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Report from RISE Research Institutes of Sweden within the field of Electrical Metrology

Organisation

RISE Research Institutes of Sweden is organized in five divisions: Bioeconomy and Health, Digital Systems, Materials and Production, Safety and Transport, and Built Environment. RISE operates from some 35 sites all over Sweden plus a few abroad. The headquarter is located in Gothenburg. RISE has a staff of 2800 and a yearly turnover of 370 M€. The Swedish state is the sole owner of RISE.

RISE have the assignment as Sweden's National Metrology Institute (NMI). The activities as NMI is coordinated by the Department for Measurement Science and Technology which is part of the Safety and Transport Division. This Department also holds most of the staff working in the field of metrology or quality assured measurements, about 160 employees. Professor Jan Johansson is the NMI director.

Technical news since CCEM meeting in 2023

Subfield DC, LF and Quantum metrology

RISE has completed its first foray into using the ac-quantum Hall effect in graphene for impedance measurements. The project (GAME) has led to the development of measurement systems and graphene samples for the realization of electrical ac resistance. RISE has produced graphene samples adapted for alternating current, designed and constructed a measuring probe and sample holder and carried out comparison measurements. The experiments were performed up to 4 kHz and the measurement results were comparable with other laboratories (uncertainty on the order of ppm). A new project has been initiated (VARG) which will continue to improve the methods and reduce uncertainties.

We have continued to develop the technology behind quantum Hall array resistance standards (QHARS). The work has resulted in a fruitful collaboration with Measurements International Ltd., which has led to the creation of commercially available QHARS devices with a wide range of resistance values. Some initial results have been presented in conferences [A1].

In addition, a new approach to QHARS has been initiated in a project (PROGRESS) that aims to develop programmable arrays by using, for instance, p-n junctions in graphene.

RISE is also involved in the recent European project on advanced quantum technology for metrology of electrical currents (AQuanTEC), in which RISE will provide high-ohmic arrays to be used to realize the ampere in a wider range of values.

References:

[A1] A. Pollarolo, K. Wendler, H. He, K. Cedergren, and R. Brown, "Calibration of room-temperature ratio bridge with graphene quantum Hall array device," *CPEM Dig. (Conference Precis. Electromagn. Meas.*, pp. 1–2, 2024, doi: 10.1109/CPEM61406.2024.10646042.

Subfield High voltage, Power and Energy

The EMPIR project 19ENG02 FutureEnergy [B1], concluded in 2023, developed traceability of HVDC up to 1200 kV with a claimed expanded measurement uncertainty of 20 μV/V approved Oct 2024. A stability study of the modular HVDC measurement system was published at CPEM 2022 [B2] with an unprecedented stability of the scale factor < 0.7 μV/V/yr of a RISE 1000 kV modular HVDC divider configuration. Stability has since been measured for the 1200 kV divider. The project extended linear extension methods for lightning impulse voltage calibration for testing of UHV equipment. It provided 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 %. Together with the intercomparison S42, concluded in 2020, new CMC claims for lightning impulse were claimed and approved Aug 2024. The project has further developed a new method for linearity determination of HV capacitors with a target calibration uncertainty for HVAC of 80 μV/V at 800 kV. Further, it was demonstrated implementation of partial discharge (PD) measurement techniques for testing of equipment under d.c. stress [B2], with specific emphasis on detection and prevention of insulation failures in HVDC cables, GIS and convertors.

The Supplementary Comparison EURAMET.EM-S36, "Calibration of high voltage partial discharge measurement systems" [B3] was piloted by RISE. The measurement campaign initiated in 2020 is complete and Draft B has been submitted to EURAMET for final review. The comparison consisted of 14 participants including members from APMP and SIM.

Two Supplementary Comparisons, EURAMET.EM-S46 and EURAMET.EM-S47 "High voltage comparison of DC ratio and high resistance" [B4] has been piloted by RISE with support from VSL and VTT. Both are complete and the Draft B was submitted Dec 2024. The comparisons started in Feb 2022 and will be completed 2025. Five systems 200 kV HVDC systems PTB, RISE, TUBITAK, VSL and VTT were collected at RISE for the 200 kV intercomparison. This was done in preparation of a 1200 kV intercomparison of EMPIR 19ENG02 FutureEnergy [B1], from which new and improved CMCs will be claimed for HVDC for RISE, PTB and TUBITAK.

RISE is participating in the EPM project "Metrology for digital substation instrumentation" [B5], with the aim to provide traceability for time synchronized sampling of voltages and currents in digital substations (21NMR02 Digital-IT). This project involves both time synchronisation to UTC and precise sampling of voltage and current.

In the ongoing EPM project 22NRM06 ADMIT [B6] traceability for wideband metrology from DC to 150 kHz was tackled for metrology of supraharmonics. An ongoing internal RMP research project has established the traceability chain for the supraharmonics. Calibration methods for both voltage and current have been established.

The most recent EPM project 23IND01 ENSURE [B7, B8] started in June 2024 with RISE as coordinator. This project develops traceability for live on-site calibrations of instrument transformers in substations in the power grids. It also access traceability of power transformer and HVAC cable losses to harmonics. It further provides tools for monitoring of PD and methods for fault locations in HVDC interties.

Traceability for composite and combined waves [B9] EMPIR 19NRM07 HVcom^2 is crucial for HV testing for which methods and measurement systems has been only roughly described in the IEC 60060 standard. This project designed the necessary metrology in terms of modular universal dividers required for the standardization of high voltage testing with composite and combined wave shapes [B10, B11]. In order to address the current lack of traceability, traceable measurement systems and calibration services has been developed for composite and combined wave shapes [B12], and the relationship between impulse voltages with High Voltage Alternating Current (HVAC) or High Voltage Direct Current (HVDC) measurements was determined. The project has provided input to the current revision of IEC 60060-2. RISE has developed metrology for composite wave up to 1400 kV and combined wave up to 700 kV.

A challenge in the EPM project 24IND08 GridForm, starting in June 2025 and coordinated by RISE, will tackle traceability in characterisation of grid-forming converters. In the steadily growing renewables and energy storage in the power grids, these new inverters are a must to stabilize a renewable-rich power grid. The amount of using standard grid-following converters to stabilize the power grid has hard limits, replacing generators with large rotating mass in the grid.

In the EPM project 24GRD05 ELITE initiating in May 2025, RISE will advance metrological techniques to improve the reproducibility and repeatability of steep voltage impulse measurements for puncture testing of insulators to ensure quality and representativeness of testing related to improved grid reliability and supply security.

References:

[B1] EMPIR 19ENG02 FutureEnergy ://www.epm-ensure.eu, https://www.ptb.de/empir2020/futureenergy/home/

[B2] Joni V. Klüss, Alf-Peter Elg and Claes Wingqvist, “High-Frequency Current Transformer Design and Implementation Considerations for Wideband Partial Discharge Applications”, IEEE Transactions on Instrumentation and Measurement, Vol. 70, 2021

[B3] Supplementary comparison, EURAMET.EM-S36, “Calibration of high voltage partial discharge measurement systems”, Draft B, https://www.bipm.org/kcdb/comparison?id=1282

[B4] Supplementary comparison, EURAMET.EM-S46, “High voltage DC ratio”, Draft B, https://www.bipm.org/kcdb/comparison?id=1819, and EURAMET.EM-S47, “High voltage comparison of high resistance”, Draft B, https://www.bipm.org/kcdb/comparison?id=1842

[B5] EPM project 21NRM02 DigitalIT, “Metrology for digital substation instrumentation”, https://www.euramet.org/repository/research-publications-repository-link

[B6] EPM project 22NRM06 ADMIT, “Characterisation of AC and DC MV instrument transformers in extended frequency range up to 150 kHz”, https://www.euramet.org/repository/research-publications-repository-link

[B7] EPM 23IND01 ENSURE, https://www.epm-ensure.eu/, accessed 25 February 2025.

[B8] Alf-Peter Elg, Gert Rietveld, et.al., “High-Voltage Metrology for Electric Energy and Supply Reliability”, CPEM 2024, Denver July 2024

[B9] EMPIR 19NRM07 HV-com^2: https://www.ptb.de/cms/en.html, accessed 27 February 2023

[B10] Alf-Peter Elg, Tatu Nieminen, Joni Klüss, Stephan Passon, Frank Gerdinand and Johann Meisner, “A Modular Universal Divider for Calibration of UHVDC and Composite Waves up to 1400kV”, Paper 645, ISH2023, Aug 2023, Glasgow

[B11] Alf-Peter Elg, Andreas Nilsson and Tatu Nieminen, “Reference Measurement System for Traceability of Composite and Combined Waves”, Paper 646, ISH2023, Aug 2023, Glasgow

[B12] J. Havunen, J. Hällström, J. Meisner, F. Gerdinand, A.-P. Elg, “Design and Verification of a Calculable Composite Voltage Calibrator”, NordIS-22, Trondheim, Norway, June 13-15 2022.

Subfield RF and MW

The high frequency laboratory at RISE is participating in three EPM projects. The first one is 21NRM06 EMC-STD, a project that does research in new electromagnetic emissions test methods for harsh environments, fully traceable time-domain measurement techniques, new calibration methods for the response to pulses of receivers and the statistical evaluation of interferences in compliance assessments. RISE is the leader for WP5 in this project. The second EPM project is 21NRM03 MEWS, a project that aims to develop practical and efficient measurement methods to better match rapidly emerging radio technologies for 5G/6G product and system over-the-air testing, for wireless channels up to sub-THz, and for radio frequency exposure assessment. Both of these projects started in 2022. The third project is the 22RPT04 RFMicrowave2. This project aims for improving European RF&MW metrology, especially in smaller NMIs, and to strengthen the potential for future cooperation among European NMIs. RISE is the leader of WP2 in this project, which started in 2023.

RISE also had one internal project during this time period, starting in 2023 and ending in 2024. The aim of the project was to improve metrology for traceable calibration of antenna efficiency up to at least 18 GHz using a reverberation chamber.

The high frequency laboratory participated in the comparison EURAMET.RF-S46, for the calibration of magnetic field strength in the frequency range up to 30 MHz. This comparison started in 2022 and the final report was handed in in 2024. RISE is also participating in the ongoing comparison CCEM-RF-K5d_2.4mm. This comparison is about measuring S-parameters in the 2.4 mm cable interface up to 50 GHz.

RISE is an active member of the Wireless Technology Centre, WITECH, which is a microwave research Centre of excellence financed by Vinnova and operated by Chalmers in collaboration with industry and RISE. WITECH is a continuation of the former GHz centre which resulted in excellent results [C1].

In December 2018 we were awarded funding for a PhD student to work on THz Metrology. The project resulted in a successful PhD defence in December 2024 [C2]. The thesis focussed on design, fabrication and characterization of harmonic mixers at frequencies from 2 – 4,5

THz. It has been in close collaboration with Chalmers university, Virginia Diodes (VDI) and the German Aerospace Center DLR.

References:

[C1] K. Karlsson, A. Lundberg, N. Arabäck and B. Bergqvist, "Test Level in Reverberation Chamber EMC Immunity Assessment Based on the Quantile to Average Ratio," *2022* International Symposium on Electromagnetic Compatibility – EMC Europe, Gothenburg, Sweden, 2022, pp. 178-182, doi: 10.1109/EMCEurope51680.2022.9901226.

[C2] Jayasankar, Divya, “Design and Characterisation of Terahertz Schottky Barrier Diode Mixers” Doctoral Thesis (2024) - ISBN: 9789181031317.

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