Publishable Summary for 15RPT04 TracePQM
Traceability routes for electrical power quality measurements

Overview

The diversification of electric power generation to include sources with fluctuating output power such as solar and wind and the growing number of appliances employing switched-mode power supplies, has led to increased demands for traceable, accurate measurement of electrical power and power quality (PQ) parameters. Conventional power measurement techniques based on thermal converters only provide information about the root-mean-square (RMS) value which is not sufficient for determination of the PQ parameters that need to address complex waveforms. Therefore, new measurement setups based on alternative measurement techniques are required and whilst a few national metrology institutes (NMIs) have developed metrology grade power and PQ measurement systems based on sampling techniques, these systems are not generally available and no NMI can currently offer accredited calibration services for all the required PQ parameters. This project will help to address these issues by developing and validating a modular metrology grade system for the measurement of power and PQ parameters using digital sampling techniques.

Need

Traceable measurement of PQ parameters entails a complex range of activities. In particular, a successful implementation of a power and PQ measurement system requires knowledge and expertise in at least four fields: (i) Establishment of an appropriate measurement system including the proper, interference-free interconnection scheme of the components of the measurement setup; (ii) Design and implementation of a system capable of controlling the digitizers that will, amongst other things, ensure synchronisation of particular digitizer channels; (iii) Mathematical processing of the sampled voltage and current waveforms in order to obtain the required parameters such as power, power factor, and various PQ parameters including the uncertainty evaluation; and (iv) Validation of the performance of the measurement system to ensure traceability to the SI system. Such a complex range of activities for each required PQ parameter is generally beyond the capacity of individual institutes such as smaller or emerging NMIs/DIs, universities, calibration laboratories and manufacturers of PQ instrumentation etc. Furthermore, independent development of all parts of the sampling power and PQ measurement system from scratch in every institute would result in duplication of existing designs and devices and hence a waste of resources.

The design of the modular metrology grade measurement setup must be flexible and allow new digitizers or PQ algorithms to be easily incorporated in order to cater for continuously developing customer's needs and to reflect documentary standards defining requirements for PQ meters. Ideally any solution should focus on maximising the use of the capabilities of existing hardware components and on simple integration of new components without the need to rebuild the entire system.

In addition, the traceability of the measuring devices and transducers over their entire operating ranges and at the required level of accuracy can be problematic, therefore harmonised and validated calibration methods are required.

Objectives

The overall aim of this project is to develop and validate a modular metrology grade system for the measurement of power and PQ parameters using digital sampling techniques. The specific scientific and technical objectives of the project are:

1. To design a modular, metrology grade measurement setup for sampled electrical power and PQ parameters measurements, including a review of existing measurement and calibration methods, associated hardware and software, investigation of the optimum use of equipment already available within the NMIs/DIs and extension of traceability for power and PQ measurements up to 1 MHz.

2. To develop and validate a modular measurement setup for sampled electrical power and PQ parameters measurements, which can be easily established at NMIs/DIs and at other organisations. The target uncertainties of the modular measurement setup are at least four times smaller than the tolerances specified in documentary standards for PQ meters, e.g. the target expanded uncertainties for the amplitude of voltage harmonics of the modular measurement setup are 1.25 % of the measured voltage harmonic for measured values higher or equal to 1 % of the nominal voltage and 0.012 % of the nominal voltage for measured values lower than 1 % of the nominal voltage.
3. To develop an open software tool for instrumentation control, data acquisition and the calculation of electrical power and PQ parameters with full uncertainty estimation.
4. To develop and make available a good practice guide for the assembly and operation of the modular measurement setup including the calibration of all components so as to establish full traceability to the SI of the electrical power and PQ parameters measured. The guide will include the manual for the open software tool to assist users in the extension and modification of the modular measurement setup.
5. For each partner to develop an individual strategy for the long-term operation of the research capability developed during the project, including regulatory support, research collaborations, quality schemes and accreditation, together with a strategy for offering calibration services from the facilities established to customers in their own country and neighbouring countries. The individual strategies will be discussed within the consortium and with other EURAMET NMIs/DIs, to ensure that a coordinated and optimised approach to the development of traceability in this field will be implemented for Europe as a whole.

Progress beyond the state of the art

The project will go beyond the state of the art by making innovative and optimum use of equipment that is commonly available within the NMIs/DIs and high level calibration labs and maximising the capabilities of the chosen hardware components in order to develop a modular measurement system for power and PQ parameters. An investigation of the possibility of implementing continuous sampling with sampling multimeters for measurements that require long interval waveform records was completed and a solution that requires no external hardware was found. Methods to improve the stability and temperature dependence of wideband digitizers has begun and so far the temperature coefficients of several digitizers were measured. A method of short term stability improvement was suggested [1]. Traceable methods for the calibration of particular components for frequencies up to 100 kHz have been developed together with an investigation of methods for extending the frequency range up to 1 MHz. A measurement setup for the calibration of the 1 MHz shunts was finished and the comparison to validate its performance is in progress.

The modular power and PQ measurement setup will be accompanied by an open software tool for instrumentation control, data acquisition and data processing, so that the end user community can add functionality for any other digitizer or PQ algorithms by simply adding new modules. The first version of the open software tool named TWM was released in Nov 2017. A unified system of calibration datasets for every component used in the setup (i.e. digitizers, current shunts and voltage dividers) was proposed in Nov 17 so that adding or interchanging the components will only require different calibration datasets to be loaded into the system. The algorithms implemented for the calculation of the PQ parameters will be accompanied by a numerical calculator of the measurement uncertainty and, for computationally expensive algorithms, by a quick uncertainty estimator based on a previous Monte Carlo uncertainty analysis. Guidance on the assembly and operation of the modular measurement setup including the calibration of all components to establish full traceability to the SI, together with a manual for the open software tool to assist users in the extension and modification of the modular measurement setup has been started with a collection of the materials for the guide. Methods for the calibration of the particular components are being investigated and typical values for the component parameters are being characterised.

In addition the project will extend the research capabilities and calibration services in power and PQ metrology across more European countries. Coordinated activities of the participating NMIs/DIs will speed up the research in this field and reduce unnecessary parallel investigations and developments, thus saving resources.

Results

Design of a modular, metrology grade measurement setup

A review and international survey of existing measurement set-ups, calibration methods and voltage and current transducers for the measurement of power and PQ parameters currently in use in NMI/DIs worldwide or published in the literature was undertaken. The existing measurement setups were categorised based on their measuring principles and/or the hardware used and several candidates for the new system were identified. The contradictory requirements on the setup design (to ensure both the lowest possible uncertainties and the highest possible bandwidth) could not be met by a single measurement setup. Therefore, the new design needed to consist of two setups: (i) for low frequency measurements of the highest accuracy, a system based on sampling multimeters 3458A was chosen; (ii) for wideband measurements but at a reduced accuracy the set-up will be based on NI 5922 digitizers. The connection schemes and synchronisation methods of both setups were selected in order to enable multichannel, multiphase measurements which are essential for the PQ analysis.

Traceable calibration methods for the transducers (voltage dividers and current shunts) in terms of amplitude and phase were developed up to 1 MHz for dividers and up to 100 kHz for the shunts, including the development of the new primary phase standards in order to meet uncertainty requirements. Traceable calibration methods for wideband digitizers for the amplitude and phase angle error up to 1 MHz were investigated and several methods identified. An inter-laboratory comparison of the setups developed for calibration of the transducers and digitizers is being planned in order to compare the methods.

Possibilities for extending the record length of the data acquired by a 3458A were investigated and a solution allowing continuous record of up to 16 Megasamples, without the need for any additional hardware, was identified and successfully tested. The short term stability and temperature dependence were measured and methods to compensate these effects developed.

Development and validation of a modular measurement setup

Based on the design proposed above, the first versions of both the low frequency and wideband set-ups were developed and successfully tested during the midterm meeting using the first version of the LabVIEW software tool described below. The setups will be further investigated to identify optimal measurement conditions.

Development of an open software tool

The low frequency and wideband setup designs were used to propose a concept for the open measurement software tool named TracePQM WattMeter (TWM). LabVIEW and LabWindows/CVI provided by National Instruments were selected as the most suitable software environments for development of the TWM. The new software tool comprises two parts: (i) a user interface (GUI) and instrument control module that will acquire and store the digitized waveforms (developed in LabVIEW and/or CVI); (ii) A calculation module in MATLAB or GNU Octave. Both modules are independent of each other so that the calculation of the parameters from the previously recorded or simulated waveform data can be executed manually, if necessary.

The first version of the LabVIEW version of TWM software tool was released as open-source project. Currently the TWM software tool can: (i) Digitize with the sampling multimeters 3458A, the digitizers NI 5922, or with an ordinary soundcard (for low accuracy measurements) and simulate a simple composite harmonics signal for testing purposes; (ii) store the digitized waveforms in unified data format that can be read in LabVIEW, C/C++, MATLAB or any other language without excessive effort; (iii) initiate the processing of the recorded data using a selected algorithm from the Q-Wave toolbox (QWTB) or by using raw MATLAB commands (both MATLAB and GNU Octave supported); (iv) display the calculated results either as a table or graph. The CVI version of the TWM software tool is in an early stage of development as it cannot be fully developed until all data formats and the behaviour of the MATLAB functions are defined, as the CVI version will be developed as a reproduction of the LabVIEW version.

Development of the algorithms for the waveform processing is progressing, a total harmonic distortion algorithm for non-coherent signals and a flicker algorithm have been developed whilst algorithms for the power parameters of coherent and non-coherent signals are under development.

Production of good practice guide

Collection of the materials for the guide has started. Methods for calibration of the particular components are being investigated and tested and the typical values of the component parameters are being characterised.

Development of individual strategies of the partners

A questionnaire was circulated and completed by all partners in order to improve the coordination of the plans for the future strategies for power and PQ standards. The results of the questionnaire were presented at the mid-term meeting. The questionnaire comprised many questions regarding current capabilities and intended future development. A selection of the results showed that 10 of 13 partners have capability to measure power (9 digitally, 1 using thermal converters). The most common digitisers are sampling multimeters 3548A and wideband digitizer NI 5922. The most common digital processing method is FFT (for coherent sampling), a few NMIs are using other methods such as a sine fitting and discrete time integration. From the PQ parameters, the most common is frequency estimation, voltage/current magnitude, harmonics and inter-harmonics measurement. Flicker is implemented in 5 of 10 NMIs. An outline of the individual strategic plans has been prepared and will be discussed within the consortium.

Impact

Information about the project and its results have been regularly disseminated via scientific conferences, international and European electricity related technical committees, and presented to relevant legal metrology organisations. Presentations on the project were given at the following events: 6th Congreso Espanol de Metrologia in March 2017; EURAMET TC-EM SC Power and Energy meetings in July 2016 and June 2017 and the TC-EM SC Low Frequency meeting in May 2017; 33rd WELMEC Committee meeting in May 2017; OIML TC12 committee in May 2016; Section 2 of Czech committee of CIRED in April 2017; Czech Calibration Society Conference in November 2016; 26th National Scientific Symposium “Metrology and Metrology Assurance 2016”, and via a paper entitled “EMPIR Project 15RPT04 Trace PQM: Traceability Routes for Electrical Power Quality Measurements” that was presented at the CIM 2017 conference and which will be published on EdP Web of Conferences.

End user uptake and exploitation

One of the partners Metrosert, has established a new accredited calibration services in electrical power measurements with the expanded measurement uncertainty below 150 μW/VA. The TWM software tool is being tested in several institutes both within and outside the consortium. For example the first release of TWM software tool was downloaded by BEV and it is being implemented in their laboratories. One of the stakeholders expressed the need for particular algorithms which will be internally used for validation of the commercial PQ meters’ installation.

Impact on the metrology and scientific communities

The TWM open software tool and good practice guide will be publicly available to all interested parties, i.e. NMIs/DIs, calibration laboratories, industry, universities and individual practitioners. They will serve both as a quick starting point for the establishment of an expandable modular sampling power and PQ measurement system and as a reference design to speed up the design of a new system, if required. The universal access to the open software tool and good practice guide and the easy to implement modular design of the power and PQ measurement setup will lead to the improvement of the power and PQ measurement capabilities within Europe, not only within the partner NMIs/DIs but also through the early uptake of the knowledge and project outputs by other interested parties, such as other NMIs/DIs or calibration laboratories.

The project incorporates early phase knowledge transfer from experienced NMIs to the less experienced NMIs. A half day workshop on power and power quality metrology organised in conjunction with the kick-off meeting provided the partners with the necessary knowledge to progress with the activities of the project. The active participation of less experienced NMIs in the development of the new system will further extend their knowledge.

The strategies for the long-term development and use of partners’ capabilities which are currently being prepared at the NMIs will ensure fast uptake and maximum use of the project’s results which will lead to the establishment of new calibration services or to the improvement of existing measurement capabilities in every participating country. The preparation of a supplementary comparison in the field of power and PQ will support the validation of the new measurement set-ups after the end of the project.

Impact on industrial and other user communities

Interaction with stakeholders through a stakeholder committee is helping the project to focus on the end-users' needs. So far 15 organisations from different fields of activities related to power and PQ (universities, test laboratories, distribution service providers, PQ test instruments manufacturers etc.) have joined the stakeholders committee. Five collaborators have joined the project to directly contribute to the technical and scientific objectives. A half day workshop related to the power quality organised by SIQ in Slovenia provided training to more than 30 participants from different Slovenian electricity distribution companies and producers of PQ instruments. Presentations from the initial workshop (held for consortium only) were collated and published on the project website. Another workshop open to all interested parties organised at the end of the project will help to ensure the uptake of the project's outputs by potential end-users.

The improved European power and PQ measurement capabilities will contribute to the metrological basis necessary for policy makers and energy suppliers in all European countries to guarantee a stable and secure energy supply to customers. This project will also assist with the growth and development of the energy infrastructure by providing wider European access to traceable measurement capabilities for power and PQ quantities. The modular design and open software tool will enable straightforward future expandability of the measurement setup to cater for continuously developing customer's needs.

Impact on relevant standards

Contact is being made with IEC TC77, WG9 "Power Quality Measurement Methods" to determine if the results of the research can be of use to the working group. The project and its achievements were also presented at OIML TC 12 and WELMEC meetings.

List of publications

[1] V. Nováková Zachovalová, et al. "EMPIR project TracePQM: Traceability routes for electrical power quality measurements", International Congress of Metrology 04001 (2017), DOI: 10.1051/metrology/201704001

Project start date and duration:		01 June 2016, 36 months
Coordinator: Věra Nováková Zachovalová, Ph.D., CMI, Tel: +420 545 555 305, E-mail: vnovakovazachovalova@cmi.cz *Assistant Stanislav Mašláň, CMI, Tel: +420 545 555 302, E-mail: smaslan@cmi.cz* Project website address: http://tracepqm.cmi.cz/		
Internal Funded Partners: 1 CMI, Czech Republic 2 BIM, Bulgaria 3 CEM, Spain 4 FER, Croatia 5 IMBiH, Bosnia and Herzegovina 6 INRIM, Italy 7 JV, Norway 8 LNE, France 9 Metrosert, Estonia 10 NSAI, Ireland 11 RISE, Sweden 12 SIQ, Slovenia 13 TUBITAK, Turkey	External Funded Partners: --	Unfunded Partners: --