Publishable Summary for 17NRM01 TrafoLoss
Loss Measurements on Power Transformers and Reactors

Overview

Driven by the Ecodesign Directive 2009/125/EC, CENELEC TC14 “Power Transformers” has expressed the need for more accurate and reliable loss measurements of high-voltage power transformers and reactors, that allow to unambiguously prove that these products comply with specific efficiency requirements of this Directive. This project has addressed this need by developing new measurement systems for transformer and reactor loss measurements up to 230 kV and 2000 A with an uncertainty of better than 50 μW/VA, together with reference setups required for the calibration of these systems with uncertainties down to the 20 μW/VA level.

Need

Improved energy efficiency is one of the three targets of the EU 2020 Energy Strategy and a crucial theme in the whole energy chain from electricity generation, transmission, and distribution to the end user. Even small improvements in efficiency can have a large impact, for example when they are made in devices that convert large amounts of energy such as grid power transformers. Therefore, the Ecodesign Directive 2009/125/EC per 1 July 2015 requires all power transformer manufacturers to unambiguously prove that their products comply with specific efficiency requirements.

Power transformer manufacturers need reliable measurement tools to unambiguously demonstrate that their products meet energy efficiency claims and comply with the Ecodesign regulations. Energy efficiency is a key performance criterion for European manufacturers to distinguish themselves from lower-priced lower-quality competition from other parts of the world. To consolidate and further expand their competitive position, the European power transformer and reactor manufacturers expressed the need via CENELEC TC14 “Power Transformers” for systems that allow more accurate and reliable loss measurements than are currently available with industrial measurement systems.

Utility companies want to make informed buying decisions based on verified efficiency specifications. Since power transformer losses constitute a very significant part of the total cost of ownership of these devices, utility companies are calling for high-accuracy verification of the losses. Increased measurement capabilities are also essential to market surveillance authorities (MSAs) in terms of carrying out their role ensuring fair competition and adherence to the Ecodesign regulations.

Industrial loss measurement systems (LMS) available at the start of the project were limited in accuracy to 100 – 300 µW/VA. That was insufficient to meet the need for measurement uncertainties of 50 µW/VA or better, and in turn required primary reference setups with 2–3 times lower uncertainties than those developed within the 14IND08 ELPOW project. Given the complexity of high-end loss measurements, CENELEC TC14 also expressed the need for guidance in measurement uncertainty evaluation.

Objectives

The overall goal of the project was to directly address the need expressed by CENELEC TC 14 “Power Transformers” for metrology research in the area of power transformers and power reactors. The specific objectives of the project addressing this need were:

1. Development of improved measurement techniques and prototypes for highly accurate measuring systems used for loss measurements of power transformers and reactors at very low power factor. The target accuracy was better than 50 µW/VA, at voltage levels of up to at least 230 kV, and current levels of up to at least 2 kA.
2. Development of reference calibration facilities capable of validating the outputs from objective 1. The goal was to generate and measure active loss power at very low power factors under laboratory and industrial

conditions, to enable validation of the system performance. The target accuracy was better than 20 µW/VA, at voltage levels of up to at least 230 kV, and current levels of up to at least 2 kA.

3. Study of the effects of using non-sinusoidal test signals on the final accuracy of loss measurements and to produce guidelines for evaluating the complex measurement uncertainties associated with loss measurements of high-power, high-efficiency power transformers and large reactors, in order to ensure an EU-wide common and correct approach.
4. Facilitation of the take up of methods, technology and measurement infrastructure developed in the project by the standards developing organisations such as IEC TC14 and CENELEC TC14. To ensure that the outputs of the project were aligned with their need, communicated quickly to those developing the standards and to those who will use them, and in a form that can be incorporated into the standards at the earliest opportunity. In addition, dissemination of the outputs of the project to MSA, and ensure their take up by instrument and power transformer manufacturers.

Progress beyond the state of the art

Advanced industrial Loss Measurement Systems (LMS)

Commercial LMS are widely used by High Voltage (HV) transformer and reactor manufacturers. Typical state-of-the-art accuracies in industrial loss measurements are in the range of 1-3 % for power factors down to 0.01, corresponding to a LMS uncertainty of 100–300 µW/VA. Driven by the Ecodesign Directive, utility companies have called for 3-5 % accuracies down to a power factor of 0.001, particularly for shunt reactors, requiring LMS uncertainties of 30-50 µW/VA. New high-voltage measurement techniques including prototypes have been realised by this project that allow this factor of 2–5 improvement in uncertainty with respect to the current state of the art. A further major advantage of the new techniques is that they will allow three-phase loss measurement of reactors, resulting in significant time saving during tests.

Primary reference setup for calibration of advanced industrial LMS

In the 14IND08 ELPOW project, a reference setup for *reactor* loss measurement was produced with a voltage range of 500 V, as well as reference setups for calibration of transformer LMS up to 100 kV but with an uncertainty of only 50 µW/VA. As required by the power transformer community, this project has realised the extension of this reactor measurement setup to the multi-kV range whilst still maintaining high accuracy: primary reference setups for LMS calibration at National Metrology Institutes (NMIs) have been improved by a factor of 2– 5 in uncertainty to better than 20 µW/VA.

Uncertainty evaluation of loss measurements

An important extension of the state of the art is a study of detrimental factors that occur on-site in the industrial environment where these systems are used, such as interference and non-sinusoidal input signals. This will ensure that the required challenging uncertainties can be achieved by industrial end-users. Given the complexity of loss measurements, the uncertainty evaluation of these measurements is also complex. Therefore, the project has developed a good practice guide to provide end-users with the necessary guidance in this uncertainty evaluation, extending the present guidance of the IEC 60076-19 standard.

<table>
<tr><th></th><th>Industrial
state of the art at start of project</th><th>14IND08 ELPOW</th><th>Result of TrafoLoss project</th></tr>
<tr><td>Industrial reactor loss</td><td>100 µW/V
single phase</td><td></td><td rowspan="2">50 µW/VA up to 230 kV three-phase</td></tr>
<tr><td>Industrial transformer loss</td><td>100–300 µW/VA up to 100 kV three phase</td><td></td></tr>
<tr><td>Primary reference reactor loss</td><td></td><td>10 µW/VA up to 0.5 kV</td><td rowspan="2">10 µW/VA up to 0.5 kV
20 µW/VA up to 230 kV</td></tr>
<tr><td>Primary reference transformer loss</td><td></td><td>50 µW/VA up to 100 kV</td></tr>
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Results

Advanced industrial LMS

A key part of the project is the development of an advanced industrial LMS to move the present 50 μW/VA uncertainty of the 14IND08 ELPOW transformer loss measurement calibration setup from the NMI laboratory to the power transformer industry test floor. This will be a factor 2–5 improvement in total system uncertainty with respect to the current state of the art. Overall LMS system requirements have been defined based on existing literature and the results of a questionnaire, filled out by 13 stakeholders with their requirements concerning advanced LMS measurement range and accuracy.

Since the weakest point of the present industrial LMSs is in the voltage channels, two complementary HV measurement techniques have been designed and constructed: a new high-accuracy inductive voltage divider, and a capacitive divider with buffered output voltage. The inductive voltage divider is based on a standard voltage transformer which uses two passive error compensation methods, standard and variable. The technical approach of the capacitive divider concentrated on developing an active low-voltage arm that can be used together with any gas-compressed capacitor as high-voltage arm. Both the inductive and capacitive divider have been realised and tested under reference laboratory conditions. Following the successful completion of these tests, the new capacitive voltage divider has been implemented in a test system of a reactor manufacturer, GE Grid Solutions Ltd, and has been used on-site to measure the losses of several reactors.

All voltage channels developed in the project, including those of the LMS reference setups, have been evaluated in the summer of 2021 at the premises of one of the project partners against its high-accuracy high-voltage reference standard. To this end, this reference standard has been carefully evaluated and improved in accuracy to better than 10 μV/V and 10 µrad for voltage up to 100 kV. Both developed industrial LMS voltage channels met the requirement of 40 µV/V ratio error during the verification tests. The inductive LMS voltage channel had slightly higher phase displacements exceeding the limit of 30 µrad but this can be corrected for via software. The capacitive LMS voltage channel was working almost as good as a reference standard since the phase displacement was typically within 10 µrad.

In conclusion, the first JRP objective of developing improved measurement techniques and prototype voltage channels for highly accurate measuring systems used for loss measurements of power transformers and reactors at very low power factor with at least 50 μW/VA uncertainty up to 230 kV and 2 kA has been met.

Primary reference setup for calibration of advanced industrial LMS

For the calibration of future commercial advanced LMS products, two NMI primary reference setups with complementary measurement approaches have been constructed that are a factor of 2–5 better in uncertainty than the 50 μW/VA setups of the previous 14IND08 ELPOW project. One of the reference setups has an extended measurement range of 230 kV in order to cover HV reactor loss measurements as well.

Several lines of research have been followed to enhance the uncertainty of the present NMI primary power transformer reference setups by a factor of 2–5 to better than 20 μW/VA. These include:

- Development of new three-stage electronically-compensated current transformers (CTs) for the accurate measurement of test currents ranging from 1 A to 2000 A with an uncertainty of better than 10 μA/A in magnitude and 10 μrad in phase displacement. After several modifications, the final version showed uncertainties of 5-10 μA/A in magnitude and better than 10 μrad in phase displacement.
- Development and characterisation of a new sampling power measurement technique, especially for the low power factors relevant for transformer loss measurements. After an extensive evaluation, the measurement uncertainty in the (low-voltage) power measurement has been reduced to less than 10 μW/VA.
- Evaluation of the voltage scaling technique of one of the reference setups, based on a high-voltage capacitor and current-comparator-based low-voltage electronics. Comparison of the calibration results of the components of the voltage divider and the divider as a whole showed agreement in phase displacement to better than 4 μrad (0.012 min) for voltages up to 100 kV.
- An improved reference HV transformer has been compared with the voltage channel of one of the LMS reference setups. For the 100 kV range of both systems, an agreement of better than 3 µV/V in ratio error and 4 µrad in phase displacement was achieved – well within the respective measurement uncertainties.

- The improvements in current scaling, voltage scaling and power measurement capabilities together have resulted in achieving the required 20 µW/VA uncertainty in the overall LMS calibration.
- Use of the complete NMI primary reference setups in calibrations of industrial LMS at the premises of power transformer manufacturers. Based on these experiences, many improvements have been made in grounding, shielding and software algorithms to lower the noise and to assure that the 20 µW/VA measurement uncertainty also is achieved under actual industrial conditions.
- A HV parallel plate capacitor has been rebuilt and has been successfully evaluated. This is a key instrument for determining the absolute value and voltage dependence of the dissipation factor (tan δ) of HV capacitors used in the voltage channels of the reference setups. However, in the process of increasing the operating voltage, a unforeseen problem with mechanical vibration was discovered. Some further experiments are planned to resolve this problem. A commercial high-voltage capacitance bridge (HVCB) has been improved and characterised in order to realise the uncertainties needed to support the intended final DF measurements. The evaluated uncertainty of the bridge is better than 1 part in 10^6 in both magnitude and phase for ratios from 1.1 to 1:100.

A good practice guide on LMS calibration has been prepared, summarising the advantages and disadvantages of LMS component and system calibration, including a discussion of the achievable uncertainties. The guide also discusses calibration intervals and cross-checks versus risk. The contents of the good practice guide have been used to train DNVGL–KEMA inspectors of power transformers. Based on the guide, also a paper has been prepared that has been presented to the wider power transformer industry at the ICTRAM'2019 conference. The feedback received at these occasions was used to prepare a final version of the guide.

An important aspect of research in the project was the study of additional detrimental factors that occur on-site in the industrial environment where these NMI reference systems are used, such as signal pollution, interference, amplitude and frequency instability of the applied test voltage, etc. This study has greatly contributed to achieving the required uncertainties in the sometimes very harsh end-user environments. The results of the study have been added as lessons-learnt to the good practice guide.

In conclusion, the second JRP objective of realising 2 NMI reference setups capable of performing a system calibration of industrial LMS at very low power factors with at least 20 µW/VA uncertainty up to 230 kV and 2 kA voltage and current levels has been realised.

Uncertainty evaluation of loss measurements

Given the technical complexity of accurate loss measurements, the uncertainty evaluation of transformer and reactor loss measurements is also complex. The project has provided the necessary guidance for power transformer and reactor manufacturers for the measurement uncertainty evaluation of their products. To this end, extensive input was provided to the present revision of the IEC/TS 60076-19 standard (version 2013) on uncertainty evaluation of power transformer loss tests. In addition, the IEC and CENCELEC 60076-19 standards have been extended by the project to include the uncertainty evaluation of reactor loss measurements. To this end, a mathematical model function was developed, and sample calculations were prepared.

A final important step forward with respect to the state-of-the-art has been a study on the effects of non-sinusoidal waveforms on loss measurement uncertainty in particular occurring during no-load loss (NLL) tests of power transformers. Several sets of NLL waveforms occurring during actual transformer tests have been recorded and analysed. One of the main outcomes of the analysis of these waveforms is that the impedance of the generator used in the NLL tests is quite important: for the highest voltages, where the voltage waveform becomes distorted due to the higher currents, the transformer starts to generate harmonic power so that the total loss power is slightly reduced with respect to the power at the fundamental grid frequency. A further important result of the study is the finding that the bandwidth of typical components in most modern LMSs will have sufficient bandwidth for reliable loss measurements. The main impact of any harmonics present will be on voltage in case conventional voltage transformers are used, but even then, an accuracy of better than 10 % for the harmonic power losses can be expected for bandwidths up to 1 kHz. Capacitive voltage dividers have sufficient bandwidth to ensure a reliable measurement with likely better than 1 % accuracy up to 1 kHz.

In conclusion, the third JRP objective has been successfully achieved since new insight has been obtained on the effects of using non-sinusoidal test signals on the final accuracy of loss measurements, and a guideline has been produced for evaluating the measurement uncertainties associated with reactor loss measurements.

Impact

The main overall impact of the project lies in the metrology support it has provided for successful implementation of the Ecodesign Directive 2009/125/EC on power transformer efficiency, which positively impacts European industry, NMIs, market surveillance authorities and standardisation development organisations. The project has disseminated its aims and results to a variety of stakeholders via 2 international stakeholder workshops, 16 conference presentations, 9 peer-reviewed papers, its website, a training course on “Power Transformer Loss Measurements: Accuracy, Calibration, Traceability & Uncertainty evaluation”, and via input to standards development organisations, in particular to CENELEC TC14 “Power transformers”.

A major achievement is the extensive early uptake of the project results by the stakeholder community: one of the new LMS voltage channels has been used in actual on-site loss measurements of reactors at the premises of GE Grid Solutions Ltd, whereas the two primary reference setups for on-site system calibration of power transformer loss measurement systems have already been used more than 20 times for on-site LMS calibrations at stakeholder premises.

Impact on industrial and other user communities

The project has stimulated innovation and impacted the competitiveness of the European HV manufacturing and test industries by providing them with advanced measurement systems for unambiguous determination of the quality of their products. The reduced uncertainty that this new instrumentation allows for in loss measurements can be used to reduce safety margins proportionately, thus decreasing production costs. This will support the European electrical power industry in keeping its competitive advantage with respect to lower-priced but also lower-quality competitors. The development of the ultra-accurate measurement technologies, including two industrial prototype implementations, has kept the European transformer and instrumentation industry at the forefront of industrial loss measurements of power transformers and reactors. An early impact of the project was achieved via testing of the new industrial prototype voltage divider at the premises of a reactor manufacturer, GE Grid Solutions Ltd. The subsequent use of the voltage divider in testing of several HV reactors proved that lower test uncertainties indeed can be achieved with the new instrumentation. Following this proof of the new technology, one unit of the final voltage divider has been sold to a test laboratory to be used for reactor loss measurements.

Next to the new industrial LMS facilities, improved calibration services have been established that provide power transformer and reactor manufacturers and MSAs with access to on-site calibration of such LMS facilities at voltages up to 230 kV and currents up to 2 kA. A major uptake of the project results are the on-site calibrations of industrial transformer LMSs using the improved reference setups developed in the project at among others Royal Smit Transformers, ABB, GE, SGB, Best, Eltaş, Astor, STD, BETA, Sönmez, Schneider, Maksan, and Ulusoy.

These on-site calibration activities and the voltage divider testing are important verifications of the accuracy of new instrumentation developed in the project under actual on-site conditions at stakeholder premises, ensuring that the developed instrumentation will indeed achieve the envisaged impact.

The good practice guide for LMS calibrations under development by the project will be beneficial for ensuring a uniform approach in Europe for LMS calibration and support consistency in loss measurement results in tests performed by power transformer and reactor manufacturers. An early uptake of this knowledge has been achieved via the training of DNVGL-KEMA inspection experts in the HV industry on several aspects of Power Transformer Loss Measurements such as accuracy, calibration, traceability and uncertainty evaluation. Based on the guide, also a paper has been presented to the wider power transformer industry at the ICTRAM’2019 conference. The feedback received at these occasions has been used to prepare the final version of the LMS calibration guide.

Two highly successful stakeholder workshops have been held. The workshops were held in September 2019 and June 2021 respectively, and advertised and held together with the 17IND06 FutureGrid II JRP. Both workshops were attended by more than 70 participants. Updates were presented of the projects progress and final results via two project overview presentations, followed by lively discussions. The presentations (both sheets and videos) of the final stakeholder workshop can be found here.

Impact on the metrology and scientific communities

The project has developed leading edge HV measurement technologies, not only via the primary reference setups for NMIs (reflected in new Calibration and Measurement Capabilities (CMCs)), but also via advanced industrial LMS with unprecedented accuracy for the power transformer industry. Knowledge dissemination to the academic and metrology community has been done at the mid-term and final stakeholder workshops and at the AMPS 2019 conference. Furthermore, the project results have been published in 9 peer-reviewed papers, and via 16 presentations at the CPEM 2018, ISH2019, AMPS2019, ICTRAM2019, CPEM2020 and I2MTC 2021 conferences.

The project objectives and progress have been presented to the attendants of the 2018, 2019 and 2020 meetings of the EURAMET TC-EM contact persons. The project results have also been presented to metrology specialists in the area of the project at the May 2019 and May 2021 meetings of the EURAMET TC-EM Sub-committee “Power and Energy” experts group. The project partners have cooperated with the national metrology institutes of China (NIM) and Australia (NMIA) on the subject of transformer loss measurement reference systems. A formal collaboration agreement was signed with NIM, and as part of this collaboration a NIM researcher has worked for 3 months with one of the project partners on the development and characterisation of a reference setup of LMS calibrations. Further collaboration was started with JV (Norway) on improvement of primary power measurement techniques that are the basis for the power measurements in the LMS calibration reference setups.

A good practice guide for LMS calibrations has written that provides useful guidance to NMIs and industrial calibration laboratories performing these calibrations. The guide has been presented to the wider stakeholder community at the ICTRAM 2019 conference, and has been finalised based on the comments received during this conference. The final version has been made available to end-users such as transformer manufacturers and MSAs with the TrafoLoss website and via sharing with the CENELEC TC14 members.

Impact on relevant standards

The project has contributed to the implementation of the Ecodesign Directive 2009/125/EC, which restricts the losses of power transformers placed on the European market after 1 July 2015, via the development of industrial LMS and of primary reference setups for LMS system calibration and validation. The H2020 INTAS project supports MSAs via proper procedures and guidelines for market surveillance as required by the Ecodesign Directive and this project has provided input to this via participation in INTAS project surveys, via new expertise that is available for use in on-site test verifications and by attending INTAS project meetings, including the final INTAS project meeting in February 2019.

The project was a direct response to needs expressed by CENELEC TC 14 on loss measurements at very low power factors. The project R&D program and progress was presented at the 2018, 2019, 2020 and 2021 CENCELEC TC14 meetings, and useful feedback was received that steered the project activities. It was suggested and agreed by the TC14 members at the final project stakeholder workshop that the project work on uncertainty evaluation of reactor loss measurements will not be shared as a New Work Item Proposal (NWIP), but in the form of a report. The background for this decision is that the present revision of the IEC 60076-19 standard is taking much longer than expected and in fact still on-going, so that the submission of a NWIP is not opportune. When the project work is shared as a report, it is available for use in future improvements of the 60076-19 standard at the earliest convenience of IEC and CENELEC.

Longer-term economic, social and environmental impacts

The HV transmission network is the backbone of our electricity supply chain, and thus requires its components to meet the highest quality standards. The project’s results allow the European electrical power industry to produce grid components of the required high quality and to unambiguously demonstrate their performance at a level that was unavailable at the start of the project. The improved measurement uncertainties allow detection of the impact of small design improvements on transformer and reactor efficiency. It furthermore reduces the need to design products with ‘better-than-spec’ performance to guarantee ‘on-spec’ performance. The improved accuracy delivered by this project reduces the required safety margin and allows manufacturers to claim a guaranteed performance that is very close to the actual performance.

Given the large amounts of energy transmitted by power transformers, higher efficiencies and lower losses have an estimated saving potential of 3.7 Mt of CO_2 emissions per year. This project has underpinned the realisation of the European 2020 goals on higher efficiency, recognised by the EURAMET Strategic Research Agenda, via the development of a high-quality metrological infrastructure for loss measurements in power transformers and reactors. Without such an infrastructure, the requirements of the Ecodesign Directive could not have been successfully implemented by manufacturers nor monitored by MSAs, and this important area for energy savings would not have fully contributed to the goal of CO_2 reduction.

A secure and affordable electricity supply is of utmost importance for our society and specifically for European industry. The lower cost of ownership of transformers for utilities will lead to more affordable customer bills and reduced fuel poverty. The project also supported to the competitiveness of European HV power transformer and instrument manufacturing industry and thereby to secure high-quality jobs in Europe.

List of Publications

[1] E. Mohns, G. Roeissle, S. Fricke, and F. Pauling, "*A Sampling-Based Ratio Bridge for Calibrating Voltage Transformers*", Proceedings of the 2018 Conference on Precision Electromagnetic Measurements (CPEM 2018). DOI: 10.7795/EMPIR.17NRM01.CA.20190411 available online: https://doi.org/10.1109/CPEM.2018.8501245

[2] G. Rietveld, E. Mohns, E. Houtzager, H. Badura, and D. Hoogenboom, *"Comparison of two Reference Setups for Calibrating Power Transformer Loss Measurement Systems"*, Proceedings of the 2018 Conference on Precision Electromagnetic Measurements (CPEM 2018). DOI: 10.1109/TIM.2018.2879171, available online: 10.1109/TIM.2018.2879171

[3] E. Mohns, J. Chunyang, H. Badura, P. Raether, *"A Fundamental Step-Up Method for Standard Voltage Transformers Based on an Active Capacitive High-Voltage Divider"*, IEEE Trans. Instrum. Meas., Vol. 68, No. 6, pp. 2121 – 2128 (2019). DOI: 10.7795/EMPIR.17NRM01.CA.20190408 available online: https://oar.ptb.de/resources/show/10.7795/EMPIR.17NRM01.CA.20190408

[4] J. Havunen, E-P Suomalainen, J. Tornberg, J. Hällström, T. Lehtonen, and A. Merviö, *"Measuring Losses of an Air-Core Shunt Reactor with an Advanced Loss Measuring System"*, Proceedings of the 21st International Symposium on High Voltage Engineering (ISH 2019), pp. 1 – 6 (2019). DOI: 10.5281/zenodo.3521194 available online: https://zenodo.org/record/3521194#.XicW2Me7KUk

[5] A. Bergman, Allan Bergman, Bengt Jönsson, Gert Rietveld, Mathieu Sauzay, Jonathan Walmsley, and John-Bjarne Sund, *"Estimating Uncertainty in Loss Measurement of Power Transformers"*, Proceedings of the 21st International Symposium on High Voltage Engineering (ISH 2019), pp. 805 – 814 (2019). DOI: 10.5281/zenodo.3559837 available online: https://zenodo.org/record/3559837#.XicWrMe7KUk

[6] G. Rietveld, Ernest Houtzager, Dennis Hoogenboom, and Gu Ye, *"Reliable Power Transformer Efficiency Tests"*, Proceedings of the 5th International Colloquium Transformer Research and Asset Management (ICTRAM 2019), pp. 1 – 8 (2019). DOI: 10.5281/zenodo.3559845 available online: https://zenodo.org/record/3559845#.XicWhce7KUk

[7] G. Rietveld, E. Mohns, E. Houtzager, H. Badura, and D. Hoogenboom, *"Comparison of Reference Setups for Calibrating Power Transformer Loss Measurement Systems"*, IEEE Trans. Instrum. Meas., Vol. 68, No. 6, pp. 1732 – 1739 (2019). DOI: 10.1109/TIM.2018.2879171 available online: http://dx.doi.org/10.1109/TIM.2018.2879171

[8] G. Ye, W. Zhao, and G. Rietveld, "*Verification of high voltage divider with $10{\cdot}10^{-6}$ uncertainty*", Proceedings of the 2020 Conference Precision Electromagnetic Measurements (CPEM2020), pp. 1 – 2 (2020). DOI: 10.1109/CPEM49742.2020.9191889 and 10.5281/zenodo.5997015. Available online: https://ieeexplore.ieee.org/abstract/document/9191889

[9] Gu Ye, Wei Zhao, and Gert Rietveld, "*Verification of a capacitive high voltage divider with 6 µrad uncertainty up to 100 kV*", IEEE Transactions on Instrumentation and Measurement, vol. 70, 1004809, pp. 1 – 9 (2021). DOI: 10.1109/TIM.2021.3056647 available online: https://ieeexplore.ieee.org/document/9353488

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

17NRM01 TrafoLoss

<table>
<tr><td colspan="2">Project start date and duration:</td><td colspan="2">1 May 2018, 41 months</td></tr>
<tr><td colspan="4">Coordinator: Dr.ir. Gert Rietveld, VSL Tel: +31 15 2691645 E-mail: grietveld@vsl.nl
Project website address: www.trafoloss.eu</td></tr>
<tr><td colspan="2">Chief Stakeholder Organisation: ABB AB Power Transformers</td><td colspan="2">Chief Stakeholder Contact: Daniel Wikberg</td></tr>
<tr><td>Internal Funded Partners:
1 VSL, The Netherlands
2 RISE, Sweden
3 TUBITAK, Turkey
4 VTT, Finland</td><td colspan="2">External Funded Partners:
5 EPRO, Austria</td><td>Unfunded Partners:
6 PTB, Germany</td></tr>
<tr><td colspan="4">RMG1: JV, Norway (Employing organisation); VSL, The Netherlands (Guestworking organisation)</td></tr>
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