23IND01 - ENSURE ELECTRIC ENERGY AND SUPPLY RELIABILITY

SCIENTIFIC OBJECTIVES

On-site CT calibration

Optical current sensors for on-site calibration in substations reducing downtime and even live connection

Harmonics-induced loss in power transformers

New reference instrumentation for determination of the impact of grid harmonics on power transformer losses

Harmonics-induced losses in HVAC cables

New traceable metrology for the determination of the skin effect of HVAC cables using both calorimetric and electrical methods up to 3 kA

PD monitoring in HVDC grids

New PD monitoring and fault detection capabilities in DC cables at 100 kV and above for use in monitoring systems

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Webpage of the project

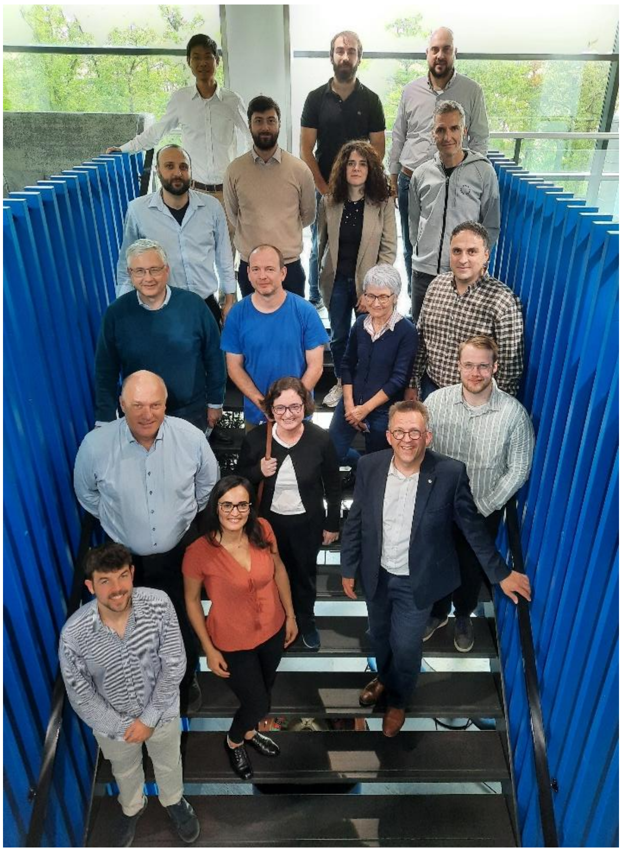
EUROPEAN PARTNERSHIP

Co-funded by the European Union

METROLOGY PARTNERSHIP

EURAMET

Novel metrology solutions to support HV manufacturing industry and grid operators



We welcome you to the 2nd newsletter in a series for the ENSURE EU-funded joint research project, which provides you with an impression of the first results achieved in the project which started 1 June 2024 and runs for three years until 31 May 2027.

The background for the ENSURE project lies in the fact that the amount of electricity generated from renewable sources needs to increase to meet the EU's aim of becoming carbon neutral by 2050. However, the connection of these renewable sources to the power grid causes harmonics which lower network power quality and increase electricity losses in e.g., power transformers and high voltage alternating current (HVAC) cables.

The ENSURE joint research project aims to tackle this problem by performing the metrology research necessary to support standardisation and the development of traceable tools for HV condition monitoring and fault detection as well as the means to ensure the reliable determination of losses in HV transformers and HV cables.

We hope you enjoy reading this second newsletter! Future newsletters will update you on the project progress and will present selected results from the research carried out. Please contact us if you want more information on a certain subject or are willing to cooperate with us in the research.

Upcoming stakeholder workshops

Book the dates

The first stakeholder workshop is arranged on April 15, at 13.00 – 17.00. The event will be on-line. Current progress and key results given in brief below in this newsletter, will be presented at this workshop with time for Q&A.

The second and final workshop before the end of the project will be in Paris May 23 – 27, 2027. Lab-visits and other events are planned so we recommend participating in person. For those who cannot attend we will make the workshop available on-line. More information of location in the coming newsletter.

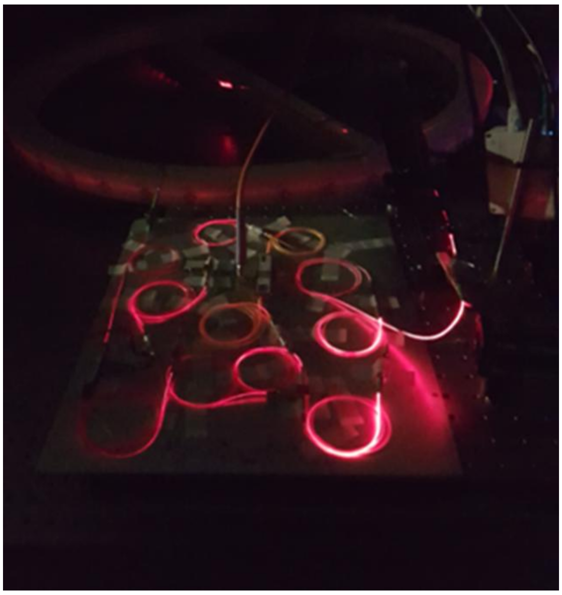
Need for the project

In the ongoing expansion of HV power grids, new power sources from renewables, wind, solar and battery power have been introduced. These sources use converters/inverters for interfacing to the grid, which pollutes it with harmonics. Harmonics will inevitably lead to increased losses in power transformers, especially in the older types, as well as in both overhead power lines and underground cables in HV grids.

HV grid operation needs new reference instrumentation both for the calibration of instrumentation in substations and for the monitoring of harmonics, to ensure stability and reliability. HV grid condition monitoring is crucial to ensure the reliability of the electricity grid. There is a strong industrial need for applying new partial discharge (PD) detection and is in particular relevant for monitoring HVDC systems.

Project extension of the state of the art

On-site CT calibration



Starting from the proof-of-concept fibre optics current sensor (FOCS) developed in EMRP JRP ENG61 Future Grid (Technology Readiness Level (TRL) 3), this project will progress beyond the state of the art by setting up a non-invasive optimised FOCS sensor as a new wideband reference.

The sensors' non-invasive design, and on-site live connection and measurement procedures, will be made available for use during the calibration phase. This will enable the positioning and measurement time to be minimised, and on-site live calibrations will be made possible with target uncertainties of 0.05 % of the fundamental current at up to 1 kA, thus reaching TRL 6.

Harmonics-induced loss in power transformers

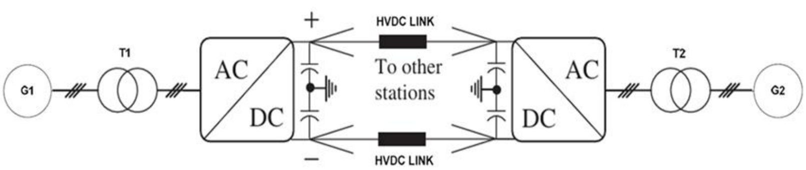
The verification of power transformer losses, in the presence of harmonics, requires systematic research with a traceable measurement system.

To get a systematic scientific inspection of the influence of harmonics on power transformer efficiency, the existing reference loss measurement systems need to be extended in frequency beyond the present power line frequencies (50 Hz – 60 Hz) to at least 2 kHz.

Harmonics-induced losses in HVAC cables

The techniques for measuring the ratio between the AC and DC resistance of a low loss cable have been established using both electrical and calorimetric measurement systems.

This project will go beyond the state of the art for both electrical, and especially calorimetric, methods for skin effect loss determination in HVAC cables, not only in the presence of the fundamental, but also in presence of harmonics.



PD monitoring in HVDC grids

This project aims to progress beyond the state of the art by developing innovative techniques for detecting online PD signals within HV cable systems that are subjected to sudden voltage changes like transients (e.g., lightning impulses, pole to ground faults at converter stations), and harmonics.

The project seeks to establish a reliable method for online PD monitoring (for the detection, classification and localisation of defects or damage before breakdown) in HVDC grids at 100 kV and above, which will be able to distinguish PD from transient noise.

Progress and key results

On-site CT calibration

Fibre Optic Current Sensor

The earlier design of the FOCS has undergone a major redesign. Some new components previously not available at the design wavelength 650 nm have been acquired. Using a circulator the optical power is better conserved in the system.

A detection scheme using ±π/2 square wave modulation according to Figure 4, the unbalance and its direction can be detected, and respective feedback signal generated. The modulation frequency is tuned to the fibre coil eigenfrequency An undoped HiBi Panda type spun fibre is used with a core diameter of 4.2 ± 0.3 µm. The cut-off wavelength is 560 ± 40 nm and spin pitch of 7 mm.

An openable clamp with inner diameter of with a hollow channel for fibre insertion has been designed to simplify mounting of the fibre in a switchyard and develop a method for live line in-situ calibrations.

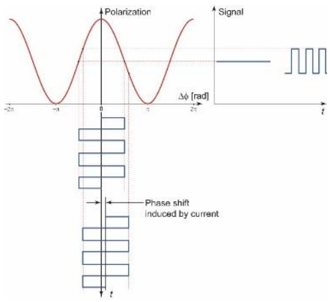
Sensors characterization under realistic substation influence quantities

Off-the-shelf Rogowski split-core current sensors have been selected, supported by Netico, as reference sensors for lab calibration under realistic substation conditions. A commercial split-core current transformer (SC-CT) has been identified as a potential non-optical sensor for use in HV substation. A FOCS sensor from NIM (China) will also be used as reference.

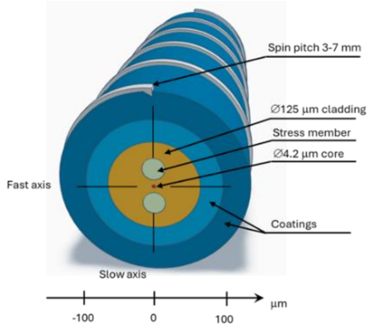
Remote calibration of CTs in substations

calibration approach and a strategic model were formulated to implement a remote synchrophasor-based calibration method for real-time determination of installed CT errors

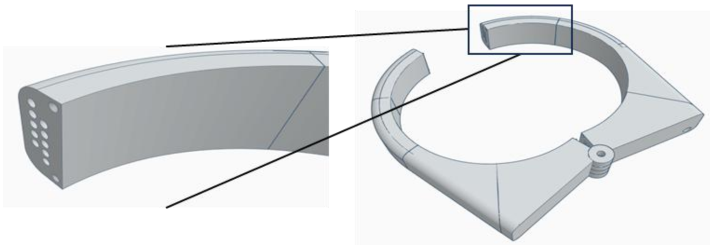
Detection scheme



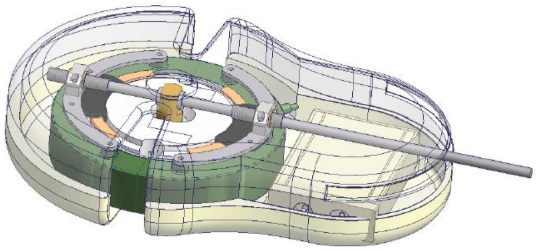
Spun fibre structure



Openable fibre spool for live connection



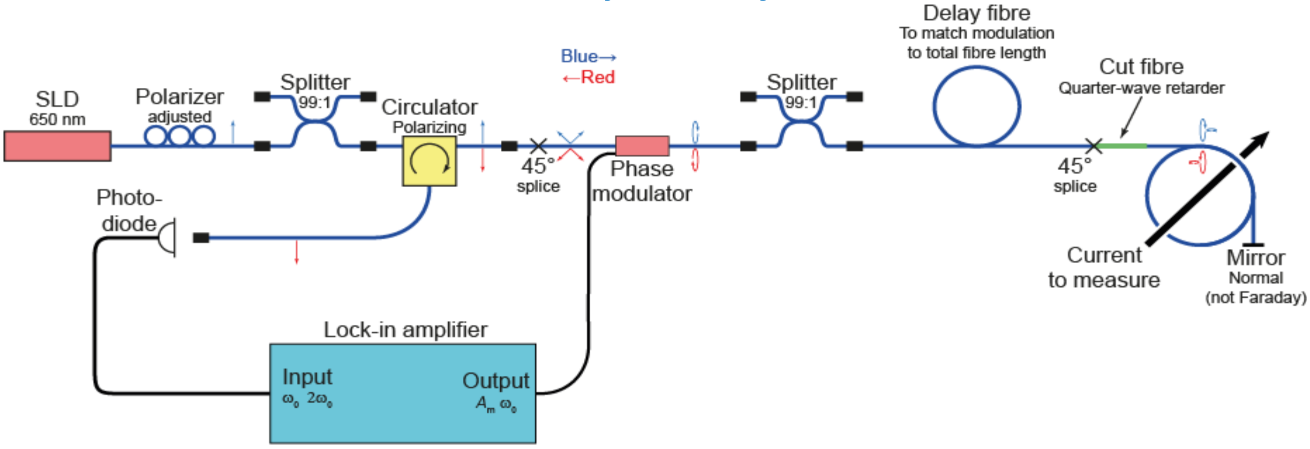
Split-core current transformer



On-site CT calibration – live connections

Contacts with two TSOs (Italy and France) and one Turkish TSO. Preliminary information exchanges hypotheses about possible substations for on-site tests under discussion.

FOCS system layout



Transformer harmonics losses

System requirements

Typical harmonic data of a transmission grid for harmonic grid analysis and stakeholder needs for loss measurements were collected. Overall system uncertainty requirements were determined for the harmonic loss reference setup to be developed and key component accuracy requirements for the harmonic loss reference setup were defined.
Also, a frequency-dependent analytical model of the harmonic losses from power transformers was developed.

Reference dividers

Existing reference wideband voltage dividers have been tested and found not to be stable enough in phase and suffer from proximity effects. Further dividers are being studied.

Reference instruments

An extensive verification of the phase displacement of the voltage channel in the harmonic loss reference setup with promising results.

Wideband current sensors

Measurement setups for wideband current sensors / transformers calibration were developed up to 2 kHz with better than 100 μrad phase uncertainty. A generation system of high value distorted currents up to 800 A / 50 Hz superimposed with harmonics up to 240 A / 2 kHz was set up.

Power transformer losses

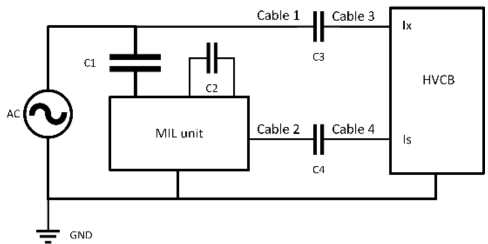
An experimental setup was developed for the wideband loss characterisation of power transformer materials, and the setup has been used for an evaluation of the harmonic losses in a laboratory autotransformer. An extended analytical model was developed for the modelling of harmonic losses in power transformers. Future work will include the evaluation of power transformer core material provided by the power transformer industry such as Royal SMIT Transformers and Siemens.

Loss references

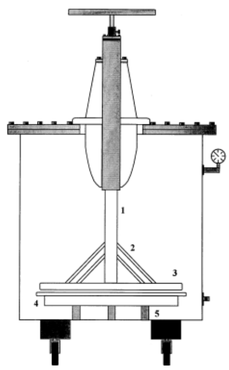
A 30 kV HV moving parallel plate reference capacitor is being modified for loss measurements. A reference measurement setup has been developed for calibration of the DF of HV capacitors up to 2 kHz. To facilitate these measurements, a wideband calibration of the reference HV capacitance bridge (HVCB) has been performed.

Characterization of universal divider

MIL unit calibration with HVCB



30 kV moving parallel plate HV capacitor



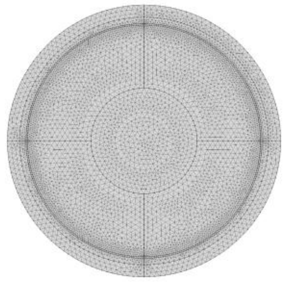
Harmonics-induced losses in HVAC cables

Review of methods and models

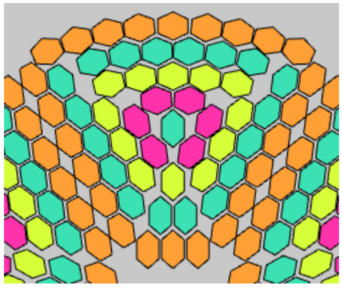
A review has been made of relevant literature related to skin effect measurements in MV and HV power cables using electrical methods, where two technical brochures CIGRE TB 272 and TB 894 are at its core.

A Multiphysics model of the losses from skin effect developed in EMPIR JRP 14IND08 ElPow is updated on the of the HVAC cable geometries using a model from NKT of the test samples and will include harmonics. The structure will be implemented in two electrical models, the SPACS to determine the theoretical skin effect k_s and the PSCAD supported by DIgSILENT. The proposed R_s factor in CIGRE TB 894 will be compared with the k_s factor used in the standard IEC 60287-1-1{ed3.0}.

10 488 nodes in Multiphysics for DC cable



Structure of an HVAC cable, NKT model



Calorimetric method

The set-up is designed for calorimetric and electric loss measurements on a 10 - 12 m long samples. Two low loss XLPE cable 220/380 kV, 3200 mm² Cu core cable and a 4000 mm² Al core cable was supplied by NKT.

With the calorimetric method the DC resistance is compared with AC resistance at 50 Hz up to 75 C°, and at 150 Hz at core temperatures up to 65 C°.

A passive thermal enclosure has been built to avoid thermal fluctuations around the cable important which is essential for the method. Cooling of the cable ends and connecting points of conductors was designed and built based on IGBT cooling pads purchased of the shelf.

Special attention was given to reduction of losses in the connection between the cable under test and the conductors for current injection. Cu sheaves were stacked and insulated between the connection points to reduced skin effect and heat losses.

A special power source, Kikusui 36 kVA, was used to induce currents in the test circuit via step-up transformers was used for heating the sample.

Owing to unique reactive compensation for each frequency, it was decided that testing will be performed with single frequencies, i.e. 150 Hz, 50 Hz and DC. The core of the cable under test is heated between 60 and 80 C°.

Experimental set-up for calorimetric method

Laminated Cu used to reduce losses

Electrical method

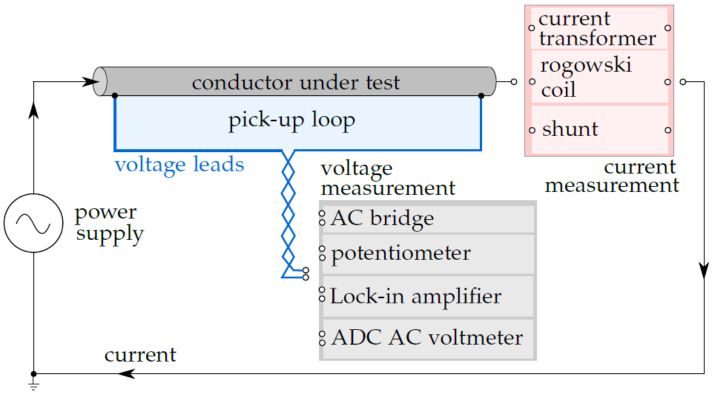
Two samples 220 kV XLPE cables have been selected for the loss measurements. Both with Cu conductors in a Milliken design with a cross-section between 1 000 mm² and 2 500 mm²

A phantom current generator was designed and bult to generate currents up to 2 kA (50 Hz) with superimposed harmonics up to 0.5 kA in the frequency range between 150 Hz and 1 kHz

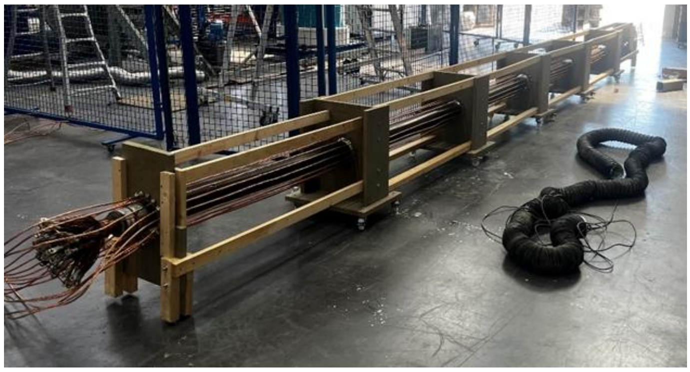
A coaxial rig was designed for studies and improvements of the electrical method. The first experimental set-up is currently measuring losses on an 8 m long XLPE 127/220(245) kV cable with 2500 mm² Cu core. Two test arrangements /methods have been applied and are being analysed.

A PSCAD-EMTDC model of losses using electric methods is being validated with test results. Initial models for two cables have been created. PSCAD software considers only solid or hollow cores, but no segmentation or stranded cores. CIRCE started developing a methodology to emulate a reduced skin effect using the available hollow core model.

Electric method measurement principle



Experimental set-up for electrical method



PD monitoring in HVDC grids

Mapping of HVDC lines in Spain to feed grid simulations of PD propagation in cables is ongoing.

PD test cells from an earlier project are used to learn detection of defects. PD from four different defects is considered, cavity, floating potential, surface and corona.

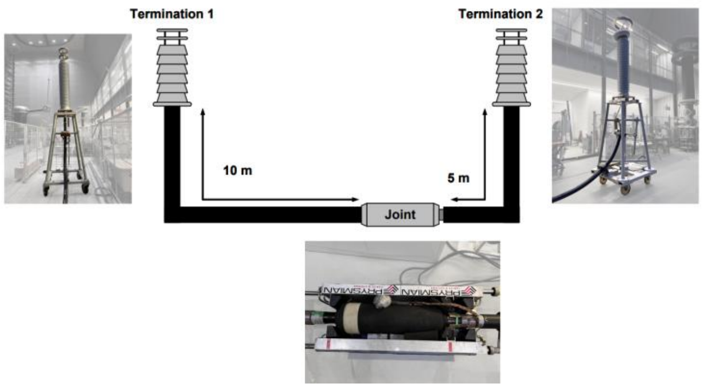
PD measurement in HVDC cables superimposed with transient over-voltages and harmonics

A setup to superimpose switching impulses + HVAC has been developed, which is going to be used to superimpose switching impulses + HVDC. Another setup is being prepared to superimpose HVDC + harmonics. Improvements to the partial discharge measurement systems are still being made. The use of a collaborator hardware is intended to be used in the measurements.

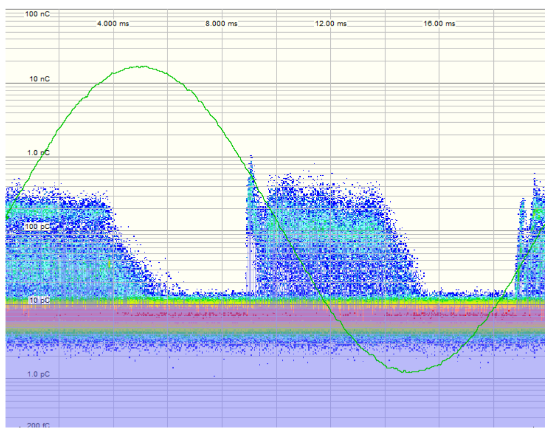
PD measurement procedure, on HVDC transmission grids

Validation of PD analyser are being prepared with support from two collaborators, at the REE-Inelfe substation between Spain and France, and another link in Germany supported by HIGHVOLT will be

Define setup and analysis techniques for PD detecting under HVDC + transients & harmonics



PD pattern – cavity



defined. Simulations of signal propagation in a HV cable have been done, and adjustment of the model to the converter station properties is ongoing to improve the simulation of the PD pulses behaviour in the border point between the cable system and the converter station.

A generator from the previous EMPIR 19ENG02 FutureEnergy project is being modified to generate PD series up to 2 seconds.

Fault location in HVDC systems

Literature has been collected and reviewed about short-circuits in HVDC systems. Transient signal behaviour has been studied and has been compared with the different kinds of HVAC faults with different kinds grounding systems.

A prototype sensor has been further developed to measure faults in HVAC and HVDC lines with aim to manufacture a second more robust version, for its use in on-site measuring conditions.

Simulations and studies of a test-bench to be used is ongoing and prototypes for the transient generation in low voltage have been studied and built. A simulation of the converter station has been made to improve the simulation of the fault signals transient behaviour in the border points between the cable system and the converter stations.

PD test cells – cavity

PD pattern generator

Consortium