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Introduction and progress in the EMPIR project TracePQM: Traceability Routes for Electric Power Quality Measurements

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Abstract. Increasing demands for traceable, accurate measurements of power and power quality (PQ) parameters have resulted in an intensive metrology research effort in this area. This paper describes the objectives and so far achieved results of the EURAMET EMPIR Project TracePQM (15RPT04), jointly founded by the European Union and the participating countries. The overall goal of this project is to develop an open, modular, and well documented metrology grade system for measurement of power and PQ parameters by means of digital sampling techniques available to everyone and to increase research capacity in this area.

1. Introduction

Conventional power measurements based on the thermal converters provide information only about the root-mean-square (RMS) value which is not sufficient for PQ measurements [1], [2], [7], therefore it is necessary to design new measurement setups based on alternative measurement techniques. Several national metrology institutes (NMIs) have developed metrology grade power and PQ measurement systems based on sampling techniques, e.g. [3], [6], however most of the NMIs have not finished this task yet. Designing such setup requires expertise in wide range of areas and is in general beyond capability of smaller NMIs.

The overall goal of the TracePQM project, which started on June 1, 2016, and will end on May 31, 2019, is therefore to use joint effort of the NMIs to develop an open, modular, and well documented metrology grade system for measurement of power and PQ parameters by means of digital sampling techniques. The developed open source software (SW) and good practice guide will be publicly available for all interested parties, such as NMIs, calibration labs, industry, universities or even individuals. They will serve both as a quick starting point for a development of an expandable sampling power and PQ measurement system and as a reference design to speed up the design of new highly specialised sampling systems.

2. Main objectives and achieved results

2.1. Design and validation of modular power and power quality measurement setup

The design of the new measurement setup for power and PQ is based on the analysis of existing metrology grade setups in the leading NMIs. From a survey carried out between NMIs it was identified that the most suitable hardware (HW) components are: (i) Sampling multimeter Agilent 3458A for low frequency (LF) measurements up to few kilohertz with highest accuracy; (ii) National Instruments 5922 wideband digitizer for wideband (WB) measurements up to at least 1 MHz, however with reduced accuracy. Therefore, two setups are being designed, one for LF measurement and another for WB measurements.

LF setup: Based on the review of existing setups it was decided to use 3458A digitizers synchronized in master-slave topology with the master unit clocked either from internal timer or from an arbitrary waveform generator (AWG). In this way no custom built HW is needed and the setup enables coherent sampling. Connection of the transducers will be single-ended.

WB setup: The time multiplexing mode of operation [5] was discarded as it requires custom HW parts. The design is therefore based on the systems developed by RISE [6] and INRIM, i.e. on the use of the separate digitizers for current and for voltage. Furthermore, the differential connection of the transducer to the digitizer channels is supported (at least for the current shunt).

An investigation of the limited stability and repeatability of the self-calibration routine of NI 5922 was carried out in scope of this objective. It was identified the self-calibration routine of 5922 occasionally produces large gain errors reaching almost 100 µV/V, so it cannot be reliably used without external calibration before the measurement itself for the highest accuracies.

Part of this objective is also characterisation of the transducers and digitizers up to 1 MHz. A new calculable resistance standard, and a unique new digital sampling impedance bridge for low impedances, were developed for the calibration of the phase angle and ac-dc transfer of the shunts, which allows to reach the target expanded uncertainty of the phase angle below 800 µrad/MHz, and expanded uncertainty of ac-dc transfer below 100 µA/A at 1 MHz. An international comparison is planned to validate the setup for the ac-dc transfer and phase angle calibration of shunts and voltage dividers. The results will be presented at the conference.

2.2. Development of an open software tool

The main goal is to develop a universal open source measurement SW tool which will be modular, expandable and transparent so the entire data processing chain can be inspected and validated. The concept was developed so that the whole SW, named TWM, is split into two modules: (i) User

interface (GUI), instrument control and raw sample data storage in LabVIEW (LV) and LabWindows/CVI (alternative system, CVI); (ii) Calculation module developed as a set of m-files executed by Matlab or GNU Octave. However, both modules are integrated together into a single interactive application.

The advantage of the concept is that the calculation module can be used independently of the LV/CVI module, so it can be used to reprocess older records to obtain new PQ parameters, or it can be used to a later batch calculation of computationally expensive parameters with uncertainty be means of Monte-Carlo method. The algorithms for the calculation of the power and PQ algorithms are placed in the QWTB toolbox [8]. Therefore, the addition of a new algorithm for a new parameter to be calculated is just a matter of adding m-files to the QWTB toolbox. Similarly, if the support for new digitizers is required, the new drivers will be included to the LV/CVI module of the TWM tool, whereas the calculation module stays unchanged and the TWM will be immediately ready to measure with a new HW.

A first version of the TWM tool was already released [9], [10]. It can do the following operations:

    (i)   Simultaneously record waveforms on any number of channels of the selected digitizer (3458A, NI 5922, ordinary sound-card for low accuracy measurements). Both 3458A and NI 5922 support the streaming mode and allow to record up to 16 MSamples (MSa) for the 3458A and unlimited sample count for NI 5922.

    (ii) Store the waveforms and information about the measurement setups (selected transducers, digitizers, sampling parameters, etc.) into unified format that can be read without any special effort in LV, Matlab or C/C++.

    (iii) Execute selected algorithm from the QWTB toolbox using either Matlab or GNU Octave.

    (iv) Display the calculated results as a formatted matrix or graph.

The QWTB toolbox already contains several plain algorithms, mostly for single and multi-tone harmonic analysis, however they have not yet implemented corrections or the uncertainty calculation. The algorithms for the TWM that will include all system components corrections, as well as uncertainty calculator, are still in development. Currently a Total Harmonic Distortion (THD) algorithm for non-coherent sampling, flicker algorithm, and frequency estimator algorithm are being finalized. Algorithms for measurement of power and harmonics of the coherently and non-coherently sampled waveforms are being developed. This project also expects the implementation of the algorithms for specialized PQ parameters such as sag, transient swell, etc.

One of the goals for this objective was also implementation of the streaming mode for multiple 3458A units without need for a custom built external HW. The driver for the sampling with multiple 3458A multimeters was implemented based on the SIQ findings. It supports any number of 3458A units synchronized in several ways. The developed driver allows to digitize simultaneously with at least three 3458A units connected via three common converters GPIB-USB-HS (one for each multimeter) at full sampling rate or 100 kSa/s. Maximum record length is limited by the multimeters to 16 MSa.

2.3. Creation of a good practice guide

A good practice guide (GPG) will be developed that will assist end-users in the design, construction, extension and modification of measurement setups for power and PQ quantities. Among other matters, it will address the choice and interconnection of the components and calibration techniques for the setup components to ensure the desired level of measurement uncertainty.

In addition to mentioned, GPG will include the user's manual for the SW tool. The manual will contain user level information, as well as developer level section, which will enable to expand the SW tool in accordance to the new needs. The manual will cover integration of new digitizers, description of the formats of calibration datasets for every component, and data exchange format between the measurement and calculation module of the system, allowing easy implementation of new algorithms.

It is expected that GPG will be of particular value to NMIs and other interested parties which are new in the field of power and PQ measurements as only adequate documentation will ensure adoption of the newly developed open modular setup.

2.4. Long-term development for each participant
Every participant will develop the long-term strategy that will ensure fast uptake and maximum use of the results of the project. It will help to the establishment of new calibration services, or the improvement of existing measurement capabilities, in every participating country. One of the approaches will be also to prepare a supplementary comparison in the field of PQ parameters to support the new measurement capabilities.

3. Conclusions
The EMPIR project TracePQM and its achievements were presented. The most important outcomes of the project will be the good practice guide and an open SW tool for power and PQ measurements, which will be freely available to download from the project website and will assist end-users to establish new or enhanced measurement facilities for power and PQ.
A first version of the TWM tool was already published and the consortium of the project would like to encourage the readers interested in digital sampling techniques to download and try the tool and provide the consortium with feedback so it can better steer the future development to ease the uptake. Further details and data are planned to be given in the final version of the paper.

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