Final Publishable JRP Summary for ENG61 FutureGrid
Non-conventional voltage and current sensors for future power grids

Overview

The drive for renewable and low carbon energy in Europe has led to more distributed energy sources, such as wind farms and solar power, being connected to the power network. The increased number of distributed sources means two way flow of electricity (e.g. from the customer side back into the grid) which can affect power quality and cause power quality degradation or blackouts. Hence, accurate and traceable measurements are a necessity to control the additional demands of future power grids. Many existing measurement instruments are approaching the end of their life span, and are not designed for a distributed network where power may flow from customer side. This project looked at non-conventional technologies that have the potential to be developed into new instruments capable of collecting more detailed information on the state of the power grid, to both replace current measurement transformers and monitor and control future power grids.

Need for the project

Europe is increasingly adopting alternative energy sources that have lower emissions and therefore contribute to meeting the EU's Horizon 2020 target of a 20 % of reduction in greenhouse gas emissions. The European power network is also evolving fast with the introduction with distributed solar and wind generators, which is changing the nature of measurements required. The connection of these distributed renewable energy sources to the electrical transmission grid means two-way flow of electricity, where previously it was only one way, and may lead to more harmonics (where the sinusoidal wave of the alternating current (AC) is altered) in the transmitted waveform, which can impact power quality.

In addition, the first generation of measurement systems installed in the European power network are becoming obsolete. Traditional instrument transformers often only work well for measurement of the fundamental (50 Hz or 60 Hz) frequency, and their performance is not good enough for measurement of power harmonics generated by distributed power sources. Therefore, there are new requirements for the measurement infrastructure for the power network in order to enable reliable and robust control and billing in future power networks.

Several novel, non-conventional voltage and current sensor technologies have shown great promise in enabling transportable, accurate measurement for power network harmonics. They are different types of sensors, which have the potential to replace traditional measurement transformers of medium and high voltage power lines. National Metrology Institutes (NMI) also need to be able to provide accurate calibration of new wider bandwidth sensors required for power quality measurements on medium and high voltage networks. However, at the start of the project, these technologies lacked the level of accuracy needed and were not mature enough for wider application for on-site calibration or power quality measurements on high voltage grids.

Scientific and technical objectives

The overall aim of the project was to support wider application of novel sensor technologies in future power networks. The first four objectives looked at different technologies, which were then calibrated and tested on real networks in the final two objectives:

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EMRP European Metrology Research Programme
Programme of EURAMET

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1. Design, manufacture and characterise a wideband sensor based on the optical Faraday Effect for traceable calibration of non-conventional and conventional current sensors on medium and high voltage networks. The target uncertainty for current measurement is below 100 µA/A.
2. Apply a magnetic shielding technique to a Rogowski coil to improve its applicability for onsite measurement and calibration. The target is to reduce the proximity related influence to below 10 µA/A.
3. Develop a precision voltage sensor for the calibration of non-conventional and conventional sensors in medium voltage networks. The target uncertainty for voltage measurement is below 100 µV/V and the target bandwidth is 5 kHz.
4. Develop traceability for new non-conventional techniques not yet commercially available, such as using a fibre Bragg grating for interrogation of sensor networks, or measurement of capacitive current flow through a high voltage capacitor for PQ measurements. The target uncertainties are below 0.2 % and 0.3 crad.
5. Test the applicability of the sensors developed in the project on existing medium voltage (c. 20 kV) and/or high voltage (c. 100 kV) substations.
6. Develop services for the calibration of transformers and non-conventional sensors with analogue and digital output in line with IEC 61850-9-2.

Results

Design, manufacture and characterise a wideband sensor based on the optical Faraday Effect

A fibre optic current sensor (FOCS) is a current sensor used for measuring direct current (DC), and is based on the Faraday Effect which describes the interaction between optical and magnetic properties. The project investigated possible solutions for the FOCS design, and a mathematical model was developed to describe the behaviour of the Faraday Effect in a fibre. Two improvements to the designs were introduced: working on lower wavelengths, and doping of the sensing fibre. Unfortunately, obtaining suitable fibres to reach the targets was more difficult than anticipated so only lower wavelength (650 nm) operation was demonstrated.

Experiments on a prototype working on stable laboratory conditions suffered from sensitivity to vibration, acoustic coupling and temperature changes, so an all-fibre system was designed which eliminated these problems. This all-fibre FOCS system was built, which uses a lower wavelength, 650 nm, than commercial systems.

The objective was to perform on-site calibrations with an uncertainty below 100 µA/A (0.01 %). However, the uncertainty demonstrated by the end of the project is 1 % in the range from 400 A to 3500 A, in laboratory conditions. The full capability of the new design was not able to be fully explored during the project.

Magnetic shielding technique on Rogowski coil

Rogowski coils are well recognised as current sensors and are suited for high-voltage applications. However, one of their weak points is the unwanted coupling of external currents near the coil, and sensitivity to position. Therefore the aim was to reduce the immunity of a Rogowski coil against these effects by more than factor of 10.

The metrological performance of the Rogowski coil developed by the project was characterised and an immunity to the effects was reduced by factor of 100. The performance of the coil was demonstrated in calibration setups on medium and high voltage levels. Together with temperature compensation techniques, the measurement uncertainties were reduced to less than 100 µA/A for ratio and 100 µrad for phase displacement. The temperature dependence of the ratio was less than 5 µA/A/K. The drawbacks of the new design for the Rogowski coil are increased weight and reduced dynamic range.

The Rogowski coil has the potential to be a good tool for NMIs and calibration laboratories for measuring current and its harmonics, although it is not yet at the point of commercialisation.

Improved precision voltage sensor

A precision voltage sensor was developed for the measurement of voltage and power quality. The sensor was designed for direct connection to medium voltage switchgear. The uncertainty of the scale factor is less than

100 µV/V (0.01 %) up to 1 kHz, and 0.2 % up to 10 kHz. The improved precision voltage compact sensor enhances power quality measurements, without compromising the accuracy of the measurement of the fundamental components.

The objectives of an uncertainty below 100 µV/V and bandwidth of 5 kHz were met and the improved precision voltage sensor is close to commercialisation.

Current clamp for power quality monitoring

A current clamp for monitoring power quality on medium and high voltage lines was developed. The clamp can be used for the measurement of currents on the ground terminal of existing capacitors on the power network. The measurement range of the compensated current clamp is from 15 mA to 9.6 A, and the uncertainty, including the digitiser system, was found to be less than 0.1 % in laboratory environment. The bandwidth of the current clamp is 100 kHz.

The objective of demonstrating measurement of voltage harmonics with uncertainty below 0.2 % using a current clamp was met by the project. The technology for using current clamp for traceable measurements of harmonic voltages in medium and high voltage networks is now ready for wider application.

Bragg grating for interrogation of sensor networks

Optical voltage and current (1 kA) transducers for distributed voltage measurements on medium-voltage networks (11 kV) based on fibre Bragg techniques were designed and constructed. The current transducers and interrogation system met the accuracy requirements for protection devices, as predicted by pre-manufacture simulation. The optical voltage transducers met the target accuracy (0.2 % in ratio error and 0.3 crad in phase displacement) in laboratory conditions, when they were not subjected to transient overvoltages.

The interrogation system has the potential for differential fault detection in power lines, due to its inherently simultaneous readout of multiple sensors. However, the fibre Bragg interrogation technique still needs further development before it can be applied for on-line measurement.

Frequency responses of conventional and non-conventional sensors

The differences in frequency responses of conventional and non-conventional sensors were studied. The measurement results confirmed that the tested non-conventional sensors had in general much better frequency response than conventional voltage instrument transformers. In contrast, the frequency responses of non-conventional current sensors and conventional current instrument transformers did not significantly differ.

Applicability for measurements on existing substations

The project was able to test some, but not all of the newly designed sensors on existing substations. The Rogowski coil design was used for medium and high voltage calibration demonstrations in laboratory conditions, but not in-service.

The current clamp was tested on-site and in-service in medium voltage network. The precision voltage sensor passed the tests required by insulation coordination standards for connection to medium voltage network, and its performance was demonstrated on-site and in-service in medium voltage network. Development of fibre Bragg grating based sensors progressed up to insulation testing, but their demonstration in on-site conditions was not possible during the project. The development of the optical current sensor proceeded only to laboratory demonstration stage, rather than the planned on-site measurements.

New services for calibration of non-conventional sensors with analogue or digital output

Calibration setups were prepared for test systems for analogue and digital non-conventional sensors. The developed calibration setups are based either on sampling measurement system, or on a commercial test set. A test system was developed for commercially available test sets for conventional and non-conventional transformers. The systems have been used for calibrations at partners PTB, VSL and TUBITAK, and respective updates on their official calibration scope have been either completed or initiated.

Two Good Practice Guides were also developed, one providing guidance for realisation of calibration setups for non-conventional sensors and test sets, and the other discussing accuracy of installation of non-conventional sensors.

The objective to develop new calibration services for non-conventional sensors and their test-systems was achieved and it is now possible to provide traceability for calibration of sensors that have an analogue input and a digital output. This is particularly important as substations become increasingly digital and the instrument manufacturers require calibration for the digital equipment.

Actual and potential impact

The main impact from the project is the provision of new services, which have been established for calibration of digital and non-conventional voltage and current transformers. The calibration services will provide a means for manufacturers to prove the performance of their new products and were developed for:

- analogue non-conventional current and voltage sensors, and respective test sets by PTB, VSL, TUBITAK and METAS
- digital output current and voltage sensors by PTB, VSL and METAS

Wider application of the new technologies developed during the project is also supported by:

- The project triggered development of new type of sensing fibre for optical current transformers at the University of Southampton.
- FFII, a project partner, is working towards commercialisation of the medium voltage probe.
- The medium voltage probe is proposed as reference measurement device for the EMPIR project 16ENG04 MyRailS
- TUBITAK used the developed Rogowski coil for calibration of customer’s medium voltage current transformer.
- PTB has performed calibration of non-conventional sensors for customers.
- PTB has discussed findings of a commercial device with the manufacturer in order to fix issues in the device software.
- SMU supported development of a commercial version of openable Rogowski coil for measurements on medium voltage network
- CMI supported development of shielding for Rogowski coil by placing ferromagnetic materials near the coil.

Standards

The project contributed to the ongoing work of a number of standardisation committees and work groups, both at the international and national levels. Internationally this included contributions to the CEN/CENELEC STAIR (STAndardisation, Innovation and Research) strategic working group, IEC TC 38 (instrument transformers) and TC 42 (high voltage and current testing and measurement techniques), and their working groups. At the national level, contributions were made to IEC TC 115 (High Voltage Direct Current (HVDC) transmission for DC voltages (above 100 kV), TC 13 (Electrical energy measurement), and AENOR CTN207 (Electric Power Transmission and Distribution). Project partners also contributed to IEC working groups dealing with instrumentation for high-voltage and high-current testing, and with uncertainty in instrument transformer calibration.

Pre-standardisation work included active participation to CIGRE (Conseil International des Grands Réseaux Electriques), Council on Large Electric Systems) general sessions and technical working groups on atmospheric influence on spark over voltage, and on measurement techniques for fast transients.

Metrology policies were influenced by attendance to EURAMET TC-EM (Technical Committee on Electricity and Magnetism) meetings. In addition, project members were active on the BIPM Consultative Committee for Electricity and Magnetism (CCEM) ad hoc working group on revising high voltage related service categories.

Dissemination

The project results were disseminated widely to the stakeholder community via 21 publications, 9 posters, 5 presentations and the project website at http://futuregrid.emrp.eu/. Two workshops were held to attract stakeholders from industry. The workshop in 2016 was arranged jointly with the EMPIR project 14IND08 Metrology for the electrical power industry and attracted 40 people representing project partners, standardisation organisations, industry and academia. During this one-day workshop, 23 posters and 12 oral presentations were presented including a keynote speech. The final dissemination workshop in 2017 was organised with two other EMRP projects ENG52 Measurement tools for Smart Grid stability and quality and ENG63 Sensor network metrology for the determination of electrical grid characteristics. About 70 people from 17 different countries attended the two-day event. The FutureGrid session of the workshop featured 10 presentations and a panel discussion. The workshops provided new insights for the participants regarding measurement capabilities of non-conventional instruments. The presentations of the workshops are available on the project website http://futuregrid.emrp.eu/

Two Good Practice Guides for application and calibration of non-conventional sensors were developed by the project: ‘(1) Recommendations related to the calibration and testing of non-conventional current and voltage sensors to support European and national standardisation groups’ and (2) ‘The installation of non-conventional sensors in order to ensure high accuracy’, which are available for download on the project website until the end of 2018.

Potential impact

Introduction of the non-conventional sensors developed during the project will facilitate the integration of alternative sustainable energy sources into the European power network, which is necessary to meet the EU’s Horizon 2020 target of a 20 % of reduction in greenhouse gas emissions. The new technologies will also enable grid operators’ to manage the network and improve grid stability, even when more new types of energy sources are introduced.

Reducing power transmission losses can only be achieved by higher precision and lower uncertainty measurements of power quality and energy loss. Equipment and procedures for calibration of the new non-conventional sensors developed in the project support this progress. It is estimated that average losses in the electricity grid are in the order of 10 % from generation to consumption points. Total electricity production in the European Union was for 2012 about 3000 TWh. Therefore, if the efficiency of 5 % of the generation is improved by 2 %, the net gain would be 0.1 % of 500 000 M€, which is 500 M€.

List of publications

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