Selected Research Topic number: **SRT-g19**
Version: 1.0

Title: Metrology for high voltage energy transmission

Abstract

The topology of electrical grids is changing in Europe and worldwide, with base generation from fossil fuel and nuclear being closed down in favour of renewable sources. The renewables are often captured in locations far from where the energy is used. High Voltage DC (HVDC) is one of the enabling technologies for this change and has been the subject of a previous EMRP joint research project, ENG07 "Metrology for High Voltage Direct Current". There is a need to build on the investigation in this previous project in order to complement it with work oriented towards increased efficiency and security of traditional alternating current as energy carrier, to achieve the full potential of renewable energy and support for the creation of a pan-European energy market.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on "Grand Challenges" related to Energy and Environment on pages 23 and 24.

Keywords

High Voltage Transmission, Electricity Transport, Energy Losses, Loss Measurement, Dielectric Testing, Lightning Impulse, Energy Metering, Monitoring, Partial Discharge Measurement

Background to the Metrological Challenges

Losses in the grid represent large costs and a potential for reduction of CO_2 emission if they can be reduced. Accurate determination of the loss plays a decisive role in the comparison of the performance between different designs of HVDC convertors. The measurement of losses in voltage source converters has been studied in EMRP JRP ENG07, where good results have been obtained for single components and modular stacks [1]. The project has also made contribution to written standards for converters by participation in IEC TC22F. Methods to measure the loss of entire convertor stations have been studied for the exceptional case that the station can be re-configured to a back-to-back mode [2]. This is rarely possible, which means that methods to measure the losses directly between AC and DC sides are required. At present it is not possible to perform such measurements with the required accuracy as the loss is the small difference between the input power and the output power. The measurement of losses of large transformers and reactors poses a similar problem since the power factor to be measured is close to zero, and reference calibration systems are very difficult to realise.

In the production of equipment for high voltage grids, dielectric testing is performed to prove that it can withstand the electrical environment in use. Methods and schemes for calibration have been identified primarily in IEC 60060-2 [3]. The system voltages are however increasing to levels higher than those covered by this standard, and there is strong need to extend the methods into the ultra-high voltage range. Traceability of HV testing of high voltage equipment is an important tool to ensure high quality and reliability of the products tested. For example, lightning impulse voltage measurement systems are typically calibrated at 500 kV, together with additional measures to extrapolate the linearity up to 2500 kV. Transmission voltages are increasing in the world and testing at higher voltages than 2500 kV are now required and are currently studied within the frame of International Council on Large Electric Systems, CIGRE [4]. At present, extrapolation by a factor of 5 is permitted, but there is no scientific proof that higher extrapolation factors are reliable, especially at the very high voltages contemplated. On the contrary, the experience is that the extrapolation to higher voltages does not provide proper proof of correct operation. Research is needed to determine the methods required for calibration on these voltage levels above 500 kV.

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The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

The reliability of the grid can be affected by its response to power quality influences, e.g. interaction between AC and DC circuits or impact of harmonic currents injected into the grid. Accurate knowledge of the state of the grid and its components is essential in assessing the need for maintenance or the replacement of equipment that approaches end-of-life. Such knowledge is also necessary to estimate component loading in adverse operating conditions. One example of the latter is the poor knowledge of the impedance of the grid at frequencies other than the fundamental. Work in JRP ENG07 has provided basic modelling of the grid for harmonic frequencies. Methods to measure harmonic impedance needs to be developed. Behaviour in the transient regime is also poorly understood.

The reliability and credibility of metering of transmitted energy is crucial for the de-regulated electricity market. Although electrical energy has been metered for some time, there are issues regarding effects of phenomena on the grid that are not well handled, e.g. the influence of harmonics and/or transients on the performance of the energy metering system. An increase in the use of convertors in the electrical grid has led to large harmonic components being present. Mitigation of the unfavourable effects needs to be based on measurements. Current voltage transformers cannot be relied upon to have a good response at higher frequencies, a fact that has been recognised by IEC standardisation for instrument transformers [5, 6]. To inject and measure harmonics at high voltage or current is in itself daunting but, in addition, the possible interaction between fundamental and harmonics due to non-linearities in the measuring device must be considered. Transient phenomena in the high voltage grid can be transmitted to the secondary circuit and possibly cause damage to the energy meter. A test has been designed by IEC for instrument transformers [7] where a fast, low-voltage, pulse is applied to the primary connection and the response is measured at the low voltage connection. Methods to perform this measurement are not yet fully consolidated.

Scientific and Technological Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP-Protocol.

The JRP shall focus on the traceable measurement and characterisation of high voltage energy transmission.

The specific objectives are

1. To develop enhanced loss measurement capabilities of grid components including measurement of losses of HVDC convertor stations and their components, calibration capability for measurement of loss power at high voltage and current, and methods to verify losses of power cables in both single-phase and three-phase configurations.
2. To extend the metrological capabilities underpinning HV testing by extension of the voltage range of calibration facilities for impulse voltages to cover the needs of the Ultra-High Voltage (UHV) regime, the extension of the bandwidth of calibration facilities for impulse voltages to cover the Very Fast Transient (VFT) regime, and the extension of calibration facilities for impulse currents, including fast rise time determination.
3. To develop metrological tools for enhancing grid reliability including theory and measurements for interaction between AC and DC circuits on the same (or close-by) towers, the use of grid modelling to study grid behaviour in harmonic and/or transient regimes, calibration methods for monitoring systems based on partial discharge (PD) pattern recognition, and calibration methods and algorithms for the calibration of diagnosis systems for power cables based on tests at Very Low Frequency (VLF).
4. To research the factors affecting metering accuracy and the realisation of versatile grid current sensors by the development of methods and equipment for the determination of the harmonic response of instrument transformers with the fundamental present, the development of non-invasive current sensors applicable for in-situ current transformer (CT) calibration and revenue metering at system voltages up to 400 kV, the characterisation of CTs with respect to the influence of nearby phase currents, and the development of traceability for the measurement of transmitted transients in instrument transformers.

If Proposers take the view that these objectives are too extensive for the available budget, they should prioritise them based on documented stakeholder needs, and explain their reasoning in the JRP-Protocol.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the R&D work, the involvement of the user community such as industry, and standardisation and regulatory bodies, as appropriate, is strongly recommended.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of EMRP projects ENG07 “Metrology for High Voltage Direct Current” and ENG04 “Metrology for Smart Electrical Grids” and how their proposal will build on those.

EURAMET expects the average size of JRPs in this call to be between 3.0 to 3.5 M€, and has defined an upper limit of 5 M€ for any project. The available budget for integral Research Excellence Grants is 30 months of effort.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

You should detail how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies
- transfer knowledge to the high voltage testing and energy network sectors.

You should detail other impacts of your proposed JRP as detailed in the document “Guide 4: Writing a Joint Research Project”

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology and includes the best available contributions from across the metrology community. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] V. Ermel, *et al.*, "Traceable Measurement of Power Losses in HVDC Converter Valves," presented at the 17th International Symposium on High Voltage Engineering ISH 2011, Hannover, Germany, 2011

[2] A. Bergman, "Analysis of metrological requirements for electrical measurement of HVDC station losses," *IEEE Transactions on Instrumentation and Measurement,* vol. 61, 2012

[3] IEC 60060-2: 2011, High Voltage Test Techniques - Part 2: Measuring systems

[4] U. Riechert. (2010, *Proposal for creation of a new working group: Special requirements for dielectric testing of Ultra High Voltage (UHV) equipment*. Available: https://www.electrosuisse.ch/fileadmin/user_upload_electrosuisse/Verband/Cigre/TOR/TOR_D1/TOR-WG_D1.36.pdf

[5] IEC TR 61869-103: 2012, Instrument transformers - Use of instrument transformers for PQ measurements

[6] J. Meyer, et al., "Accuracy of harmonic voltage measurements in the frequency range up to 5 kHz using conventional instrument transformers," presented at the CIRED 21, International Conference on Electricity Distribution, Frankfurt, Germany, 2011

[7] IEC 61869-1: 2007, Instrument transformers - General requirements