Online Verification System for Phasor Measurement Units

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***Abstract* — In this paper, a portable standard is proposed for allowing online PMU calibrations without service interruption. This system is connected in parallel with the under test PMU, using current and voltage sensors that do not need any disconnection of the PMU.**

***Index Terms* — Calibration, high voltage, network, power, synchronism. Uncertainty.**

I. Introduction

The use of Phasor Measurement Units (PMU) in power networks increased from the first developments in 1988. These instruments measure voltage and current phasors in real time, supporting smart protection systems. In 1995, IEEE 1344 standard [1], replaced in 2005 by IEEE 37.118.1 [2] and the new version in 2011 [3], describe the metrological characteristics of these instruments. Additionally, IEEE C37.242 [4] describes the requirements of synchronization, calibration, testing and installation.

From the point of view of conventional metrology, these instruments unify two fields that are usually studied separately: Electricity and Magnetism, and Time and Frequency. Then, calibration systems must be traceable to voltage, current and time standards. In these fields, there are different levels of development. Some National Laboratories use commercial calibrators and others developed their own systems. The North American Synchro Phasor Initiative (NASPI) and the National Institute of Standards and Technology (NIST) facilitated the manufacture of commercial systems for different tests and calibrations in accordance with [2], under static and dynamic conditions. This system is based on a three-phase commercial calibrator of extended use in Power Quality measurements, plus a GPS time reference and software [5]. To calibrate such systems, it is required sophisticate equipment, which only few National Laboratories have. On the other end of traceability, there is a need for calibration of commercial PMU that have been installed in substations. There are some developments of PMU calibrators [6] - [8], but all of them require disconnecting the device from the network, and connecting it to the calibrator. This leads to a period during which there is no protection of the network, unless there is a back-up unit (not usual). For online calibration, these authors do not know of any available calibrator. This work proposes a system to fill this gap.

II. Proposed calibration system

This proposal is based on the development of a standard PMU that is installed in parallel with the PMU under test. Online calibration allows to measure the PMU errors without disconnecting it from the network. However, it has some limits. It cannot vary voltage and current freely as in conventional calibrations. Only the actual voltage and current variations of the network during the measurement period can be used. Under these variations, static tests can be reasonably done, recording data during some days. However, dynamic conditions are very difficult to test because the probability of a serious failure in the network, that produces large parameters variations, is very low during short test periods. Anyway, many deviations over the standard limits can be detected under static tests. As there is no other online test option, it is at least possible to detect PMU departures under partial testing.

For current sensors, high accurate current clamps were developed to measure the current without interrupting the circuit. Voltage is measured connecting the voltage probes in parallel with the inputs of the PMU under test. This also does not require to interrupt the circuit. A GPS based calibrator measures the deviation of the local clock, and software calculates all static parameters. The laboratory develop of the prototype is shown in Fig. 1.

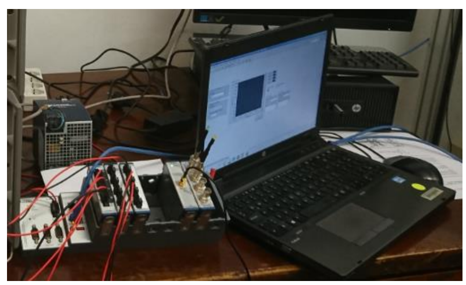

Fig. 1. Development of the proposed system.

A. Hardware

Evaluating different platforms, NI-CompactRio was chosen. This chassis has a dual-core 667 MHz CPU and a FPGA (Field-Programmable Gate Array) type Xilinx Zynq 7020, which allows to run two processes at the same time.

There is a wide range of digitizers for this platform with several input voltages, accuracies and sampling frequencies. The development of a reference PMU needs of high precision measurements of voltage and current, and sampling frequencies of thousands of sample per second. 24-bit Sigma-Delta digitizers, with simultaneous sampling, up to 50 kS/s of sampling frequency per channel were selected.

For the voltage measurement, the NI-9242 model was chosen, which has 3 input channels with maximum voltage of 250 V between phase and neutral.

For current measurement, current to voltage transducers are used. A digitizer NI-9239 was selected, which has 4 input channels that manage a maximum voltage of ±10 V.

The sampling frequency can be chosen from a set of discrete values between 1.613 kS/s and 50 kS/s. These sampling frequencies can be exported to other modules which is necessary for this project.

The digitizers were calibrated to assess their behavior with respect to: accuracy, linearity, temperature behavior and phase shift. The reference for this was a binary inductive divider [9], with accuracy of 1 µV/V and 1 µrad at power frequency and Agilent 3458 multimeters running the algorithms described in [10], with uncertainties lower than 3 µV/V and 3 µrad at power frequency,

B. Current transducers

Clamp-on current sensors are used as current transducers. An electronic circuit converts the output current of the clamp to a proportional voltage [11]. Additionally, this electronic device compensates ratio and phase-displacement errors, increasing the accuracy of the original sensor. This is achieved by nulling the magnetic flux in the core. In this way, the magnetizing current is also nulled. The input ranges are 1 A, 2 A and 10 A, and the rated output voltage, 4 V. The calibration errors were lower than 0.05% and 0.1 crad at 50 Hz, one order lower than the errors without compensation.

C. *Synchronization*

For a time reference from a GPS signal, NI-9467 and NI-9402 modules were chosen. The first one provides the time stamp and a 1 PPS signal (Pulse Per Second) for the other modules. Its specification states accuracy of ±100 ns in the generation of the 1-PPS. The second module has digital input/output ports that allows to access to the 1-PPS signal in one of its outputs. Its specification states a maximum propagation delay of 55 ns (18 ns typical). Calibrations were done with respect to the UTC obtaining deviations less than 150 ns. The stability of these measurements in 7 days were ± 50 ns.

Depending on the phase change values in the digitizers (voltage and current), it is possible to implement a correction to minimize this phase change.

Complementary to this, the project has a Common View System to verify its own time error and the error of the synchronism signal of the substation. It is based on a Septentrio PolaRx5TR equipment that has a 1 PPS input. It is connected to the substation synchronism signal for measuring the delay between that signal and those from the viewed satellites of GPS. A similar equipment is installed in our Laboratory, connected to the output of a cesium clock with traceability to the UTC. The difference between both systems allows to calculate the absolute error of the substation time stamp, independently of the GPS accuracy. A similar calibration is done to the proposed PMU to assure that its time error is under specifications.

D. Software

The FPGA program configures and drivers the GPS and digitizer modulus. The GPS 1-PPS signal starts all digitizers. It stores the sample values and other information in the FIFO memory. At the same time, the software in the CPU runs the mathematical algorithms for calculation of PMU parameters. Using Interpolated Discrete Fourier Transform, the frequency, modulus and phase of voltages and currents are computed. Corrections are applied to take into account the constants of the system and to compensate deviations of the digitizers.

The Rate of Change of Frequency (ROCOF) calculation was implemented using the Fast Hilbert Transform, to obtain the phase change versus time.

III. CONCLUSIONS

A proposal for PMU online calibration was described. It is based on the development of a standard PMU connected in parallel with the PMU under test. Results of actual calibrations will be presented at the conference.

Primary results and uncertainties budget will be presented at the congress.

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