Publishable Summary for 19ENG02 FutureEnergy
Metrology for future energy transmission

Overview

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.

Specifically, the project will create critical metrology infrastructure in four areas: reliable and traceable lightning impulse measurements above 2500 kV; extended traceability of UHVDC up to 1600 kV; improved HVAC traceability via linearity determination of HV capacitors up to 800 kV; development of partial discharge measurement techniques in support of equipment testing under HVDC stress.

Need

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.

Methods for linear extension of lightning impulse (LI) calibration, for dielectric testing of UHV grid equipment, urgently need revision. Research performed by CIGRE, a non-profit power system expertise community, and a recent EMPIR JRP 14IND08 ElPow, has raised questions regarding the validity of the current linearity extension methods for voltages beyond 2500 kV. There is an urgent need to provide recommendations to high voltage testing techniques standardisation.

New methods for calibration are needed for the 0.2 class HVAC voltage instrument transformers for system voltages up to 1200 kV. Compressed gas capacitive voltage dividers used for such HVAC calibration are largely limited by the voltage dependence of capacitance. The current methods used for determination of the voltage dependence are very time-consuming, highlighting the need for methods allowing faster assessment, especially for on-site calibration where planned interruption periods need to be minimised.

With new HVDC transmission grids and associated components, novel methods are needed for detection, classification and localisation of partial discharge (PD) under d.c. stress. The industry needs methods for reliably monitoring critical components such as cables (both HVAC and HVDC) and gas insulated substations (GIS), and techniques for addressing new challenges introduced by HVDC technologies, such as the ability to distinguish PD signals from switching transients in converters and other sources of noise..

Objectives

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:

- 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, 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**.
- 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 voltage above 2.5 MV, with an uncertainty for peak voltage better than 1 %, and to resolve unexplained effects on measurements from front oscillations, corona, proximity, and measurement cable.
- To develop new efficient method(s) for linearity determination of HV capacitors with **a target calibration uncertainty** for HVAC of **80 µV/V at 800 kV**.
- To develop and **demonstrate implementation of partial discharge (PD) measurement** techniques for diagnostics 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 characterization setup up to 100 kV for a HVDC gas Insulated switchgear GIS.
- To facilitate the take up of the technology and measurement infrastructure developed in the project, by the electrical power industry and to make recommendations to standards covered by IEC TC38, TC42, TC115, TC122 and TC22F.

Progress beyond the state of the art and results

UHVDC traceability

Building on the d.c. voltage traceability obtained in EMRP JRP ENG07 HVDC for on-site calibration up to 1000 kV, capability will be enhanced from 20 µV/V at 1000 kV to 1200 kV with a 40 µV/V uncertainty for calibration of reference measurement systems used for calibration of d.c. voltage instrument transformers. A lower-echelon measuring system will be constructed with capability up to 1600 kV (possibly 2000 kV), which will satisfy the need for calibration of UHVDC measuring systems, with a target measurement uncertainty of 200 µV/V.

Lightning impulse linearity extension

Typically, NMIs can provide traceability for lighting impulse voltage measurement systems up to 500 - 700 kV. For calibration of large LI measurement systems in industrial laboratories which are typically used up to 3000 kV, linear extension is needed to support approved measurements up to 3500 kV. Scientific proof is lacking to confirm this extension validity above 2000 kV. Typical errors of 1 % for test voltage values were observed at 2700 kV in 14IND08 ElPow, but more than 3 % errors for experiments above 3000 kV are reported. Errors in the determination of the rise time of the impulse is even more significant. This project will extend metrology beyond the 2000 kV limit by developing and validating methods for linear extension up to 3500 kV, determining measurement uncertainties, and finding solutions for the large front time errors.

Voltage linearity of UHVAC references

Voltage traceability for a.c. is typically provided by using inductive voltage transformers or capacitive voltage dividers with an uncertainty of around 50 µV/V at 200 kV, and 500 µV/V at 800 kV. Higher uncertainty at higher voltage levels is due to the voltage non-linearity in compressed gas capacitors and increasing intensity of corona. Existing voltage linearity determination methods (Latzel et al) have uncertainties much lower than 10 µV/V but are applicable to compressed gas capacitors only and rely on mechanical design data. This project will extend beyond the state of the art by developing new effective methods (applicable to any reference capacitor) for on-site determination of linearity errors in HV capacitors with a target uncertainty of 80 µV/V at 800 kV.

HVDC grid condition monitoring

HVDC systems have recently been modelled, and a PD waveform generator developed, to study insulation under d.c. stress in EMPIR JRP 15NRM02 UHV. Low-level PD calibration services below 1 pC have also been developed. However, neither specific methods, nor characterisation setups for GIS, nor any PD calibrators to recognise or reproduce PD patterns applicable to measurements under d.c. stress, currently exist. Going beyond the state of art, a calibration procedure will be developed to qualify PD analysers working in the frequency range between 1 MHz and 30 MHz, emphasising the system's ability to discriminate between PD signals and representative noises in cables and converters. The project will extend PD charge evaluation in HVDC GIS in the 30 – 300 MHz range using a specialised high voltage GIS setup up to 100 kV with reference test cells.

Impact

Impact on industrial and other user communities

The project currently has 15 stakeholders, ranging from TSOs, HV instrument manufacturers, standards development organisations, national metrology institutes and universities. These stakeholders will benefit from the project's outputs, which will boost the development of strong backbones for both HVDC and HVAC transmission networks by enabling more reliable, sustainable, and lower loss solutions. The methods and hardware developed (including on-site applications) improving uncertainty and enabling traceable calibration of metering to the highest voltage levels, will allow grid operators to minimise losses and improve monitoring of critical assets. The realisation of necessary metrological infrastructures for testing ensures improved quality control of high voltage transmission system components, thus benefiting manufacturers, suppliers, and users alike.

The European power industry, with vast experience in both a.c. grids and d.c. transmission, has a leading position in producing and testing of high voltage components. The improved traceability and quality of measurement developed in this project allows for more precise (reduced) safety margins and thereby increased operability of manufactured products and systems. For example, the industry will benefit from the new methods of creating traceability for instrument transformers at the highest voltages and thereby for power loss measurement systems for e.g. reactors.

New offshore renewable energies and extensive electrical links between islands and countries require very large submarine cables and GIS in HVDC. Unexpected dielectric failure in these critical HVDC facilities due to dielectric degradation has serious consequences for the continuity of power supply and the stability of the power grid. Partial discharge measurements have proven to be effective in preventing such risks in HVAC. By extending this approach to HVDC, this project will support the metrological base to improve and verify reliability of HVDC networks (cables, GIS and convertors). Development of methods, equipment, and interpretation of PD data under d.c. stress advances the ability to detect and prevent insulation failures, providing means for grid condition monitoring and fault detection largely impacting the TSO's ability to also handle d.c. grids.

Transparency of the project's work will facilitate the uptake of its outcomes by the stakeholders and will enable end-results to be fed into the metrology network created by EMPIR JNP 18NET03 SEG-net (EMN-SEG). Close co-operation between NMIs and European industry will lead to better control and prevention of losses and damage mechanisms crucial for the next generation transmission grids.

Impact on the metrology and scientific communities

The HV scientific community will benefit from new and enhanced measurement capabilities in areas where scientific information has been lacking or measurements have been difficult to achieve. The needs addressed in this project resulted from explicit input from the HV industry and discussions with standardisation bodies, confirmed by experiences from on-site calibrations as well as from previous Horizon 2020 projects. Collaboration and consultations with these organisations have been key for addressing the developments needed as voiced by the metrology and scientific communities. Project outputs will include several important additions and extensions to NMI/DI Calibration and Measurement Capabilities (CMSs) related to the calibration of UHVDC voltage instrument transformers and testing equipment, calibration of lightning impulse voltage measurement systems, linearity determination of reference measurement systems for a.c., and PD measurements under d.c. stress for cables and GIS.

Impact on relevant standards

This project will have a major impact on IEC standardisation committees and working groups with new methods and an improved measurement traceability. The consortium is expected to generate results that will be very valuable to standardisation work within IEC and CENELEC, namely the IEC 60060 series, IEC 60270, and the IEC 61869 series, and standards covered by IEC TC38 and TC42. Other standardisation and pre-normative bodies which will benefit are TC115, TC122, TC22F, and CIGRE SC D1 and working groups D1.63 and D1.66. For example, supporting the pre-normative and standardisation work in d.c. PD currently discussed in depth within CIGRE D1.63 will feed into the revision of IEC 60270 or a new standard; harmonisation of test voltage curves and extending calibration methods to UHV levels above 2.5 MV will help to shape new input to measurements and time parameters defined by IEC 60060-2 for lightning impulse voltages; new methods for the determination and correction of a.c. voltage non-linearity in HV capacitors which are used as references for calibration of UHVAC systems, and will enable more efficient testing and development of system components and support standardisation within IEC TC122.

Longer-term economic, social and environmental impacts

All the areas of emphasis within the project aim to improve grid stability and operability, to ensure a sustainable and affordable energy supply for European society. Electric power interties (transmission lines that connect separate electric grids) between continents and demands for reduced energy losses over long distance transmission are driving grids to operate at ever higher voltage levels. Transmission losses can be sharply reduced by increasing the present transmission voltage levels leading to more affordable energy for customers and reducing the environmental impact of our electricity infrastructure. The primary aim for this project is to contribute to a reduction of European grid losses, and prepare for a stable future UHV transmission grid. With the research and outputs from this project, highly competitive HV testing facilities will give strong support for the European manufacturers to remain forerunners in grid innovation. This has a direct impact on the competitiveness of European power industry on the international market, leading to additional jobs, providing high quality and high reliability in equipment compared to low-cost and low-quality non-European manufacturers.

Reliable and affordable energy delivery is the prime societal need. Europe needs a renewal of the electricity grid as a new backbone for the infrastructure, which is mirrored in the enormous interest in the bi-annual CIGRE meetings and the annual IEEE Power and Energy meetings. This project offers a unique opportunity for European NMIs to pool their collective strengths, and unique capabilities and facilities, to make a robust contribution to the realisation of the future grids.

Supporting higher transmission voltages will reduce losses, especially when using d.c. transmission, and even the smallest contribution to this improvement will result in a reduction in CO_2 emissions from energy transportation of many kilotons per year. Furthermore, PD, a key diagnostics tool, is an important measurement for preventing failures especially for GIS which are commonly filled with SF_6 (1 kg SF_6 has the ozone-depleting potential of 23 tons of CO_2). Today there are more than 10000 such installations, which if released would be the 15 % of the EU GHG equivalent in 2017.

Project start date and duration: 01 June 2020	01 June 2020, 36 Months	
Coordinator: Alf-Peter Elg, RISE Tel: +46706955734 E-mail: alf.elg@ri.se Project website address: http://www.vtt.fi/sites/FutureEnergy		
Internal Funded Partners: 1. RISE, Sweden 2. FFII, Spain 3. LNE, France 4. PTB, Germany 5. TUBITAK, Turkey 6. VSL, Netherlands 7. VTT, Finland	External Funded Partners: 8. TAU, Finland 9. TU Delft, Netherlands 10. UPM, Spain 11. VETTINER, France	Unfunded Partners: