Metrology for future energy transmission

4th Newsletter

FutureEnergy project

This is the first newsletter of the EMPIR project ‘Metrology for future energy transmission (FutureEnergy)’. The three-year project started in June 2020, and it is building on the EMPIR projects ‘Metrology for the electric power industry (14IND08 ElPow), ‘Techniques for ultra-high voltage and very fast transients (15NRM02 UHV) and the EMRP project ‘HVDC future power grids (07ENG HVDC)’.

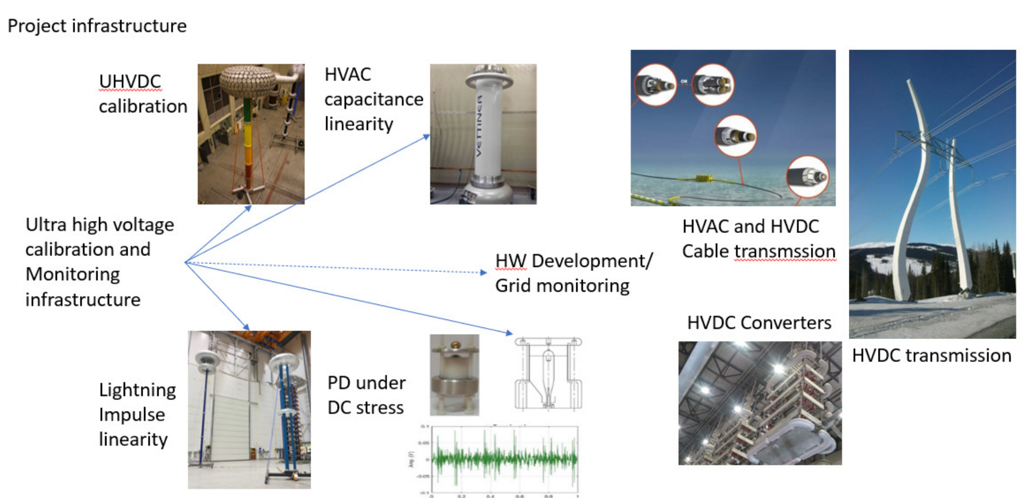
Driven by the need for increased efficiency, transmission grid voltages have been pushed to ultra-high voltages (UHV), beyond 1000 kV. This project will realise metrology solutions for grid component testing and condition monitoring required for successful implementation of future UHV transmission grids.

Society’s increasing demand for electrical energy, along with the increased integration of remote renewable generation has driven transmission levels to ever higher voltages in order to maintain (or improve) grid efficiency. Consequently, high voltage testing and monitoring beyond voltage levels covered by presently available metrology infrastructures are needed to secure availability and quality of supply.

Calibration services for UHVDC are not available above 1000 kV. There is a need to extend the calibration capabilities for voltage instrument transformers up to 1200 kV and for factory component testing capabilities up to 2000 kV.

The overall aim of the project is to provide traceability for metrology in testing and calibration of components for future electricity grids, and to provide improved means for HVDC grid condition monitoring. The specific objectives are:

- extend the traceable calibration of Ultra-High Voltage Direct Current (UHVDC) up to at least 1600 kV
- extend and research methods for lightning impulse voltage calibration for testing of UHV equipment
- develop a new method(s) for linearity determination of HV capacitors
- develop and demonstrate implementation of partial discharge (PD) measurements under d.c. stress
- facilitate the take up of the technology and measurement infrastructure developed in the project



Research highlights

UHVDC traceability

For the traceability to 1200 kV with the target measurement uncertainty of 40 µV/V, in total seven new 200 kV HV modules have been built. One HV module increases the 1000 kV modular divider to 1200 kV for RISE. Five HV modules increase the 200 kV modular divider to 1200 kV for PTB. One HV module increases the 200 kV modular divider to 400 kV for TUBITAK. Two complete sets of HVDC dividers are now available for calibration with traceability to 1200 kV in Europe from RISE and PTB. An expanded measurement uncertainty of 20 µV/V for 1200 kV will be claimed.

In total three measurement systems were set up in the lab of RISE in March 2022 for calibration. Prior to the HV calibration a LV calibration of all collected system components was done in the precision lab of 16 HV modules and six LV arms. The 1200 kV calibration was performed in a step-up procedure with 200 kV, 600 kV, 800 kV to 1200 kV. An intercomparison took place between two 1200 kV dividers from RISE and PTB and an 800 kV configuration combining the dividers from TUBITAK, VSL and VTT.

Field modelling to avoid corona discharge in the 1200 kV divider design showed additional corona rings need to be added to joints between the HV modules. During the campaign at RISE the diameter of the connecting tubes needed to have a minimum of 250 mm diameter with smooth surface for corona free measurements at 1200 kV.

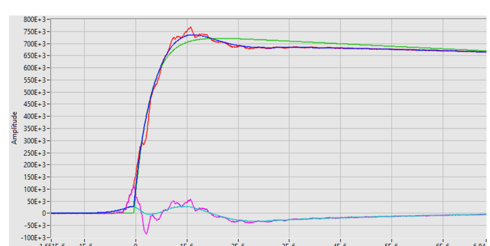
Two divider designs have been developed for UHVDC operation. The first shielded RCRC divider has been designed and assembled by PTB with support from RISE and VTT. Five 400 kV UHVDC divider modules have been built to reach 2000 kV. The second design is an unshielded RCR divider that has been designed and calibrated by RISE with support from PTB and VTT. Two 500 kV modules were built for the RCR divider to reach 1000 kV.

An UHVDC generator was designed by PTB and set up for 2000 kV at an outdoor open area field test range in May-June 2022. During a campaign two 1200 kV HVDC dividers were intercompared with the 2000 kV RCRC divider and the 1000 kV RCR divider. An expanded measurement uncertainty of 100 µV/V was reached at 1600 kV for the RCRC divider and 80 µV/V at 1000 kV for the RCR divider.

Lightning impulse linearity extension

A draft of a good practice guide is in its final stage. VTT and LNE has modelled signal cable effects. Simulation models based on telegraphers' equations and Schelkunoff equations embedded into circuit simulator show good correspondence with practical measurements. In parallel to modelling, a literature study has been carried out by PTB and TUBITAK, and in-depth PhD work by FFII and PTB, to investigate the influence of the attenuation, cable quality and length in the coaxial cable between the high voltage hall and control room.

Further experimental work at RISE has indicated possible origins of front oscillations. A collaborator [10] has also been engaged to practical experimental work on this subject. It has been decided to implement the results from the measurement campaign taking place in October 2022 in the guide.



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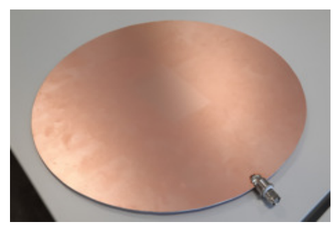
Nine different dividers have been selected to take part in the intercomparison in October 2023, with various designs and properties, i.e., resistive and mixed capacitive dividers. These dividers have been modified and characterised to fine-tune the performance. There are three categories of reference measurement systems to be used for the campaign; the first is 400-600 kV, the second is 1200 kV and the third is 2000-3600 kV.

Collaborations were established with 1) NIM, China, to support the work on front oscillations; 2) Haefely AG, Switzerland, to support the work on front oscillations, the cable effect, and to provide a measurement system for the measurement campaign; and 3) NMIA, Australia, to support the work on linearity extension methods.

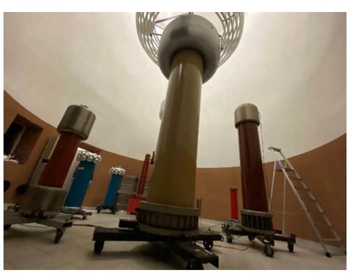
Voltage linearity of UHVAC references

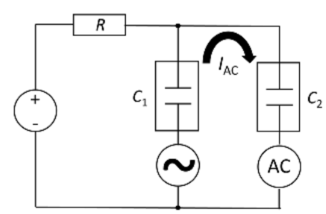
Information has been collected by TUBITAK on gas-capacitors accessible to project partners and their voltage dependencies based on which the best references as well as the measurement bridges have been selected. The influence of high-level harmonic distortion up to 10 % at 50/60 Hz on the uncertainty of HV capacitor measurements in a traditional capacitance bridge has been determined and published by LNE [6].

Latzel's method has been repeated by LNE on a high-voltage capacitor to review the technique. The resulting measurements have been published [6]. The new design of an 800 kV high-voltage capacitor has been upgraded by VETTINER after testing of the first version and is being prepared for a measurement campaign at PTB in January 2023.



VTT and VSL reviewed linearity extension techniques used in industry utilising electrical field probes. A new prototype field probe designed by VSL to further develop the probe technique and the expected uncertainty, was manufactured and tested with good results. The field probe has been used as input to the work by VTT and TAU. VTT has performed direct measurements up to 180 kV to determine the non-linearity and also using a field probe up to 240 kV with good results.





PTB has measured the temperature dependence of their eight capacitors, which will be used in the development of a new calibration method. This method is based on the comparison of three high-voltage capacitors at a small and constant AC voltage and a variable high DC voltage. First tests show promising results and have been submitted for publication. The new method will be evaluated during the measurement campaign in January 2023.

HVDC grid condition monitoring

PD procedure for qualifying PD analysers used for d.c. measurement in the 1 – 30 MHz range

An attenuation study in HVAC and HVDC cable systems has been carried out. This study includes attenuation tests in AC cable samples (MV and HV) and theoretical determination for AC and DC cable systems. Attenuation is much lower in HV cable systems than in MV cables. Real data have been supplied from on-site tests.

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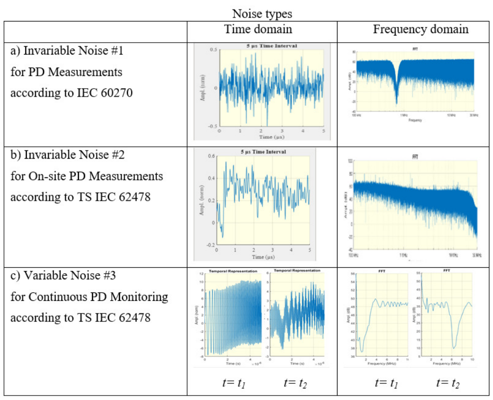
Test cells of representative defects have been used for aging (floating electrode, cavity, corona and surface) in two different testing facilities, one site focused on corona, surface and on floating charge and the other is focused on cavity defects. A comparison between real data and laboratory test cells has been performed with a small number of PD trains, and the conclusion is positive: test cells represent real defects. Further comparisons are ongoing using a larger number of PD pulse trains for improvement of the test-cells in preparation of ageing experiments.



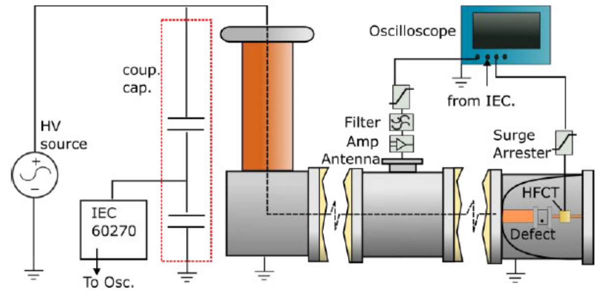
A set of 1000 PD pulse trains was supplied by a collaborator (DIAEL) to be used for an artificial intelligence (AI) tool. The results from the laboratory set-up using test cells have fed into setting up a neuronal network for DC PD pattern recognition by UPM. An HVDC converter test cell has been developed for tests in a lab by UPM with support from FFII and discussed with RISE, TAU and TU Delft. A review of the bibliography about the state of the art of failures in DC and HVDC converters has been presented together with a test plan.
Real data of noises were obtained from grid installations (wind plants, PLC from MV substations and DC Plants). Several time series have been incorporated in a synthetic PD generator for a round-robin test, using noise data to be mixed with real PD pulses through data analyses to reproduce such noises by a synthetic generator, FFII has developed three software tools for characterisation of PD analysers for AC: a) PD sensitivity vs noise, b) PD pattern recognition, c) PD clustering. These tools allow the determination of the capabilities of PD analysers and are now extended to include DC PD patterns. Validation of the calibration procedure to qualify PD analysers working in the frequency range between 1 MHz and 30 MHz developed in EMPIR project 15NRM02 UHV has been completed.

An adjustable synthetic calibrator has been designed and built for representative PD defects and noises, i.e., a versatile reference PD source. This calibrator will use adjustable parameters (PD amplitude and PD repetition rate) to simulate the four defects. A round-robin test assessing HF PD analysers using the developed adjustable PD calibrator is performed between FFII, RISE, TAU, TU Delft and UPM. The following performances will be evaluated: PD sensitivity for reference PD pulses, PD pattern recognition, PD clustering, noise rejection and PD location.

PD charge evaluation in HVDC GIS using magnetic sensors measuring in the 30 MHz – 300 MHz range

The magnetic antenna design for PD measurements in GIS has been improved extending the bandwidth above 300 MHz. A modification in the design has been introduced to minimise the effects of resonances. A mathematical model of the antenna frequency response has been developed that will be instrumental for the charge estimation of the partial discharges, which was published [4] by TU Delft. Analysis on the GIS PD signal attenuation is done in the working frequency range of the magnetic antenna.
A testing workbench, with dimensions similar to a real GIS, has been built, in which calibration of the charge estimation in GIS has been verified to prepare a full-scale laboratory GIS for calibration [5]. Preliminary work

on charge estimation error calculation shows positive results and will be extended with theoretical developments and laboratory experiments to demonstrate the suitability of the proposed method based on the double time integral of the measured signal. An improved design of the magnetic antenna which shows better sensitivity is under research. A calibration procedure has been proposed where the calibration constant for the charge estimation method was found for the electric and magnetic antennas. A combination of the magnetic and electric antennas has been studied, resulting in a method to discriminate backward reflections and PD power flow in the GIS [7,8,9].



A HV characterisation set-up has been built. The validation of the high voltage and low-voltage methods are under test. The collaboration with SuperGrid Institute has focused on testing the magnetic antenna under noisy conditions and testing artificial defects under SF6 and alternative gases.

Contact and further information

The consortium consists of 7 National Metrology Institutes, 3 universities, and 2 companies and thus have measurement capabilities traceable to national standards, sites to host the measurements facilities and test their performance and companies to develop and exploit their technology.

Metrology for Future Energy Transmission

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

To register as a project stakeholder, contact Alf-Peter Elg, RISE (alf.elg@ri.se).

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Project partners:

	RISE	Research Institutes of Sweden	Sweden	National Metrology Institutes
	FFII	Fundación para el Fomento de la Innovación Industrial	Spain	
	LNE	Laboratoire national de métrologie et d'essais	France	
	PTB	Physikalisch-Technische Bundesanstalt	Germany	
	TUBITAK	Turkiye Bilimsel ve Teknolojik Arastirma Kurumu	Turkey	
	VSL	VSL B.V.	Netherlands	
	VTT	Teknologian tutkimuskeskus VTT Oy	Finland	
	TAU	Tampereen korkeakoulusäätiö sr	Finland	Academia
	TU Delft	Technische Universiteit Delft	Netherlands	
	UPM	Universidad Poltécnica de Madrid	Spain	
	Vettiner	Appareils Vettiner	France	Industry