

- **Partial discharge (PD)**
  - A localized breakdown
  - A current pulse with fast rise time (range of ns – depending on insulating medium)
- **An effective PD monitoring system allows to**
  - Detect the presence of defects inside GIS (factory acceptance tests, on-site tests)
  - Recognize the kind of defect
  - Prevent a flashover via online monitoring
  - Optimize the maintenance plan
- **Main questions for HVDC GIS**
  - Type of measurements / sensors
  - Number / Position of sensors
  - Correlation AC and DC
  - Defect recognition
  - PD characteristics of SF_6 substitute gases

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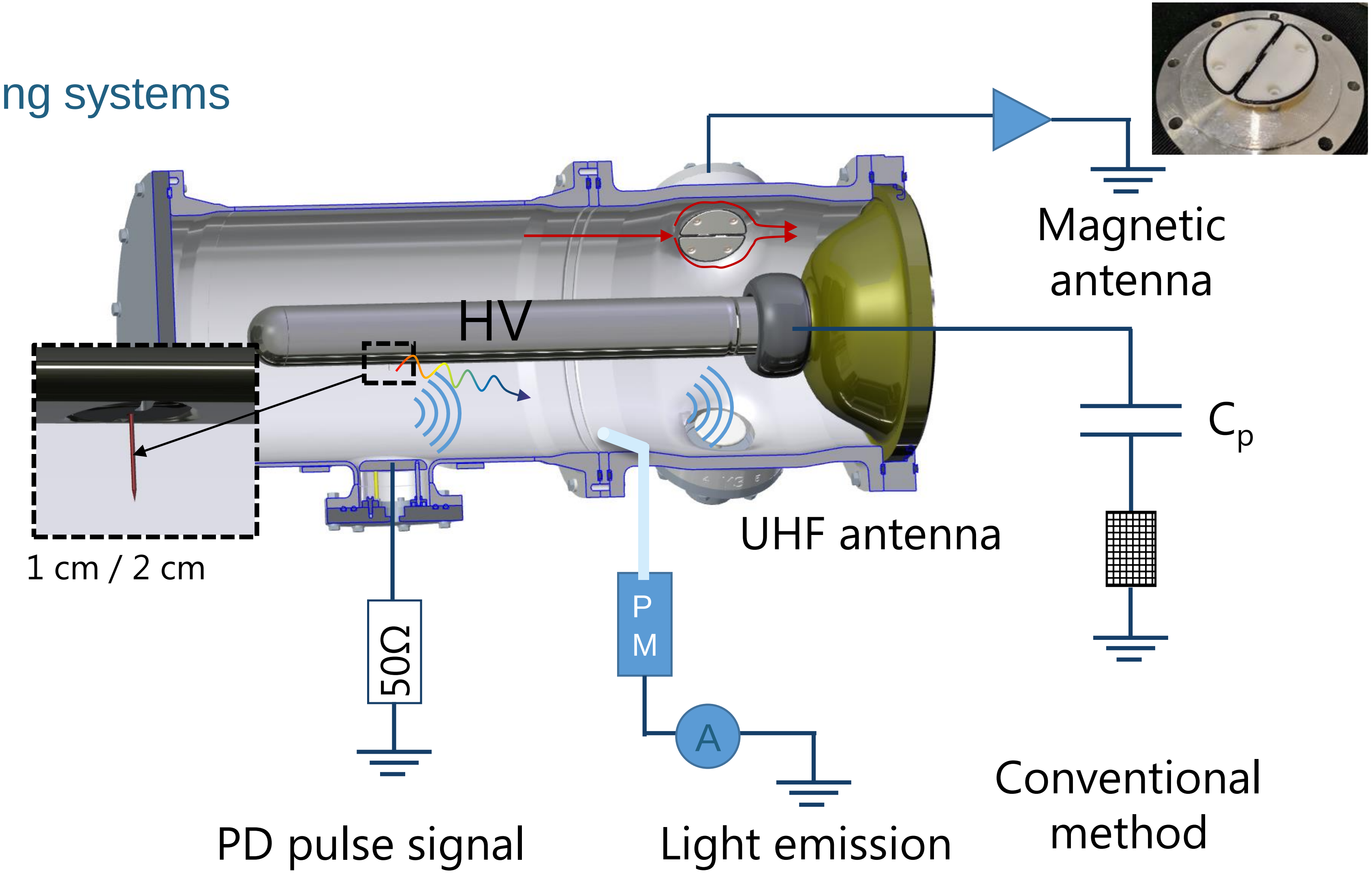
Partial discharge measurement

- Measuring systems



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PD behavior under HVDC

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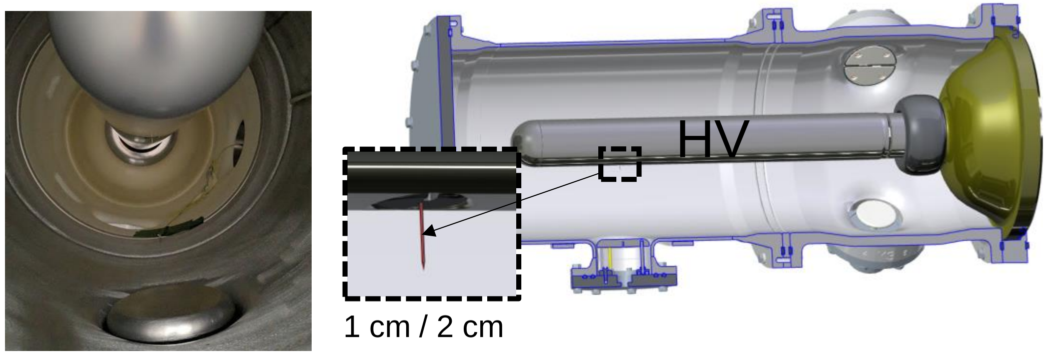
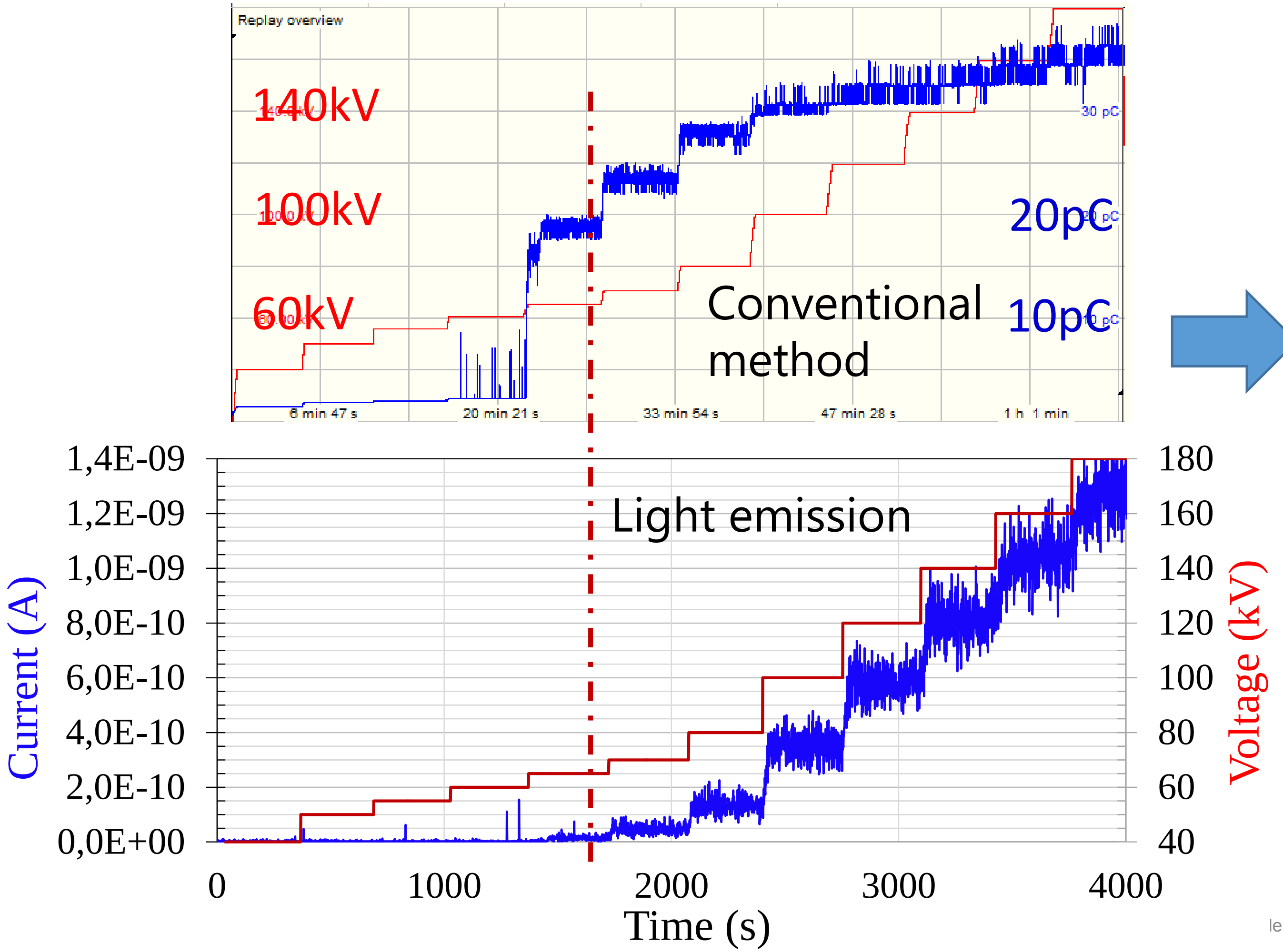
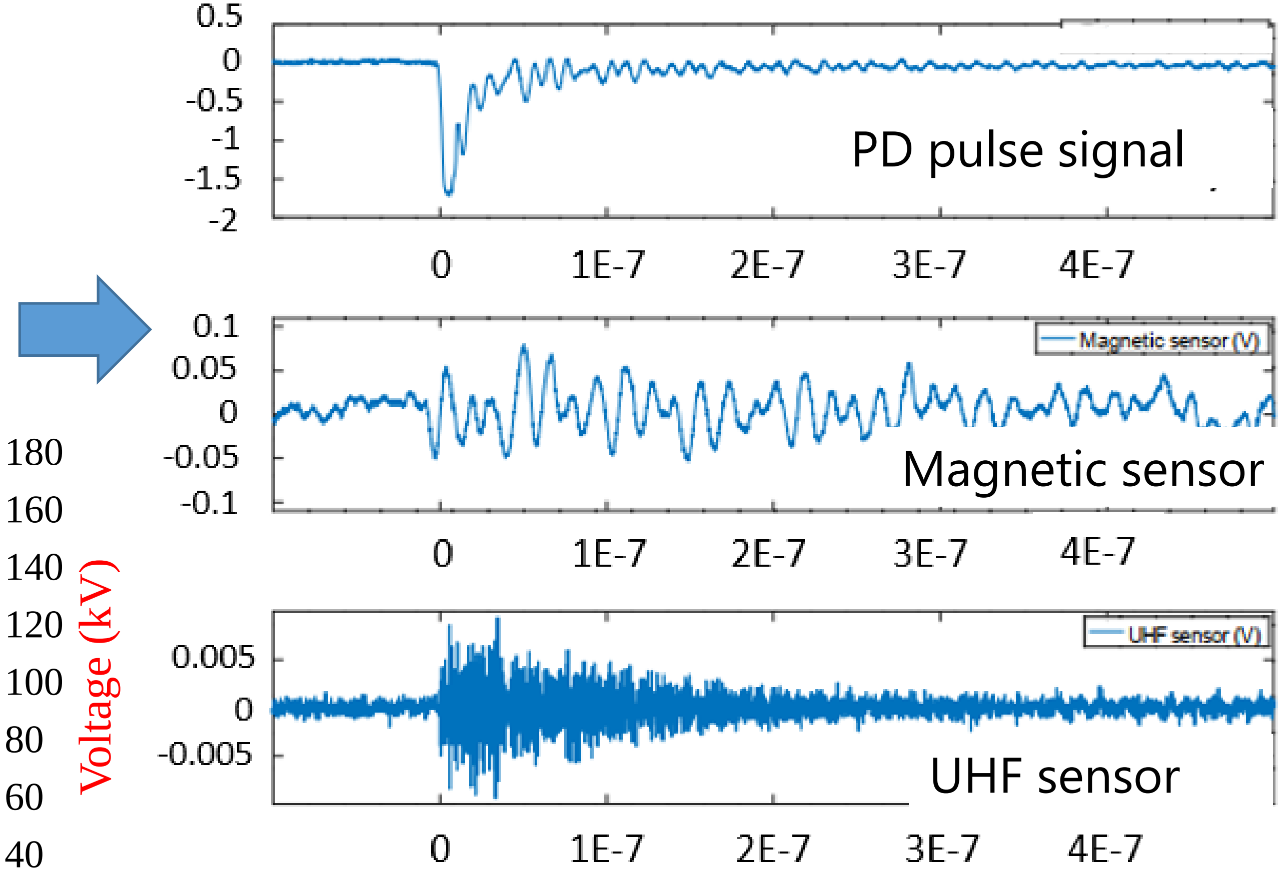
Example of PD signals

PD signal can be detected by different measuring systems







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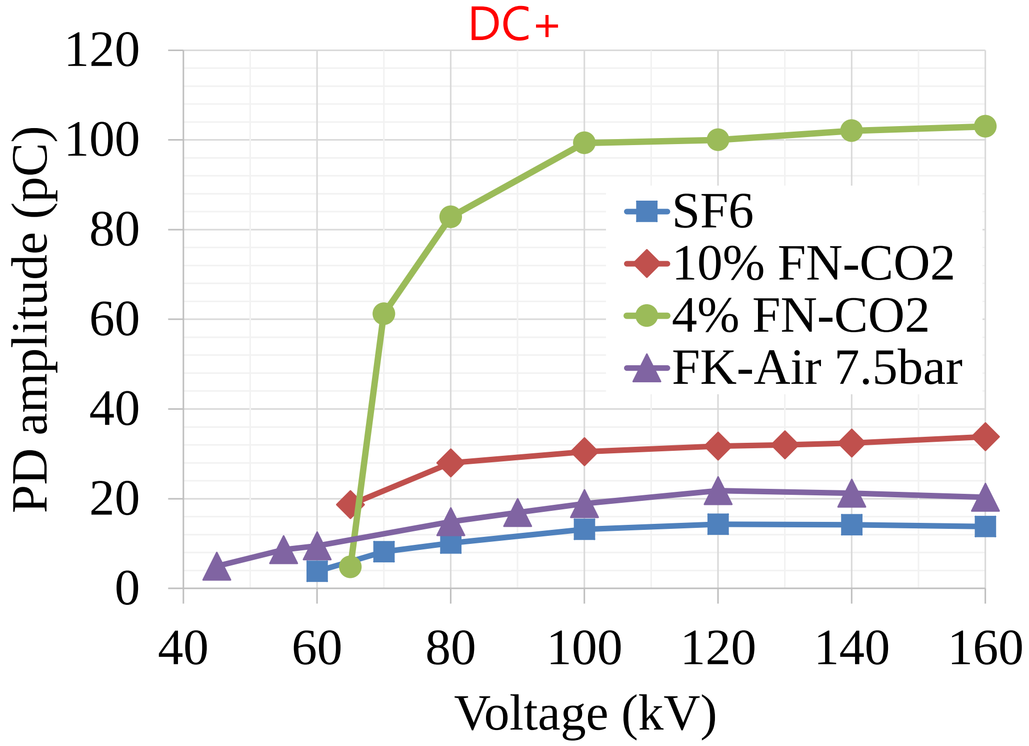
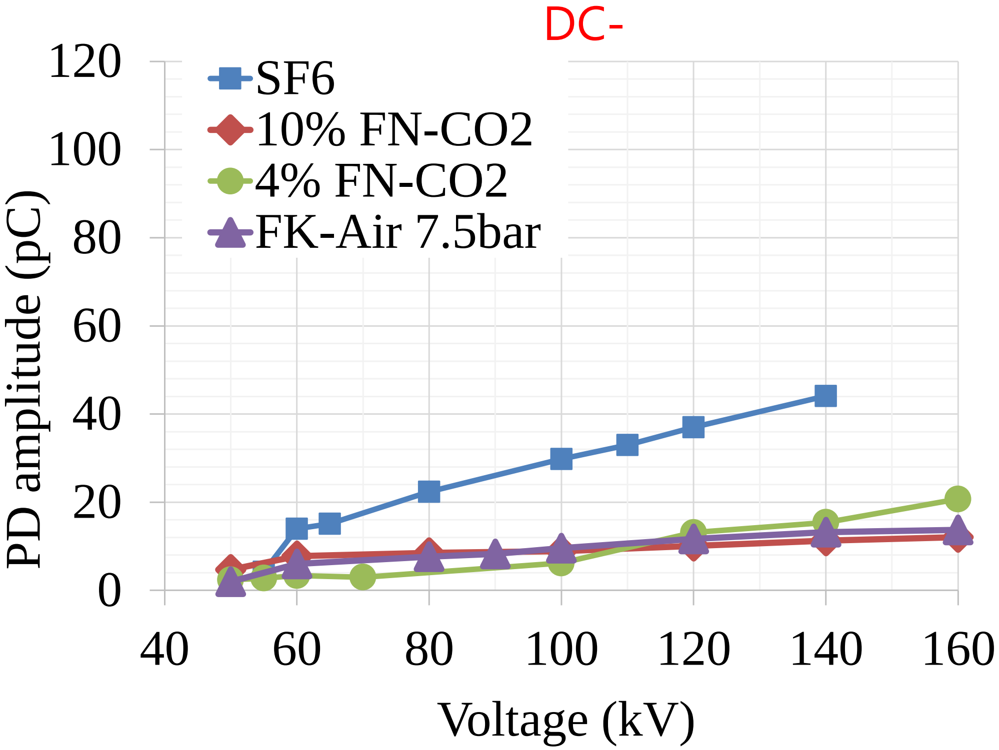
Gas comparison – PD behavior

- PD amplitude





Highest PD amplitude observed in positive polarity for alternative gases while it is observed in negative polarity for SF_6

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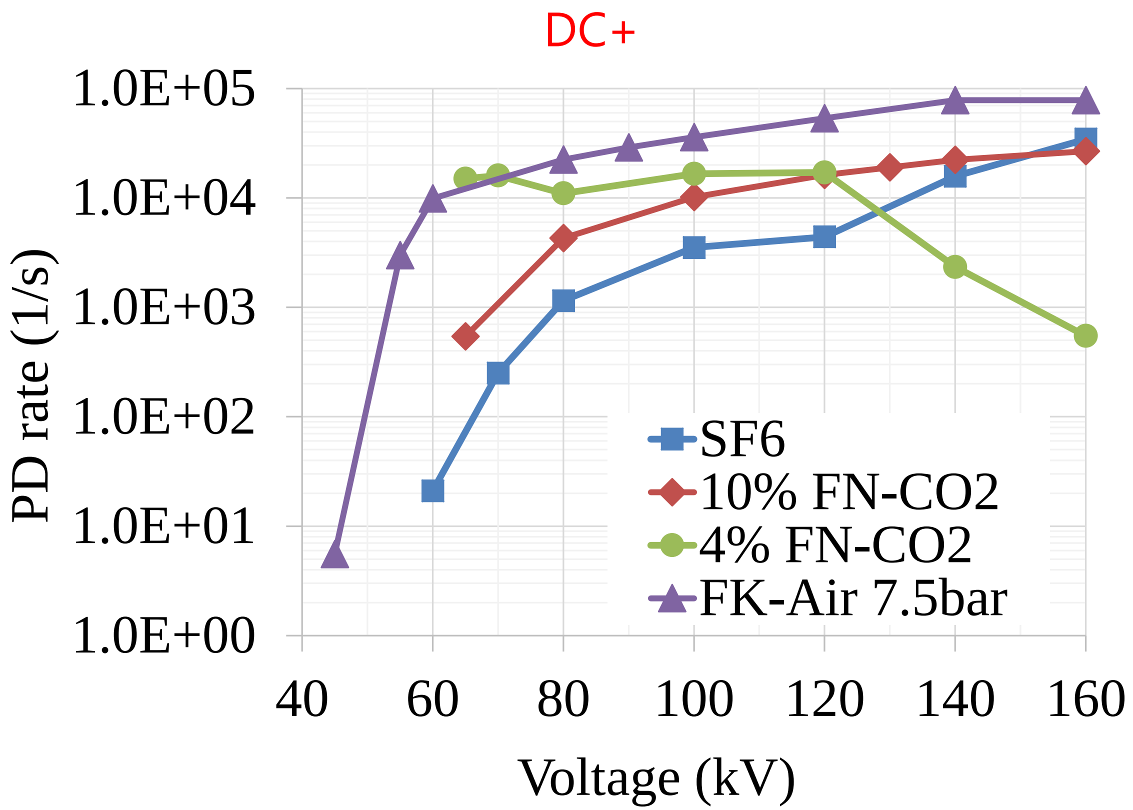
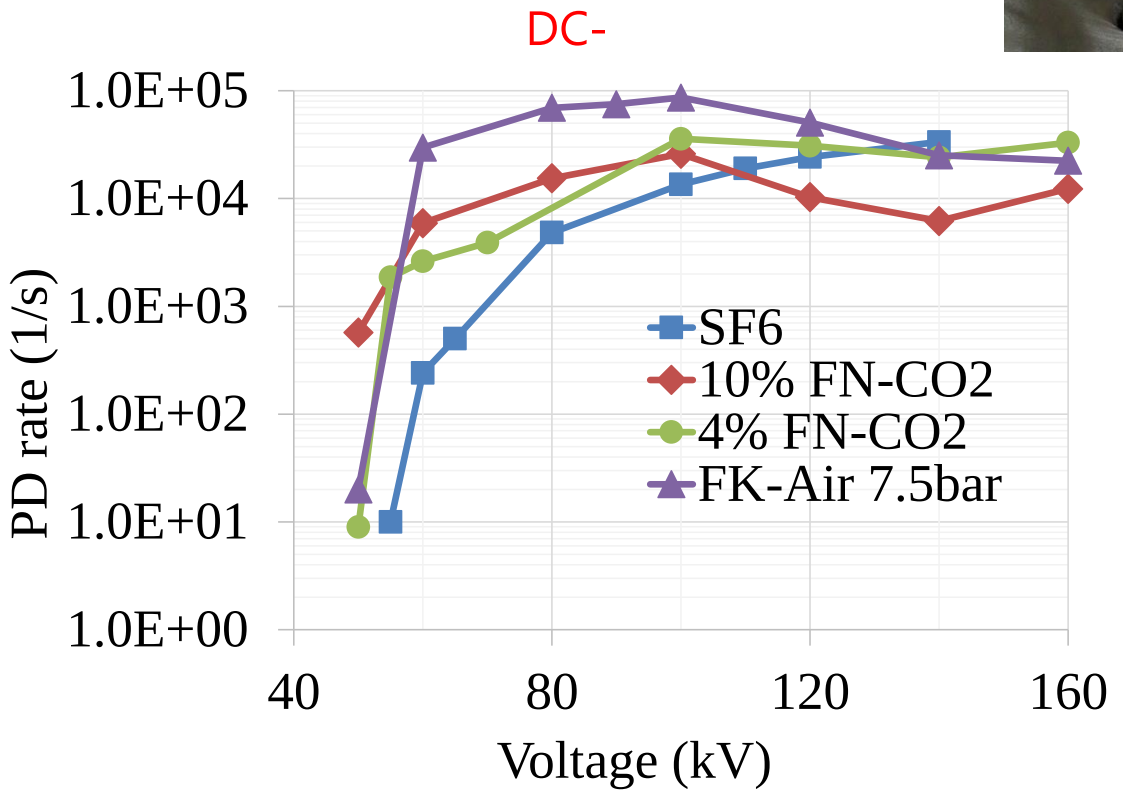
Gas comparison – PD behavior

- PD repetition frequency





SF_6 alternative gases showed higher PD repetition frequency than SF_6

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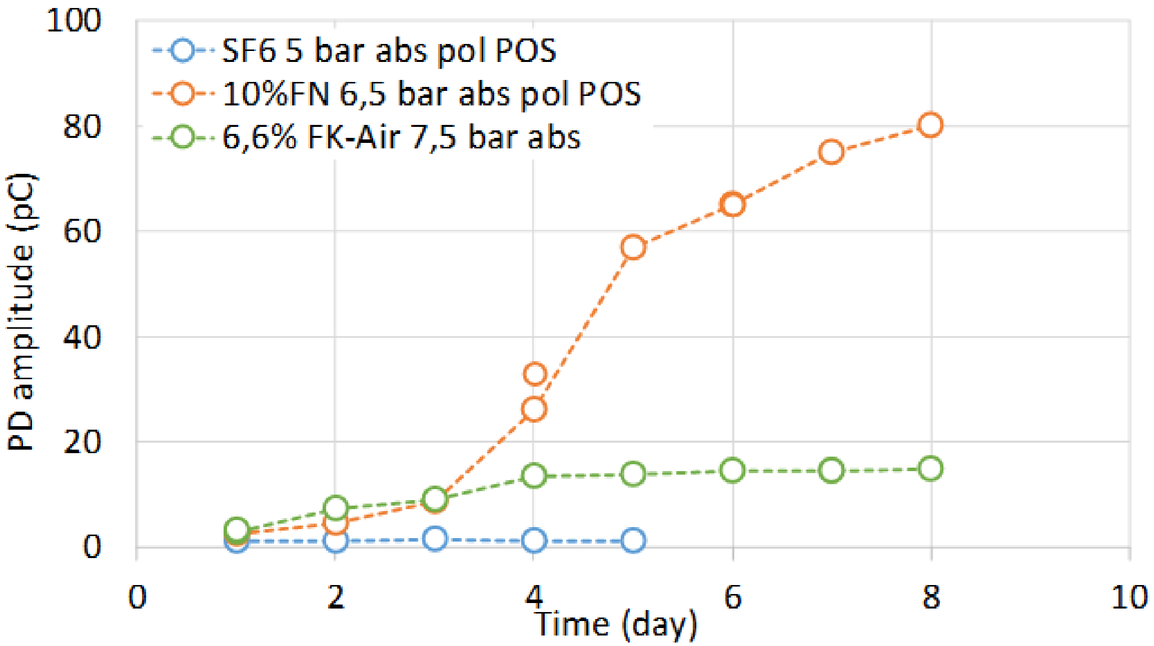
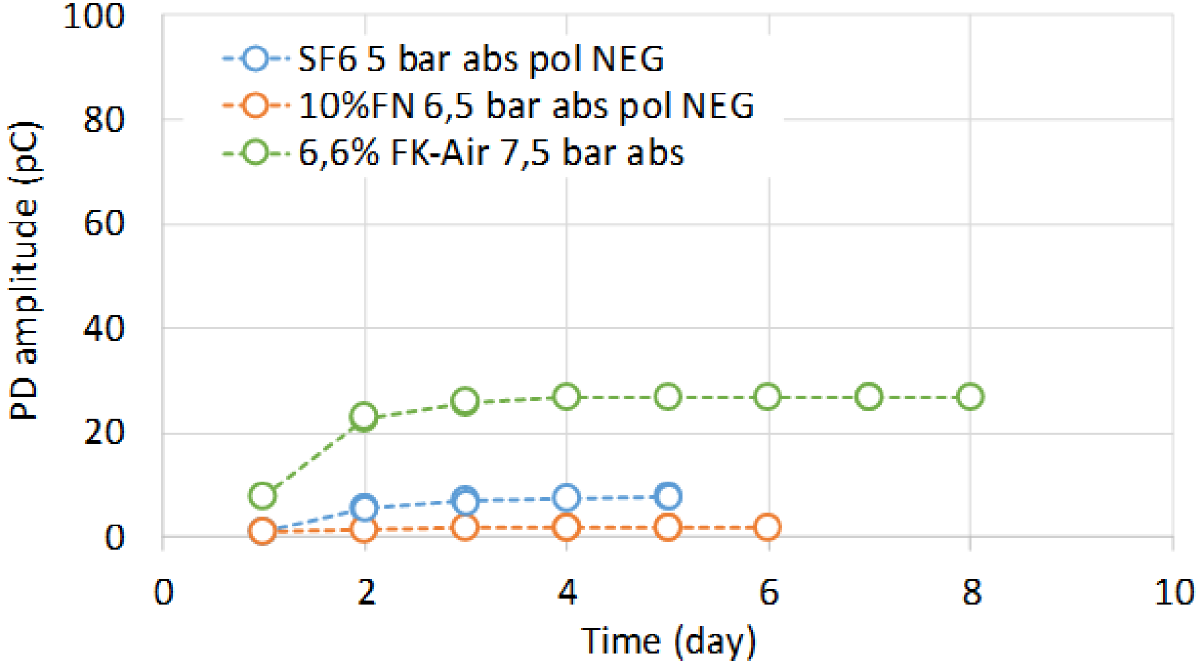
Gas comparison: evolution of PD behavior in function of time

- PD amplitude

DC+



DC-



PD amplitude increases with time before reaching a steady state

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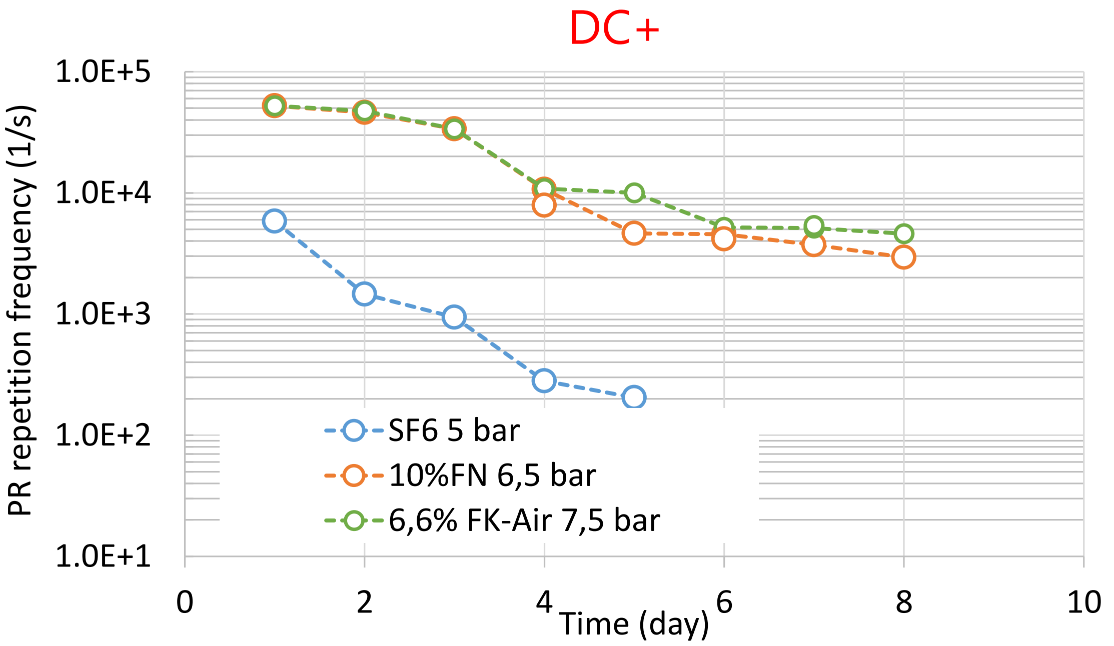
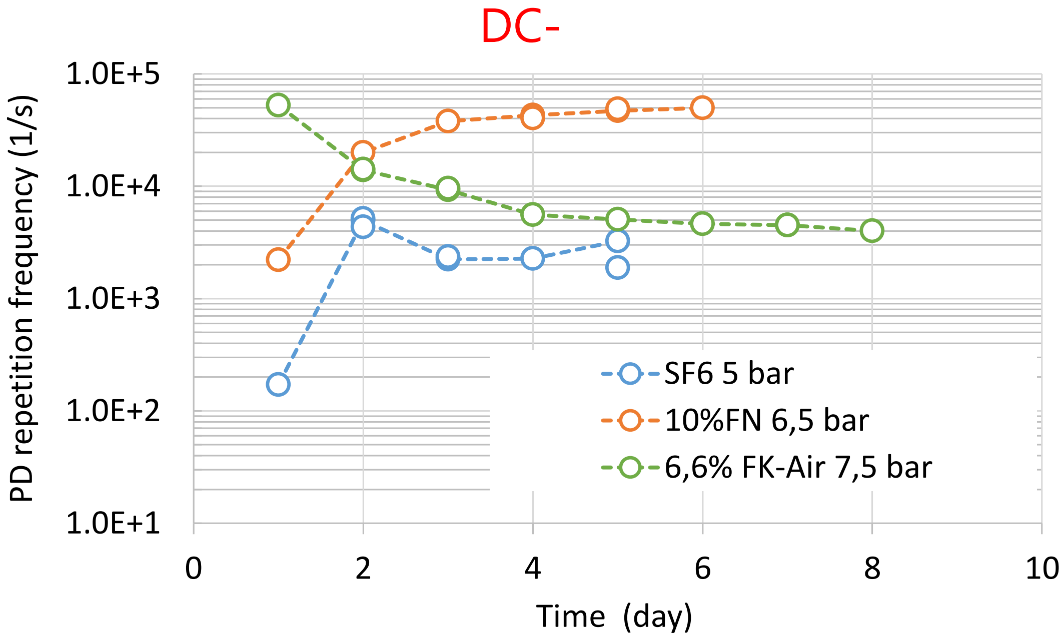
Gas comparison: evolution of PD behavior in function of time

- PD repetition frequency





Higher PD repetition frequency for alternative gases compared to SF_6

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Conclusion & summary

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Conclusion & summary

- SF_6 alternative gases compared to SF_6
  - Higher PD amplitude in positive polarity while it is observed in negative polarity for SF_6
  - High pulse repetition rate
  - Similarly to SF_6, PD amplitude increases and repetition rate decreases with time of application of DC voltage.
- PD behavior of alternative gases is comparable to SF_6. Those results have to be confirmed with other defects

On DC GIS the replacement of SF_6 by SF_6 substitutes is not an obstacle for effective PD monitoring systems

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APPENDIX

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