Metrology for Future Energy Transmission

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The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

STAKEHOLDER WORKSHOP

EMPIR 19ENG02 FutureEnergy

Metrology for future energy transmission

Braunschweig April 26, 2023

Alf-Peter Elg

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AGENDA

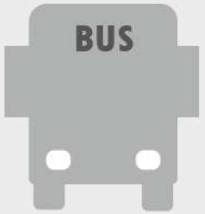
FutureEnergy	09:00–09:30	Welcome and Overview	
	09:30–10:15	WP1 – UHVDC calibration and testing	PTB
	10:15–10:45	Coffee Break and Poster Session	
	10:45–11:30	WP2 – Lightning impulse voltage calibrations for UHV testing	VTT
	11:30–12:00	Coffee Break and Poster Session	
	12:00–13:00	Lunch	
	13:00–13:45	WP3 – Voltage dependence at HVAC	VSL
	13:45–14:15	Coffee Break and Poster Session	
	14:15–15:00	WP4 – HVDC grid condition monitoring	FFII
	15:00–15:30	Coffee Break and Poster Session	
	15:30–17:00	WP5 – Impact, discussion, further needs, AOB	RISE
	18:00–21:00	Dinner *Schadt's Brauhaus, Marstall 2/Höhe 28, 38100 Braunschweig*	

PRACTICALITIES

WiFi

SSID: PTB-Gast

Monday, April 24th	Tuesday, April 25th	Wednesday, April 26th	Thursday, April 27th
WPA2-Key: jg5H2twS	WPA2-Key: qtZcfybk	WPA2-Key: QU5Ech$m	WPA2-Key: QUfy79N2



461 PTB - Hauptbahnhof

PTB	6:43 am	7:08 am	7:13 am	-	7:43 am	every 30 mins	18:43 pm
Bundesallee	6:45 am	7:10 am	7:15 am	-	7:45 am		18:45 pm

CONSORTIUM

NMI

UNIVERSITIES AND INDUSTRY

COLLABORATORS

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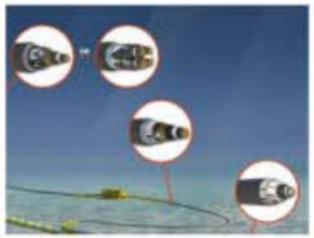
Project infrastructure

UHVDC calibration

HVAC capacitance linearity



HVAC and HVDC Cable transmssion

HVDC transmission

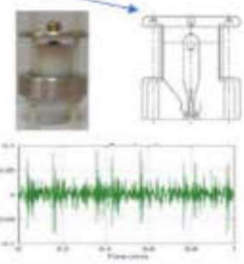
Ultra high voltage calibration and Monitoring infrastructure

HW Development/ Grid monitoring

HVDC Converters

Lightning Impulse linearity

PD under DC stress



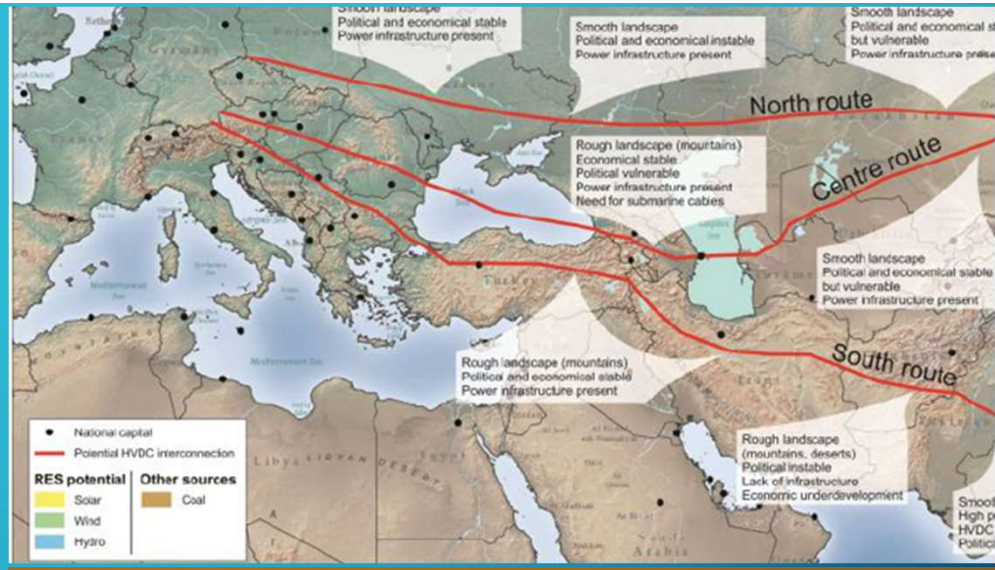
FUTUREENERGY

'PROVIDE TRACEABILITY FOR METROLOGY IN TESTING AND CALIBRATION OF COMPONENTS FOR FUTURE ELECTRICITY GRIDS'

https://www.ptb.de/empir2020/futureenergy/home/

PREPARING EUROPE FOR FUTURE ENERGY GRIDS MEET HORIZON 2050

- Metrology for increased energy efficiency for power transmission in **long interties**
- **Integration** of renewables
- **Grid balancing** and redundancy
- Create means for a strong grid **backbone**
- Minimize losses beyond 20/20/20 – **Horizon 2050**



SCIENTIFIC CHALLENGES

State of the art (2020)

1. HVDC 1000 kV (20 µV/V)
2. Lightning impulse – No proven traceability for linear extension beyond 2500 kV
3. Method for voltage dependence of any HV capacitor
4. PD detection under DC stress in HVDC cables, GIS and converters

OBJECTIVES

WP 1: UHVDC (Dr. Meisner, PTB)

To extend the traceable calibration of Ultra-High Voltage Direct Current (UHVDC) **up to at least 1600 kV, possibly 2000 kV,** by developing new methods and hardware. In addition, to **facilitate on-site measurements** by developing two modular voltage dividers, one with an expanded measurement uncertainty better than **200 µV/V at 1600 kV,** and one better than **40 µV/V at 1200 kV**.

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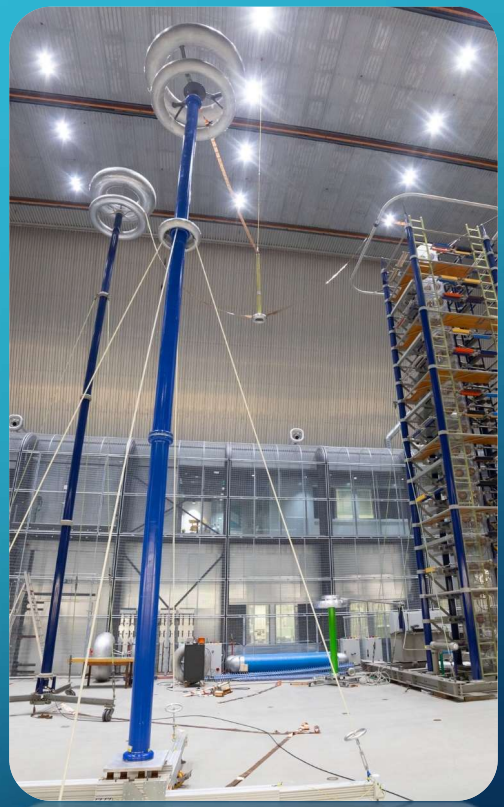
OBJECTIVES

WP 2: UHV Lightning Impulse - UHVLI (Dr. Hällström, VTT)

To extend and research methods for lightning impulse voltage calibration for testing of UHV equipment. The target is to provide new input to IEC 60060-2 for time parameters and voltage measurement on ultra-high voltages above 2.5 MV, with an uncertainty for peak voltage better than 1 %. To resolve unexplained effects on measurements from front oscillations, corona, proximity, and signal cable.



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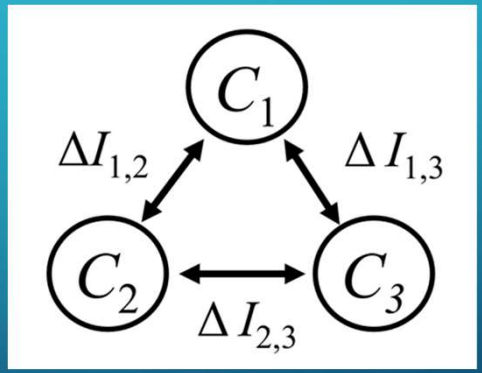
OBJECTIVES

WP 3: Non-linearity of HV capacitors (E. Houtzagher, VSL)

To develop new methods for linearity determination of HV capacitors with a target calibration uncertainty for HVAC of 80 µV/V at 800 kV.



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OBJECTIVES

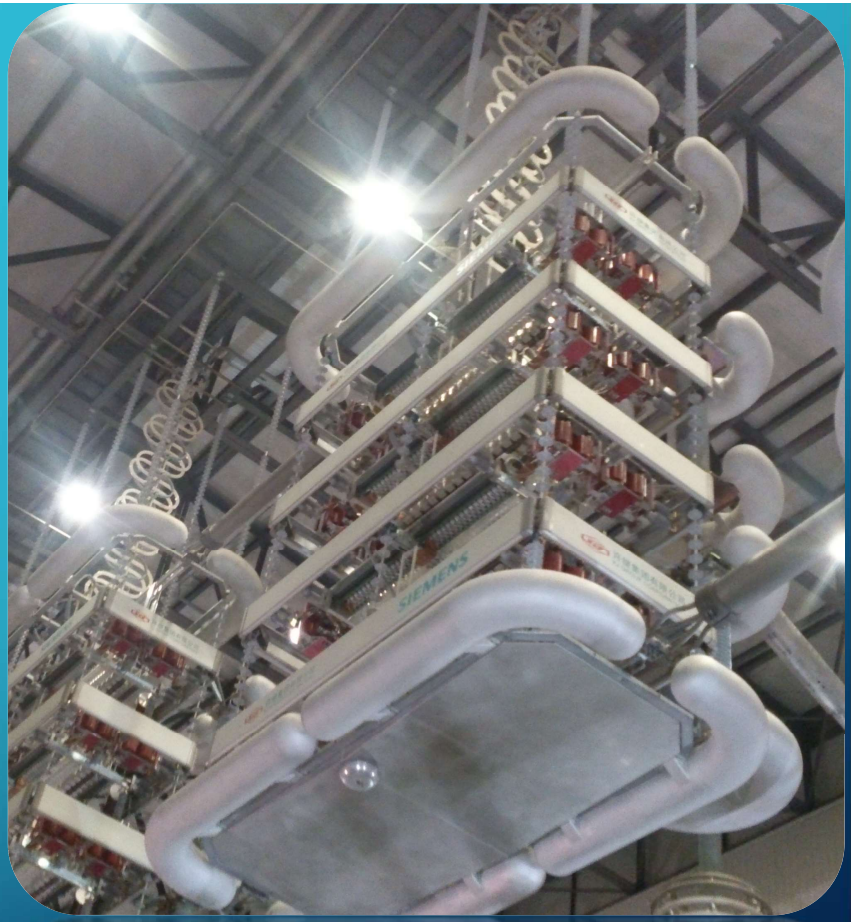
WP 4: PD detection under DC stress in HVDC cables, GIS and converters (Prof. Garnacho, FFII-LCOE)

To develop and demonstrate implementation of partial discharge (PD) measurement techniques for testing of equipment under d.c. stress, with specific emphasis on detection and prevention of insulation failures in HVDC cables, GIS and convertors.

To develop special PD calibrators of representative PD pulses associated with insulation defects and a new characterisation setup up to 100 kV for a HVDC gas insulated substations (GIS).

WORK PACKAGES

1. UHVDC **traceability for metering** to 1200 kV and **traceability for testing** to 1600 kV and beyond
2. UHVLI **linearity methods** >2500 kV
3. UHVAC new **methods** for voltage **non-linearity of HV capacitors**
4. HVDC **PD detection methods** - HVDC grid monitoring, develop HV cables, GIS and converters



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Summary of results achieved

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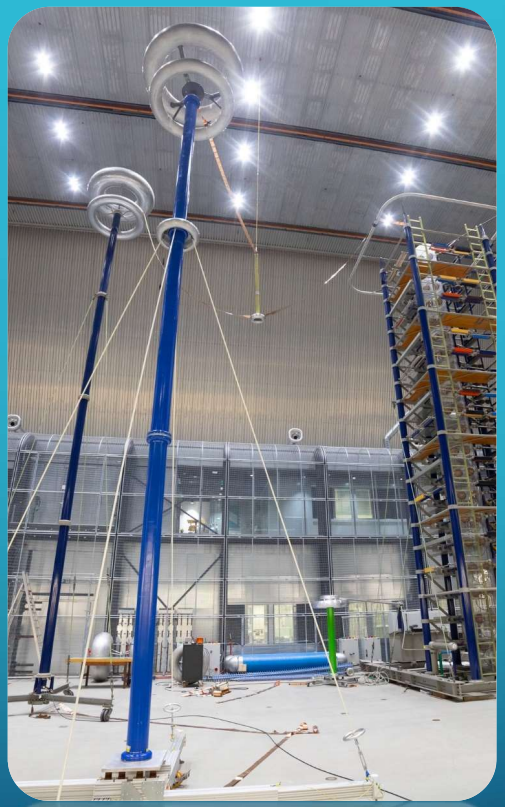
SUMMARY OF RESULTS



UHVDC TRACEABILITY TO 1200 KV

- **UHVDC 1200 kV unc. < 20 µV/V (40 µV/V)**
- 9 existing 200 kV modules from ENG07 HVDC + 7 new 200 kV modules 19ENG02 FutureEnergy
  - RISE and PTB - Two complete 1200 kV dividers
  - TUBITAK – Two modules, 400 kV divider
- Intercomparison 1200 kV at RISE March 2022 - UHVDC Traceability → 1200 kV unc. < 20 µV/V (target 40 µV/V)
- One paper at CPEM2022 (stability of HVDC systems)
- IEEE TIM in progress

UHVDC TRACEABILITY TO 1600 KV

- **UHVDC 1600 kV unc. < 40 µV/V (200 µV/V)**
- New modular dividers
  - RCRC divider – 5 x 400 kV (< 40 µV/V @ 1600 kV)
  - RCR divider – 2 x 500 kV (< 35 µV/V @ 1000 kV)
  - UHVDC Traceability → 1600 kV unc. < 40 µV/V (target 200 µV/V)
- New Greinacher/Cockroft-Walton DC generator
  - Ultra-low ripple 2000 kV (500 Hz)
- New testing site – open air 50 x 60 m arranged at PTB
- Intercomparison up to 1600 kV PTB in June 2022
  - Two papers at ISH 2023

PTB Messen ▪ Forschen ▪ Wissen

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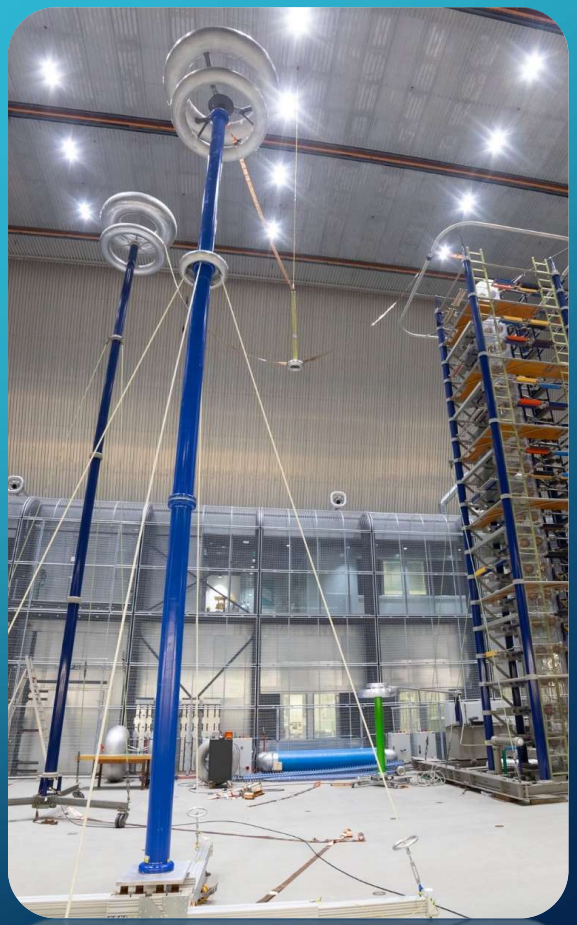
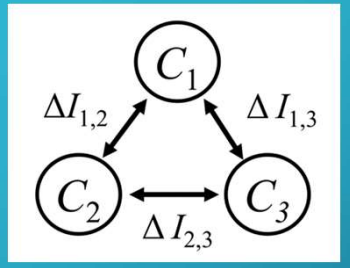
UHVLI LINEARITY TO 3000 KV

- Good practice guide for UHVLI dividers
  - Linear extension - Charging voltage, field probe, system with higher rating
  - Influence factors - Front oscillations and sources, Corona, Proximity and Signal cable length effects
- Intercomparison at TU Delft to 3000 kV
  - Six resistive dividers (400 – 2000 kV)
  - Four damped capacitive dividers (1000 – 4000 kV)
  - Agreement within 1% of peak voltage up to
  - Paper submitted to ISH 2023



UHVAC METHODS ON LINEARITY OF HV CAPACITORS

- Six methods evaluated – one new
  - Kinetic method (Latzel) - 0.1 µV/V (ISH2021)
  - Three equations method – 10 µV/V (CPEM2022)
  - Field sensor – 50 µV/V
  - Simplified tilt and CCD method – 10 and 6 µV/V (NIM)
- Papers CPEM2022 – method and loss factor of bridges
- New 800 kV gas capacitor designed by Vettiner
- Campaigns to 300 kV (2022) and 500 kV April 2023
  - Vettiner 800 kV capacitor delayed (subsupplier)



HVDC PD DETECTION METHODS – HVAC AND HVDC

- HV cables 1 – 30 MHz
  - Synthetic PD generator
    - Qualification of PD calibrators for insulation diagnostics of HVAC and HVDC cables
    - Generates PD pulse trains of stable charge values from 2 pC to 15 nC with an uncertainty of less than ±2% or ± 1 pC
  - Round-Robin ongoing (FFII, LCOE, UPM and RISE)

HVDC PD DETECTION METHODS

- Calibrated PD charge evaluation in HVDC GIS 30 – 300 MHz
  - 1GHz bandwidth workbench developed and validated for PD sensors characterization
  - Balanced magnetic antenna with a frequency range of up to 300MHz
  - Combination of VHF electric and magnetic sensor for PD power flow
- More than 5 peer review papers

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Impact, discussion, future needs and AOB

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IMPACT - INDUSTRY AND USER COMMUNITIES

- **Power industry testing**
  - The HVDC 1000 kV shield divider was used to calibrate tests with composite wave DC/SI to 1100 kV
  - New UHVDC 1200 kV – 7 on-site calibrations 2022
  - Linearity uncertainty of < 1% to 3000 kV validated. Guide on lightning impulse testing
  - Non-linearity determination of any HV capacitor now available to 800 kV < 40 µF/F
  - Grid operator monitoring – new PD detection in development of HV cables, GIS and converters

IMPACT - INDUSTRY AND USER COMMUNITIES

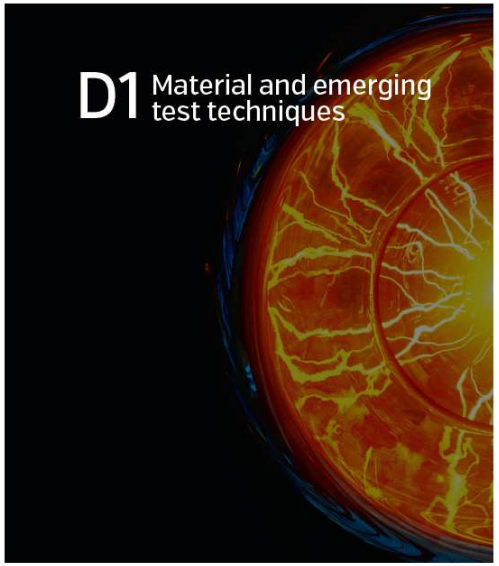
- **Grid operator monitoring**
  - HVDC grid in Germany – need for support of existing installation with new PD metrology
  - New research proposal 2023 – Electric energy and supply reliability, ENSURE
  - TSO of Sweden Svenska Kraftnät need monitoring of power quality from renewables and means for grid balancing

IMPACT – INPUT TO RELEVANT STANDARDS

- **Input to relevant standards**
  - IEC TC38/CENELEC TC38 - Instrument transformers
    - IEC 61869 series
  - IEC TC42 - High-voltage and high-current test techniques
    - IEC 60060 series (HV testing), 61083 series (Impulse) , 60270 (PD)
  - IEC TC22F - Power electronics for electrical transmission and distribution systems
  - IEC TC99 (TC28) - Insulation co-ordination and system engineering of high voltage electrical power installations above 1.0 kV AC and 1.5 kV DC
  - IEC TC115 - High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV
  - IEC TC122 - UHV AC transmission systems

IMPACT

- **Input to pre-normative work by CIGRE SC D1**
  - Cigre D1.63 – "Partial discharge detection under d.c. voltage stress" 19NRM02 UHV and 19ENG02 FutureEnergy
  - Cigre D1.66 – "Requirements for Partial Discharge Monitoring systems for gas insulated systems"
  - Cigre D1.50 – Atmospheric and altitude correction factors for air gaps and clean insulators – TB 888. (coordinated by J. Rickmann) task given by IEC TC42/JWG 22 (convener E. Gockenbach)



cigré
INTERNATIONAL COUNCIL ON LARGE ELECTRIC SYSTEMS

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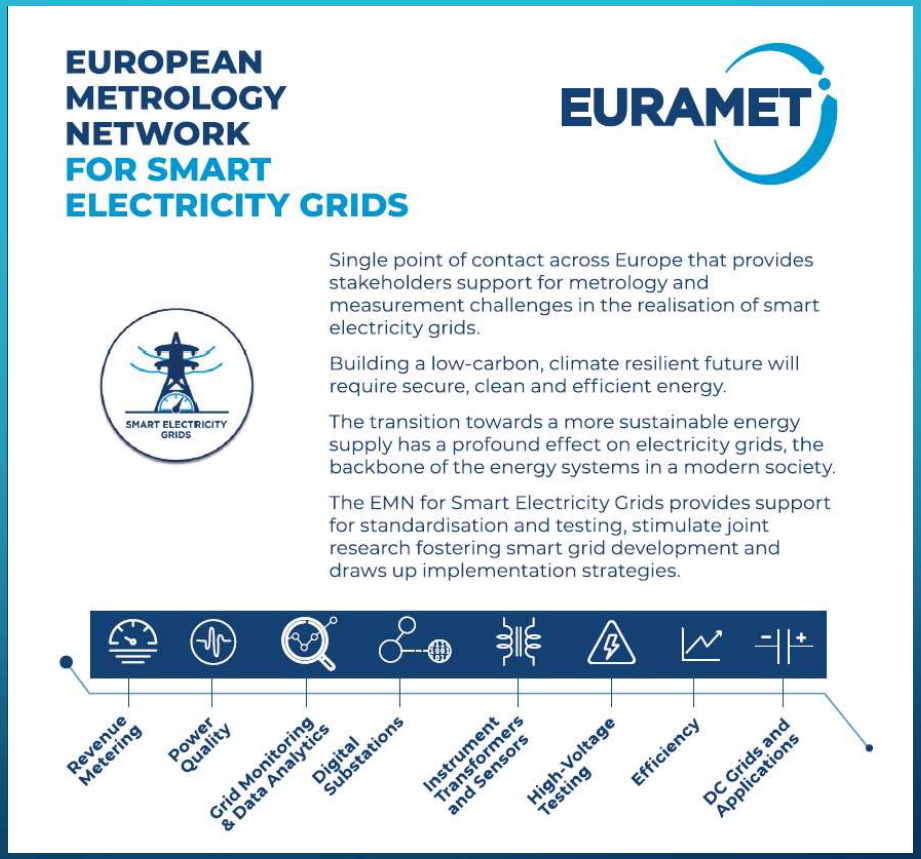
IMPACT

- **Input to EMN** 18EMN03 SEG – Smart Electrical Grids
- Flyer in foyer
- Web page



SMART ELECTRICITY GRIDS

EUROPEAN METROLOGY NETWORKS

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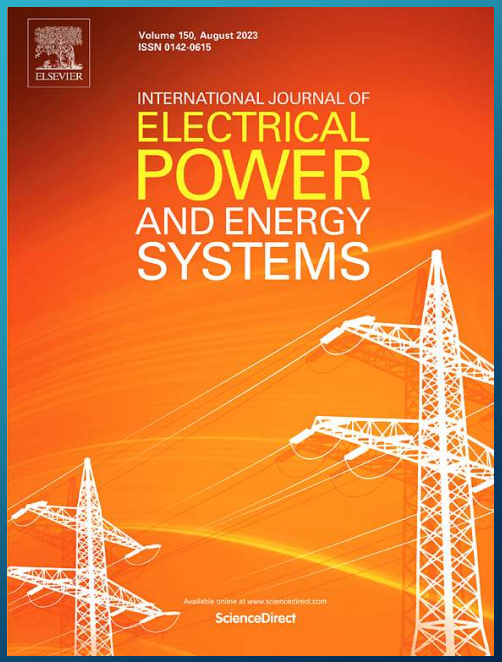
IMPACT - INDUSTRY AND USER COMMUNITIES

- **Papers published**
  - VDE 2020 – 1 paper
  - IEEE TIM – 2 papers
  - IEEE Sensors – 2 papers
  - International Journal of Electrical Power and Energy Systems - 2 papers
  - EIC 2021 - 2 papers
  - ISH 2021 – 1 paper
  - ICD 2022 – 1 paper
  - CPEM 2022 – 3 papers
  - ISH 2023 – 3 papers
  - Sensors 2023 – 1 paper



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IMPACT – PUBLICATIONS, 11 CONF, 6 (5) PEER-REVIEW JOURNALS

	Lead author	Title of publication	Journal	Publication status	Peer-review journal
1	Alf-Peter Elg	Research Project EMPIR 19ENG02 Future Energy	VDE2020	Published	
2	Christian Mier Escurra	Test-bench and frequency response of a Magnetic Antenna used in GIS PD measurements	EIC2021	Published	
3	Abderrahim Khamlichi	Error in the measurement of partial discharge pulses according to the frequency response of HFCT sensors	EIC2021	Published	
4	Joni Klüss	High-Frequency Current Transformer Design and Implementation Considerations for Wideband Partial Discharge Applications	IEEE Transactions on Instrumentation and Measurement 70, 1-9, 2021	Published	1
5	Christian Mier Escurra	Design and Characterization of a Magnetic Loop Antenna for Partial Discharge Measurements in Gas Insulated Substations	IEEE SENSORS JOURNAL, VOL. 21, NO. 17, SEPTEMBER 1, 2021	Published	2
6	Mohamed Agazar	Determination of voltage dependence of capacitance of 1000 kV and 300 kV compressed gas capacitors using the kinetic method	ISH2021	Published	

IMPACT - PUBLICATIONS

	Lead author	Title of publication	Journal	Publication status	Peer-review journal
7	Christian Mier Escurra	Partial Discharge Charge Estimation In Gas-Insulated Substations Using Electric and Magnetic Antennas	ICD2022	Published	
8	Christian Mier Escurra	Magnetic and electric antennas calibration for partial discharge charge estimation in gas-insulated substations	International Journal of Electrical Power and Energy Systems, VOL. 141	Published	3
9	Christian Mier Escurra	Magnetic and electric antennas synergy for partial discharge measurements in gas-insulated substations: Power flow and reflection suppression	International Journal of Electrical Power and Energy Systems, VOL. 144	Published	4
10	Alf-Peter Elg	On the Stability of a Modular 1000 kV HVDC divider design	CPEM 2022	Approved, awaiting publication	
11	Johann Meisner	New reference HVDC divider for the calibration of testing equipment up to 1600 kV	ISH 2023	Submitted	
12	Alf-Peter Elg	A modular universal divider for calibration of DC, AC, SI and LI and composite waves up to 1400 kV	ISH 2023	Submitted	

IMPACT - PUBLICATIONS

	Lead author	Title of publication	Journal	Publication status	Peer-review journal
13	Jari Hällström	Experience on Performing Linearity Extension of Lightning Impulse Voltage Dividers up to 3000 kV	ISH 2023	Submitted	
14	Abderrahim Kamlichi	Effects of coaxial cables on high-voltage lightning impulse measured parameters: A comparative between measurements and simulations	CPEM 2022	Approved, awaiting publication	
15	Wei Zhao	Resonance at the Front of Lightning Impulse Voltage Waveforms Caused by the Load Capacitor	IEEE Transactions on Instrumentation and Measurement 70, 1-9, 2021	Published	5
16	Stephan Passon	New Method for the Determination of Voltage Dependency of High-Voltage Capacitors	CPEM 2022	Approved, awaiting publication	
17	Alf-Peter Elg	New precision UHVDC traceability to 1200 kV and NMI interoperability	IEEE TIM	Drafted	
18	Fernando Garnacho	Functionality Test for Qualification of PD Analysers used for insulation diagnosis of HVDC and HVAC Cable Systems	Sensors	Submitted	6

IMPACT – NEW IDEAS/PROPOSALS

	Proposal	Affiliation	Description	Project/Time frame
1	M. Kharezy	RISE	Long term stability, ageing, MTBF, Cigre A3.43	2018 – 2021(?)
2	M. Kharezy	RISE	Development of new HV insulation gases, Cigre A3.60	2020 – 2022(?)
3	M. Kharezy	RISE	Generation AC to 150 kHz	22NRM06 ADMIT
4	F. Böhme	HIGHVOLT	PD in HVDC grid monitoring	EPM2023 i21 - ENSURE
5	F. Böhme	HIGHVOLT	PD detection for LI	
6	J. Rickmann	Siemens	Method for HVDC divider linearity	
7	A Lindskog	Sv Kraftnät	Support for live connections – voltage and current harmonics monitoring/calibration	EPM2023 i21 - ENSURE
8				
9				
10				

Metrology for Future Energy Transmission

FUNDACIÓN PARA EL FOMENTO DE LA INNOVACIÓN INDUSTRIAL

LCOE
LABORATORIO CENTRAL OFICIAL DE ELECTROTECNIA

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2nd STAKEHOLDER WORKSHOP

Madrid May 24, 2023

Course HV metrology 9^{00} – 12^{00}
Workshop 13^{00} - 18^{00}

F. Garnacho, J. Rovira

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NILS-HYLTEN CAVALLIUS (PDF)

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ACKNOWLEDGEMENT

This project (FutureEnergy) has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

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Spectrum of HVDC metrology

On behalf of the FutureEnergy consortium

Thank you for your attention!

Alf-Peter Elg

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