PROMOTioN PROJECT
NOVEL SWITCHGEAR FOR FUTURE MULTI-TERMINAL HVDC GRIDS

DEVELOPMENT AND PERFORMANCE DEMONSTRATION OF HVDC GAS INSULATED SWITCHGEAR

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

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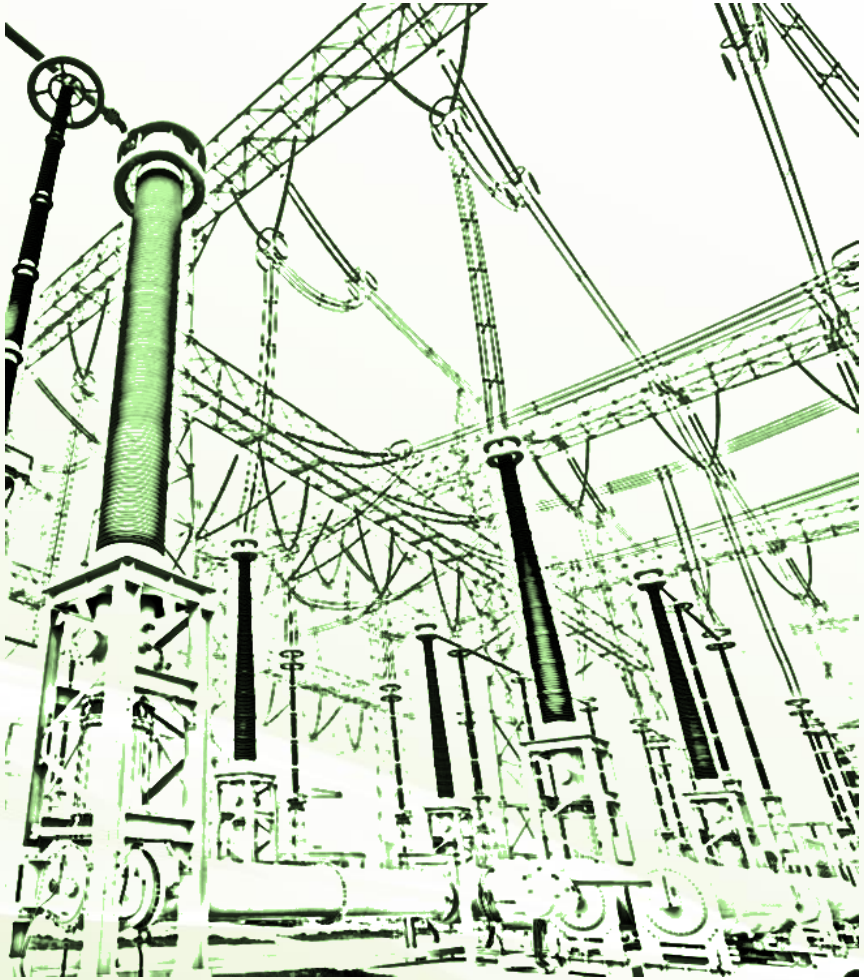
ABB Switzerland Ltd

What you can expect?

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS



- **Introduction**
  - GIS & HVDC
- **HVDC Gas-Insulated Systems**
  - Design
  - Components
  - Testing
  - Verification of test values
- **PROMOTioN GIS Demonstrator**
  - Work Package
  - GIS Demonstrator
  - Diagnostics & Alternative Insulating Gases
- **Conclusions & Summary**

20 Years HVDC GIS

First 150 kV GIS Gotland 2

First long-term test BPA (USA)-ABB

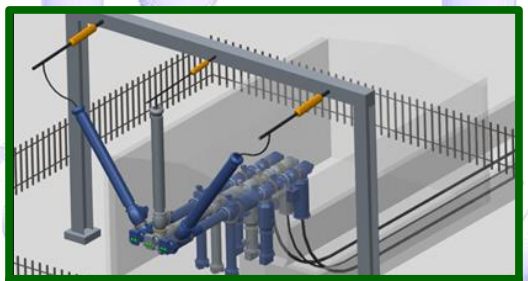
First 250 (500) kV GIS KII – link (Japan)

New generation (DE)

First research

150 kV GIS Gotland 3

First long-term test (Japan)



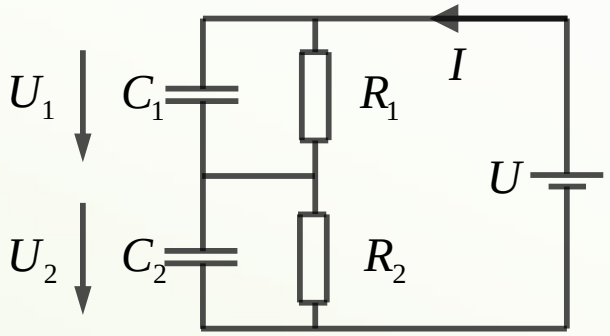
New generation (CH)

New generation (Japan)

1980 1983 1987 1990 1995 2000 2013 2014 2018

AC DC: Electrical Field

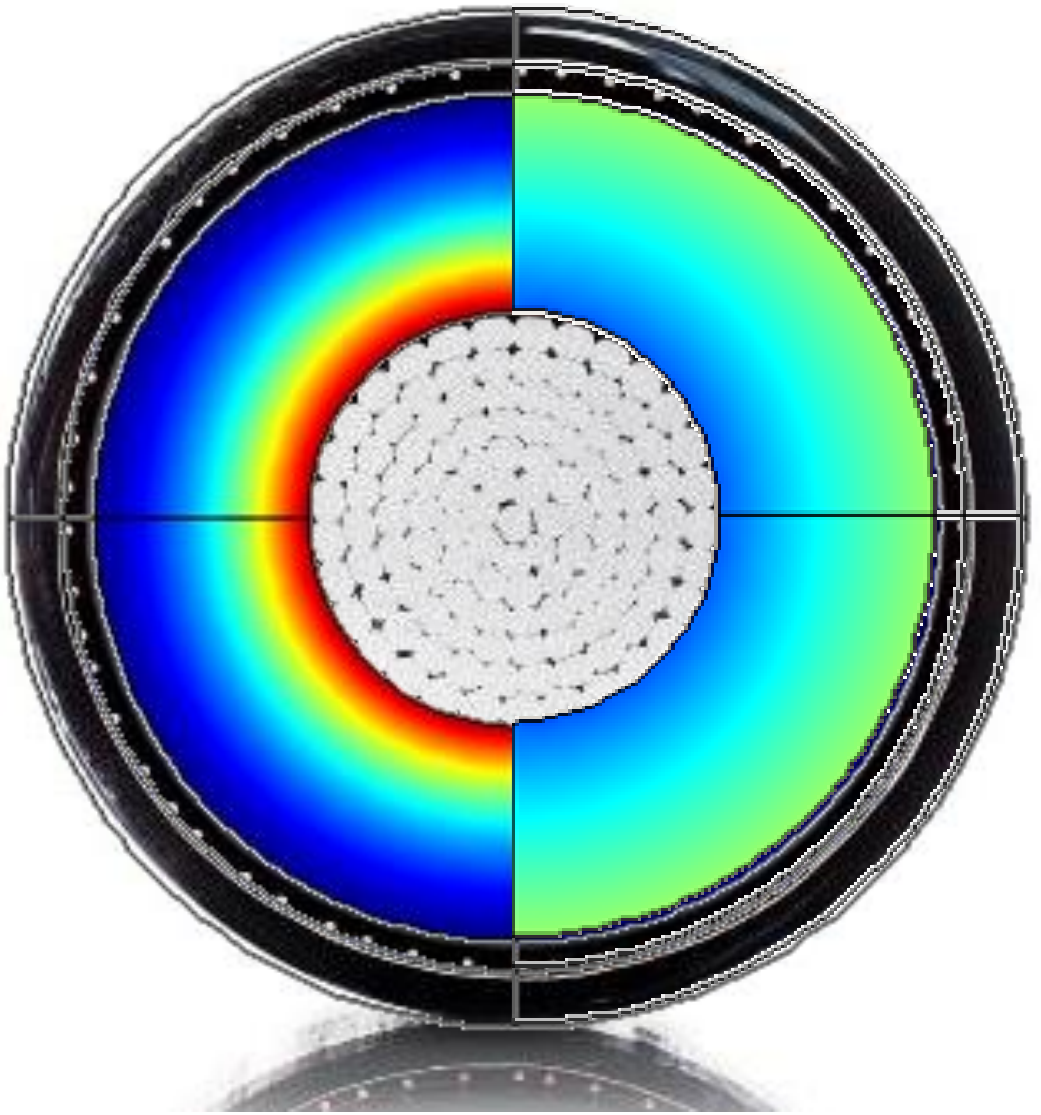
Basics - Cable



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

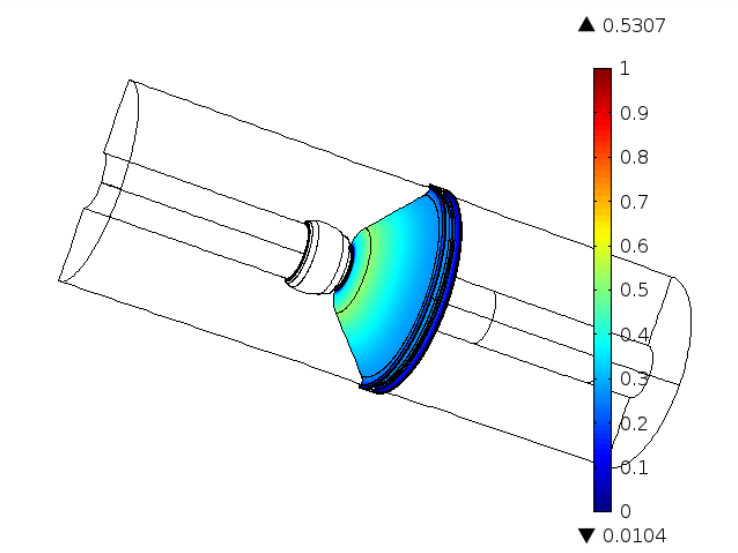
$$\tau = RC = \frac{\varepsilon_0 \varepsilon_r}{\sigma}$$

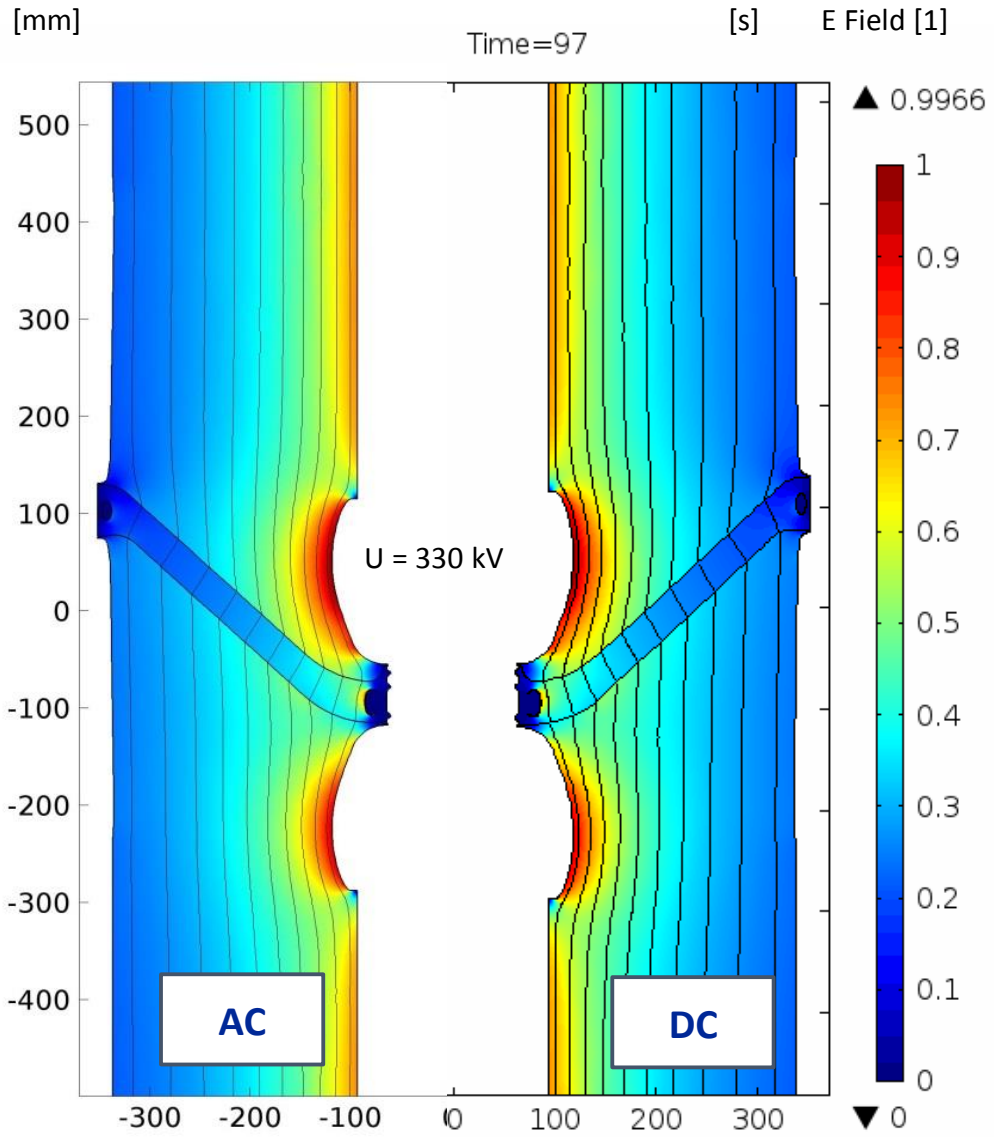
$t = 0$ ("AC") $\quad t \to \infty$ ("DC")



HVDC: Electrical Field

Basics GIS





HVDC Gas Insulated Systems

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%.

Components

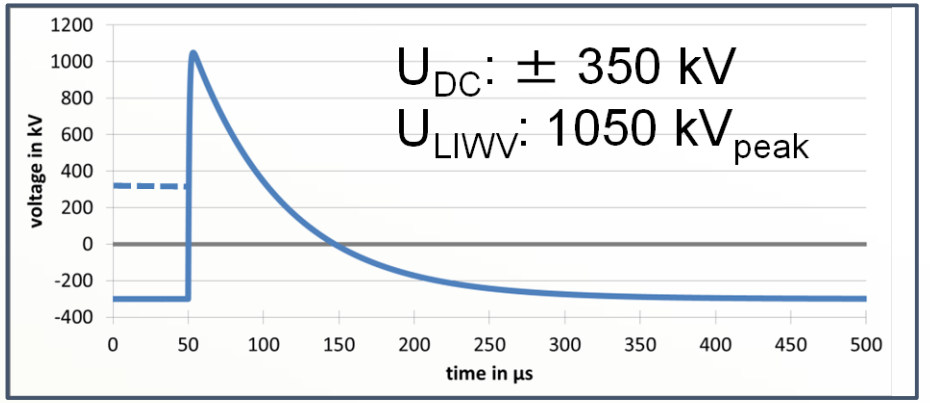
The HVDC-GIS technology spans a number of switchgear components, e.g.:

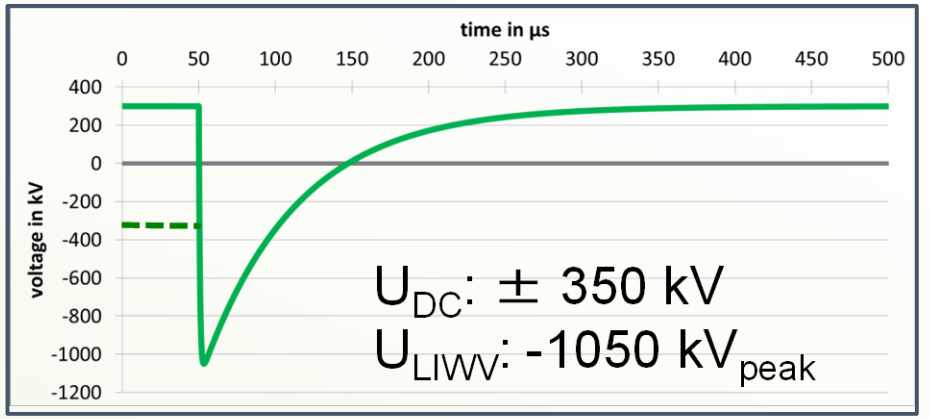
- Bus-ducts and high voltage DC conductors
- Disconnect- and earthing switches
- Bushings and cable terminations
- Current- and voltage measurement sensors
- Surge arresters

Testing

Dielectric Tests

- DC withstand voltage tests
- LIWV tests
- SIWV tests
- Superimposed LIWV tests (bipolar and unipolar superposition)
- Superimposed SIWV tests (bipolar and unipolar superposition)
- Polarity reversal tests (only required for Line Commutated Converters [LCC])
- All dielectric tests: under high load (HL) and zero load (ZL) conditions
- Partial Discharge (PD) measurements AC and DC





JWG D1/B3.57: Dielectric Testing of Gas-Insulated HVDC Systems

IEC 62271-2XX-1 DC Common Specification for Assemblies
IEC 62271-2XX-2 DC GIS
IEC 62271-2XX-3 DC GIL

Testing

Dielectric Tests

- DC withstand voltage tests
- LIWV tests
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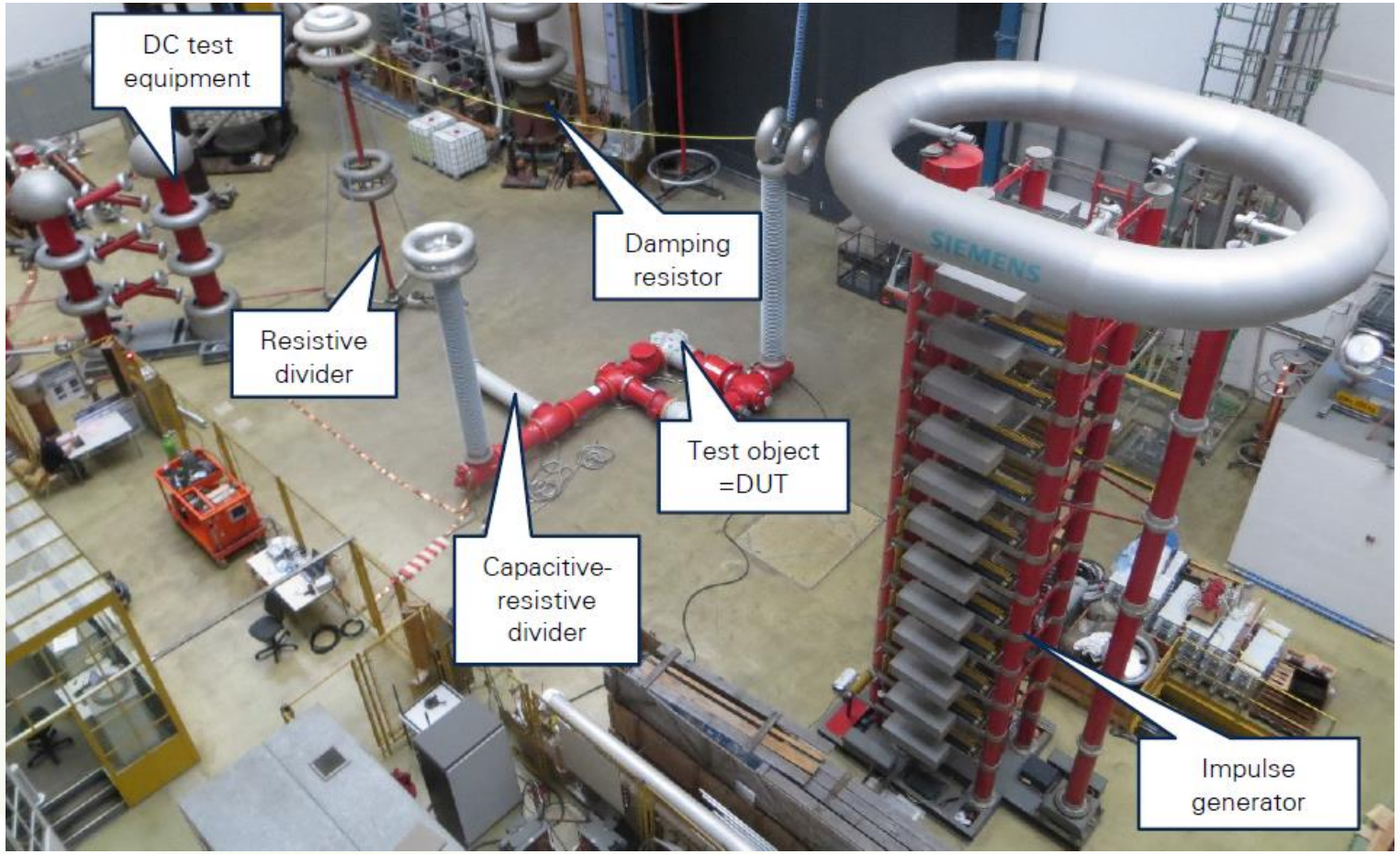
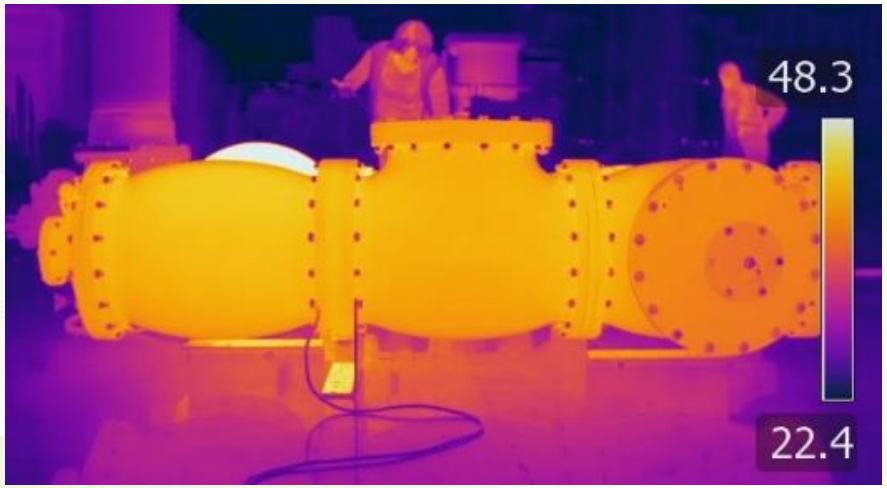
- All dielectric tests: under high load (HL) and zero load (ZL) conditions
- Partial Discharge (PD) measurements AC and DC
- **DC insulation system test**



DC Insulation System Test



Test	Conditions	Load	
Pre-tests	Heating Dielectric Pretests		
Long duration continuous DC voltage test	**Maximum continuous operating DC voltage (-)**	**HL**	**Time duration d**
Superimposed LIWV tests (bipolar and unipolar superposition) Superimposed SIWV tests (bipolar and unipolar superposition)	Rated values	HL	
Polarity reversal		HL	
Long duration continuous DC voltage test	**Maximum continuous operating DC voltage (+)**	**HL**	**Time duration d**
Superimposed LIWV tests (bipolar and unipolar superposition) Superimposed SIWV tests (bipolar and unipolar superposition)	Rated values	HL	

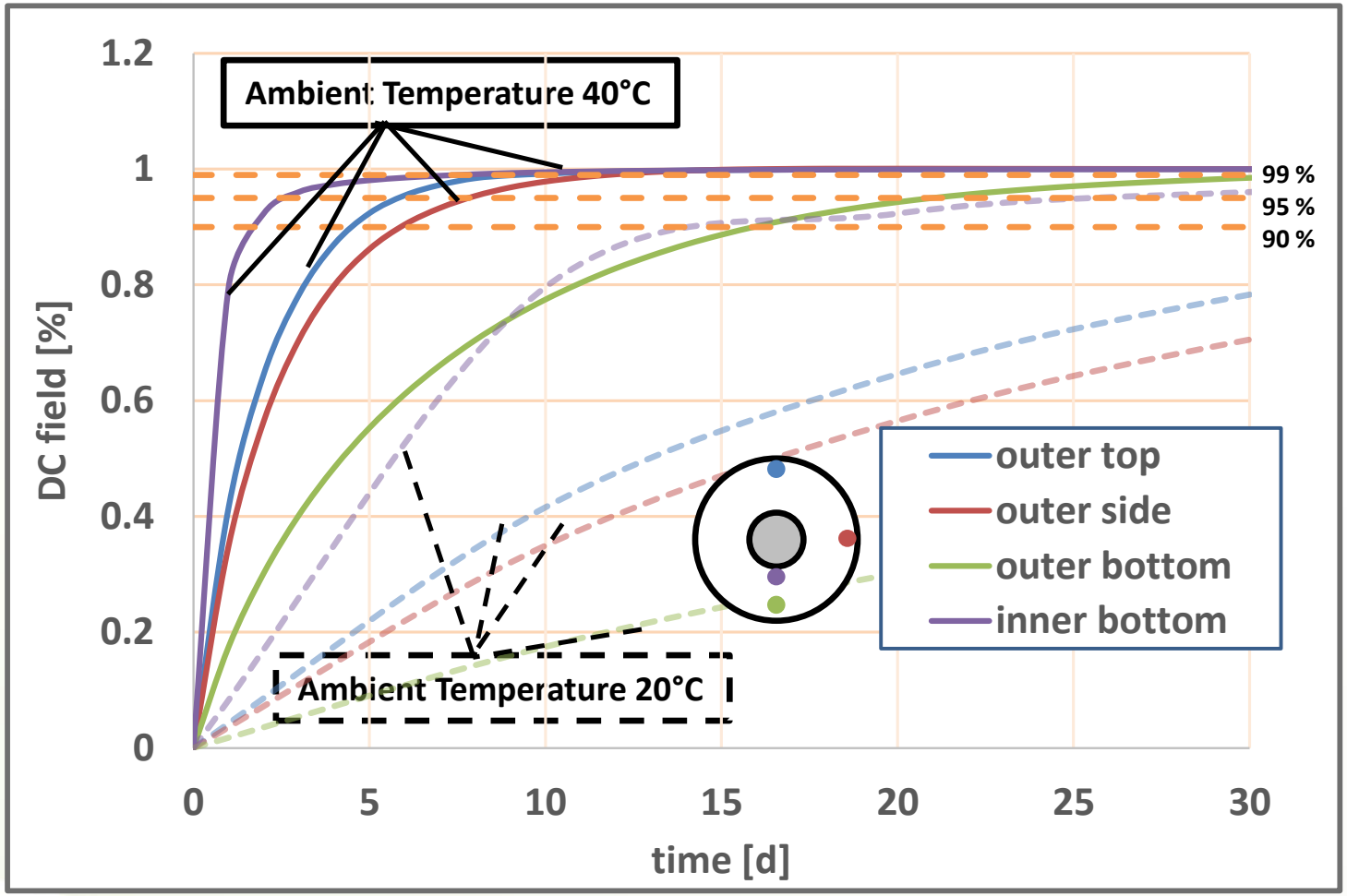
DC Insulation System Test

Tests

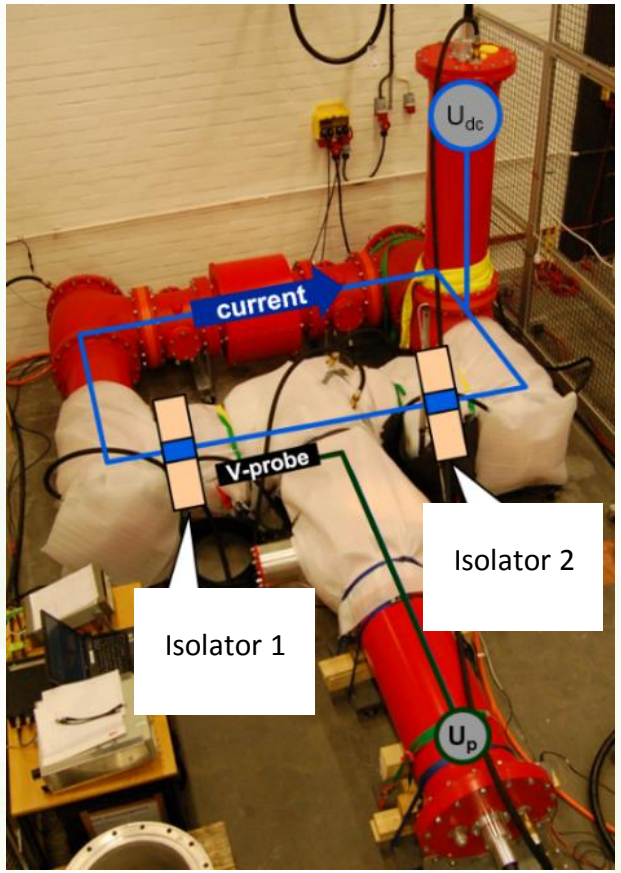
Transition time from capacitive to resistive field conditions

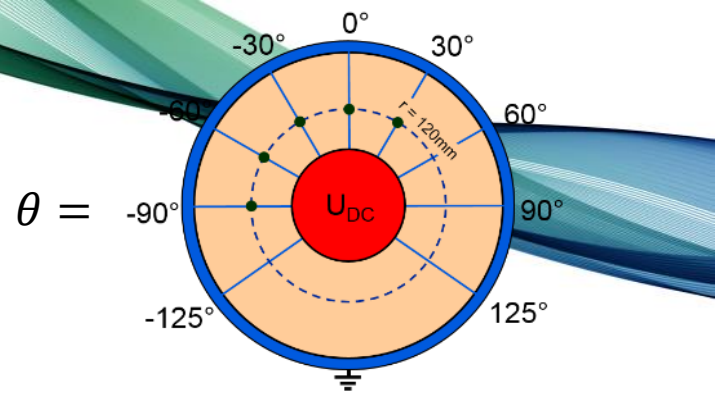
$\tau_m = \varepsilon_0 \varepsilon_r / \sigma$ DC conductivity σ = 10^{-14} to 10^{-17} S/m

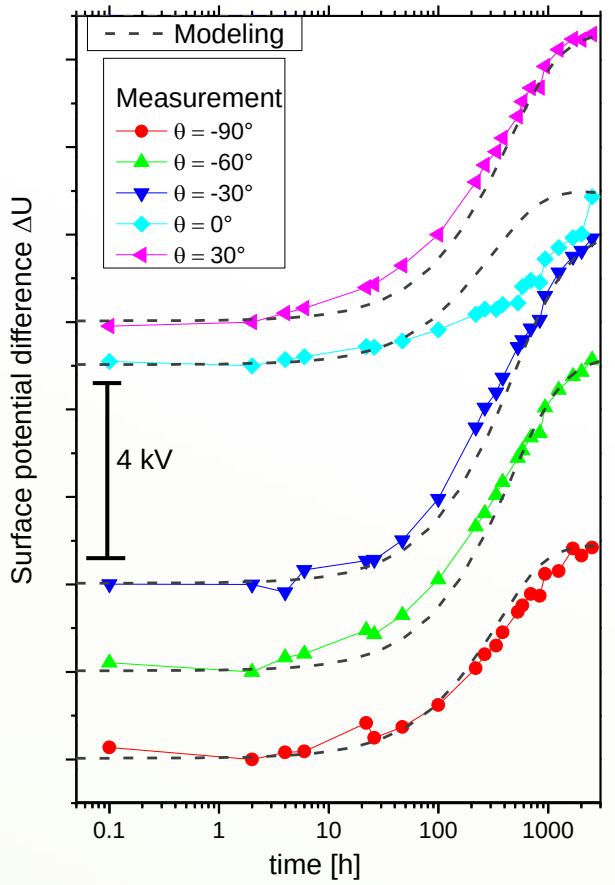
Duration *d*: 30 days, to obtain at least **90 %** of the DC steady field condition at higher temperatures.



DC Insulation System Test







Main objectives (WP15)

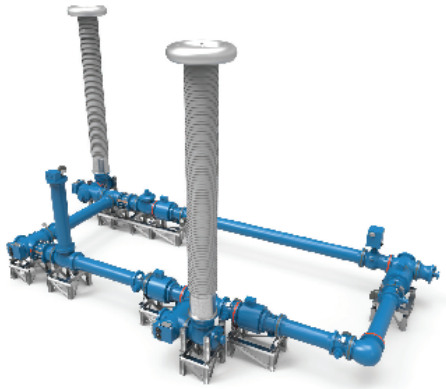
Full scale technology demonstrations of HVDC gas insulated systems

- To increase the **Technology Readiness Level (TRL) from 6 to 8** for HVDC GIS equipment
- 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 **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 CIGRE work (JWG D1/B3.57: Dielectric Testing of Gas-Insulated HVDC Systems).
- 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.**

Prototype installation test

HIGH VOLTAGE PRODUCTS

HVDC gas-insulated switchgear



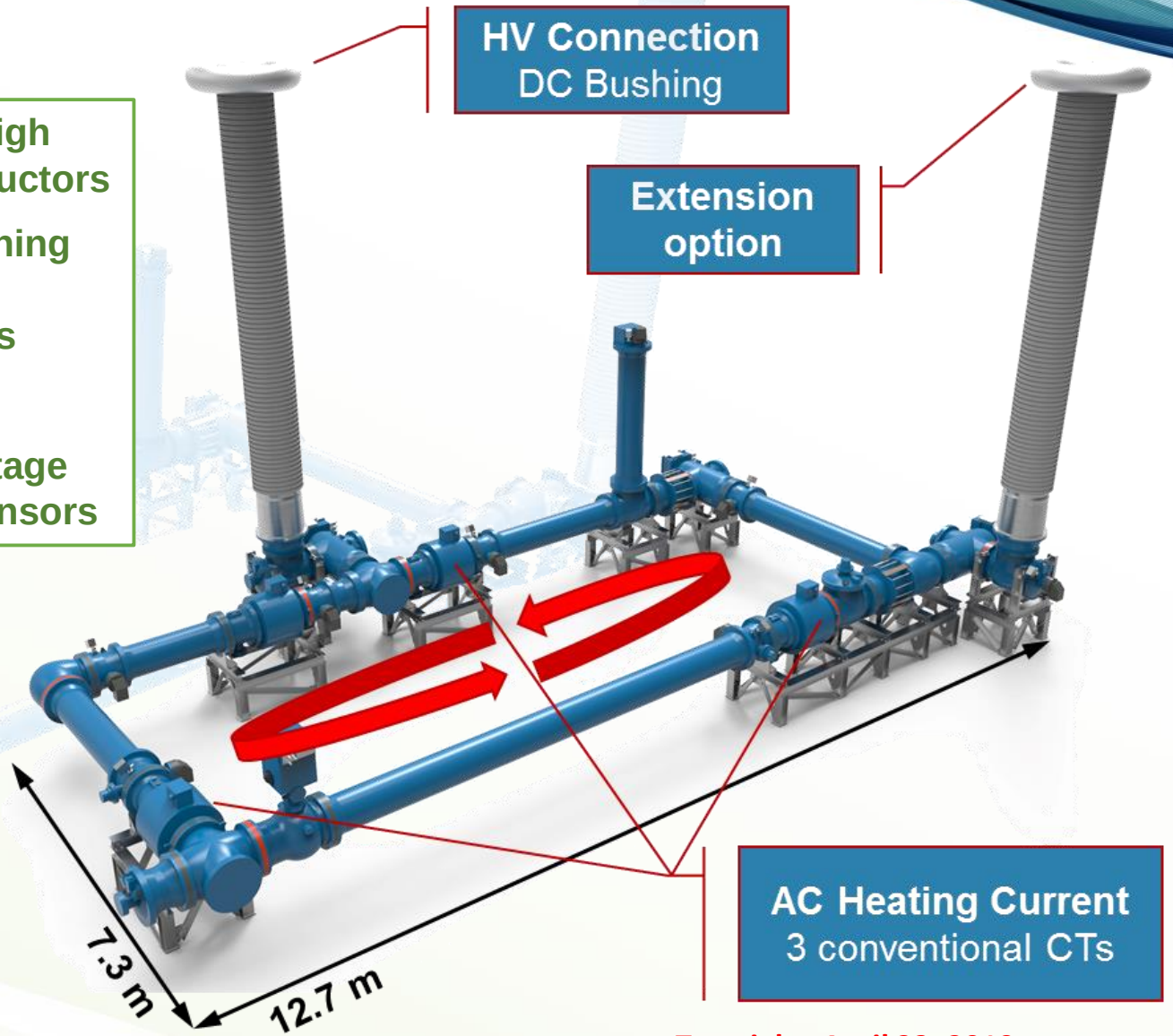
Technical data		
Nominal DC voltage	kV	320
Rated DC voltage	kV	350
Rated lightning impulse withstand voltage	kV	1050
Rated switching impulse withstand voltage	kV	950
Rated DC withstand voltage	kV	610
Rated normal current	A	4000
Rated short-time withstand current	kA	64
Rated duration of short circuit	s	1
Rated peak withstand current	kA	160
Ambient temperature range	°C	-30...+40

Bus-ducts and high voltage DC conductors

Disconnect, earthing and fast acting earthing switches

Bushings

Current- and voltage measurement sensors



HVDC GIS demonstrator – Test values

Demonstrator	Value	Unit
Pre-Tests Thermal calibration, Commissioning tests, PD, LI, SI		
Long-term test cycles with DC	± 1.2 High Load (HL) (AC equivalent)	pu
Superimposed LI / SI withstand voltage	on-site test values ± 0.8 (rated value)	pu
Long-term test cycles with DC	± 1.2 Zero Load (ZL)	pu
Superimposed LI / SI withstand voltage	on-site test values ± 0.8 (rated value)	pu
Final verification tests & additional tests		

HVDC GIS prototype installation test procedure

Pre-Tests	BLOCK 1 60 days -DC ZL SIM LI/SI 10 C/O	2 -DC HL SIM C/O	3 +DC ZL SIM C/O	4 +DC HL SIM C/O	AC PD	5 -DC HL SIM C/O	BLOCK 6 60 days +DC HL SIM LI/SI 10 C/O	BLOCK 7 30 days LC (+ and -) SIM LI/SI	add. Tests

Jan. 2019 — 14 month — April. 2020

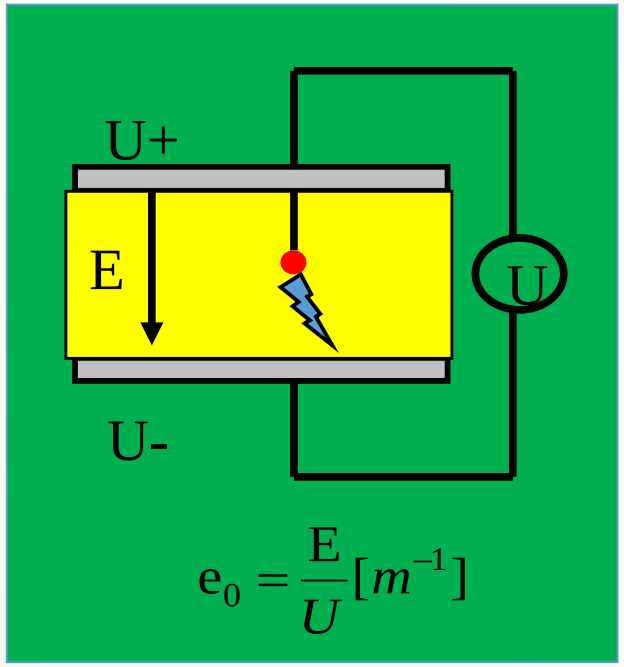
Monitoring
Gas density
PD: UHF/Optical/HFCT
Arc Detection
Enclosure Temperature

ZL = zero load (zero heating)
HL = high load (continuous heating)
LC = load cycle
SIM = Superimposed switching and lighting impulse voltage test
ACPD = AC partial discharge measurement at U_{ac}

Status

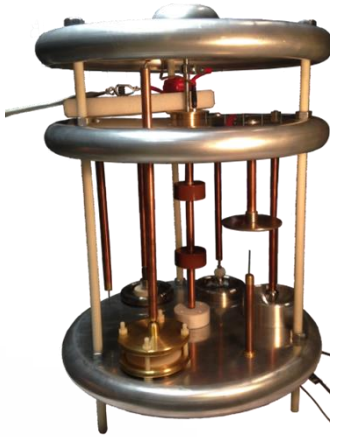
Step	Test	Conditions	Load	
1.	Thermal cycle pre-test	Heating up to steady state with I_{eqac} or I_r	LC / HL	
2.	AC PD measurement	Pre-stress at U_{acpre}; PD measurement at U_{acpd}.	ZL	
3.	DC PD measurement	Pre-stress at $\pm U_{dcpre}$; PD measurement with $\pm U_{dcpd}$.	ZL	
4.	Lightning impulse test	LI voltage U_{TP}	ZL	
5.	Switching impulse test	SI voltage U_{TS}	ZL	
6.	Superimposed LI test	Positive and negative rated DC voltage U_r and U_{TP}	ZL	
7.	Superimposed SI test	Positive and negative rated DC voltage U_r and U_{TS}	ZL	
8.	Polarity reversal test	Polarity reversal $\pm U_T$	ZL / HL	
9.	1. Cycle	$-U_T$, 60 days, SIM, 10 CO	ZL	
10.	2. Cycle	$-U_T$, 60 days	HL	

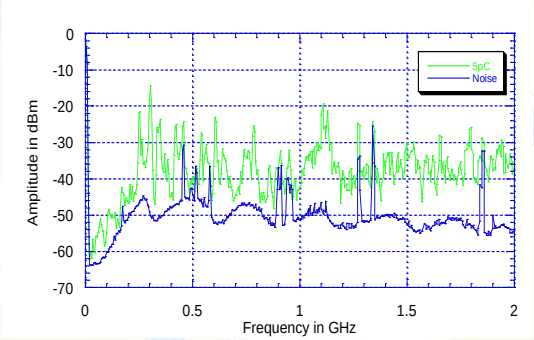
HVDC monitoring and diagnostic methods

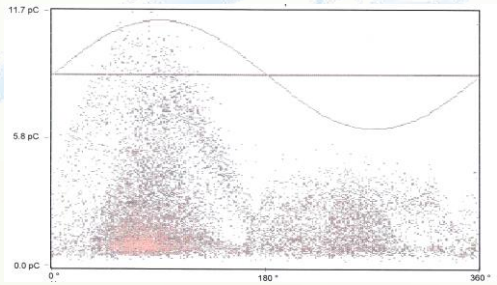


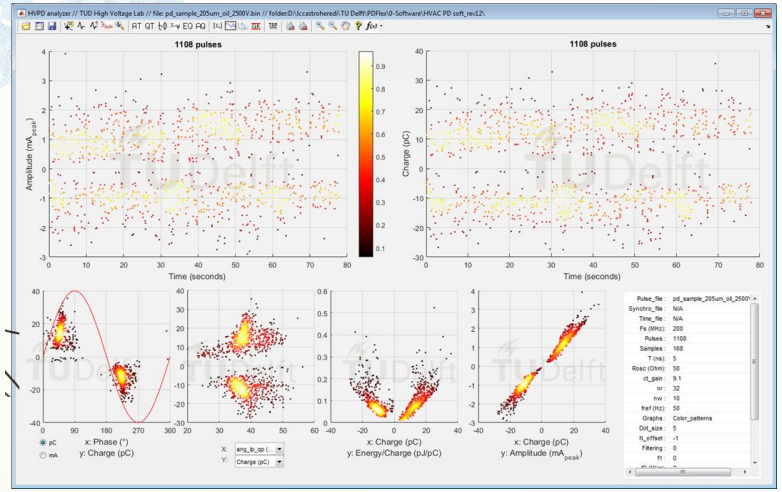
- A localized voltage breakdown in gas
- A current pulse with a very fast rise time <1 ns

- **Fundamental Questions**
  - Type of sensors (HFCT, Antennas)?
  - Correlation AC and DC?
  - Number and where to install sensors?
  - Which other parameters can be monitored?

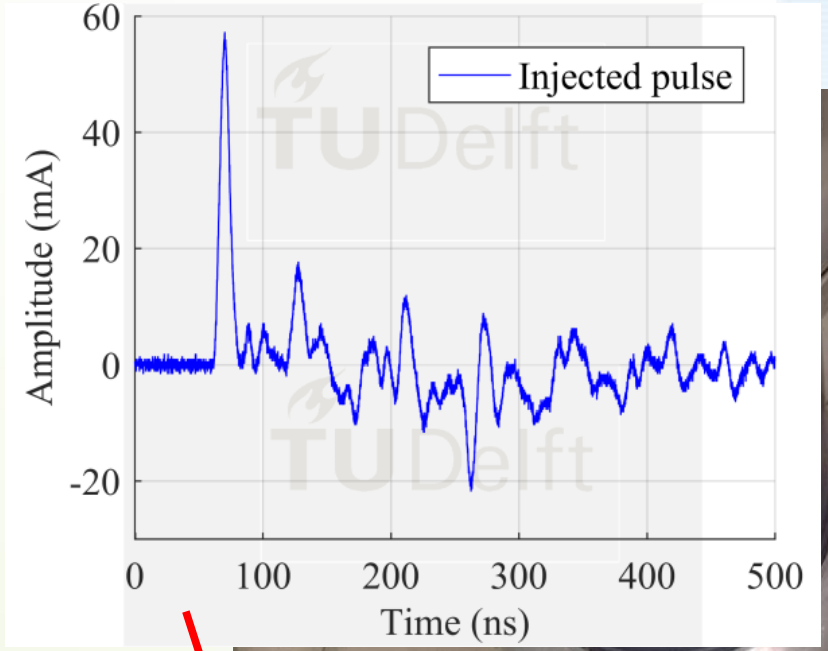


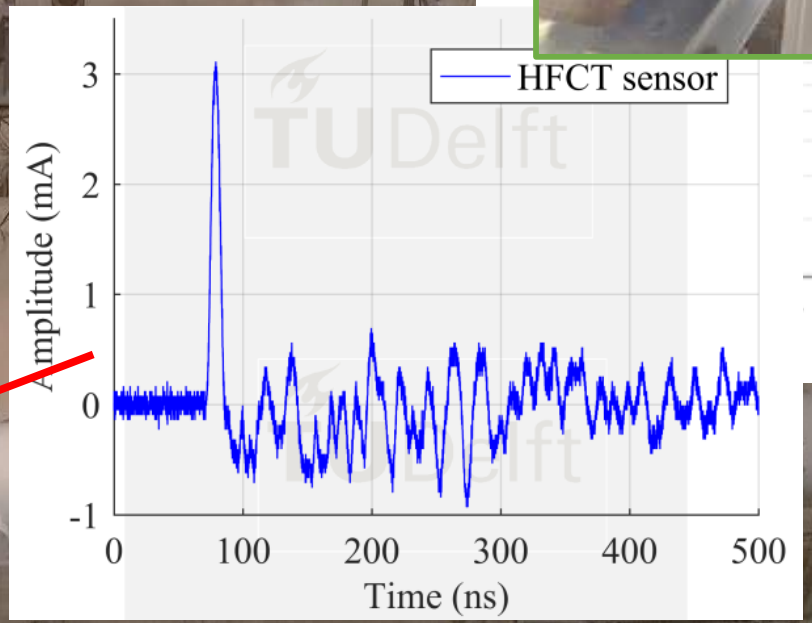


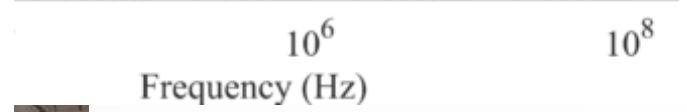




Development of M&D System based on HFCT



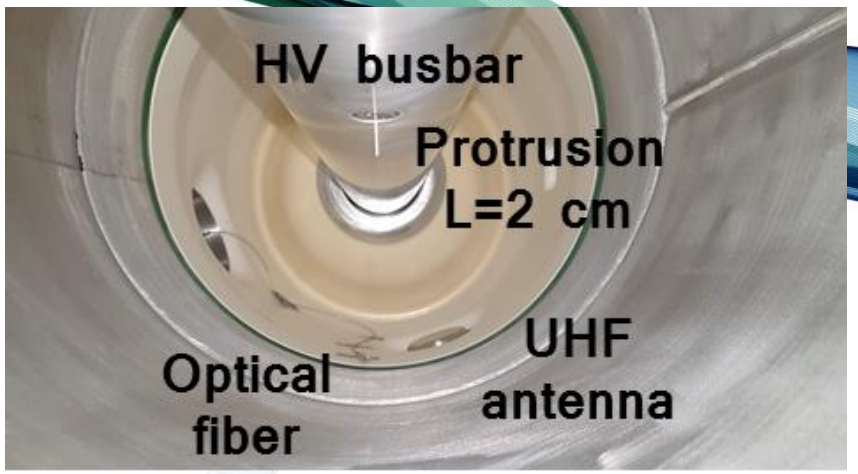




SF_6 and alternative gases

Mediums	SF_6	$C0_2$	Fluoroketone (FK)	Fluoronitrile (FN)
CAS number	2551-62-4	124-38-9	756-12-7	42532-60-5
Boiling point (°C)	-64	-78.5	26.5	-4.7
GWP	23900	1	<1	2100
Flammability	none	none	none	none
Dielectric strength (relative to SF_6)	1	0.3	≈2	≈2
Toxicity TWA (ppmv)	1000	5000	225	65
Potential insulator	✓	✓	✓	✓
Potential interrupter	✓	✓	✓	✓

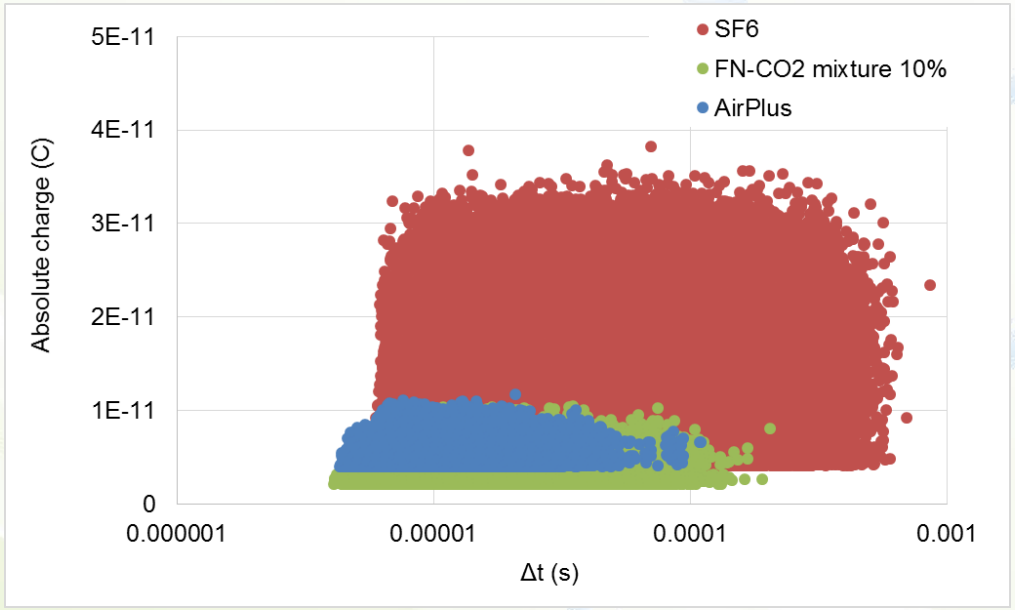
PD behavior for SF_6 and alternative gases



Lower time between PD impulses for alternative gases compared to SF_6

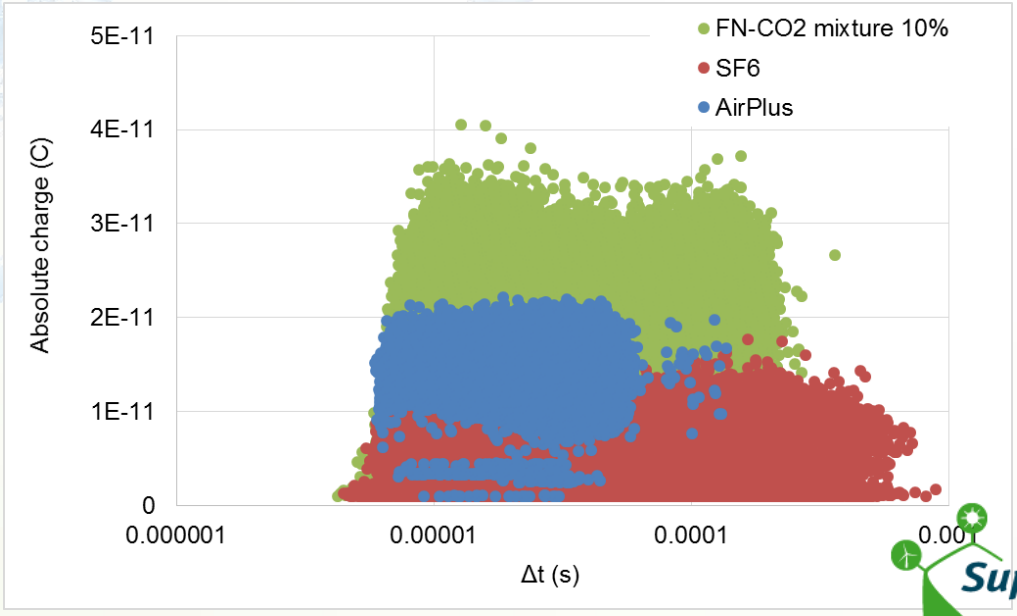
Higher PD level observed for SF_6 under negative polarity while it is observed for alternative gases under positive polarity

Negative polarity



100kV

Positive polarity



Questions?