Trilateral South American project: a reference system for measuring electric power up to 100 kHz – progress report III

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Abstract. Three countries in South America are jointly developing a reference system for measuring electric power up to 100 kHz. The objective is the construction of three similar measuring systems, one for each institute. This project will contribute to provide calibration services in measuring ranges still not covered by the three institutes both in ac-dc transfer and in electric power. The status of its development by the end of 2019 is described here.

Keywords. Electric power, harmonics, metrology, measuring system, regional project

1. Introduction

As reported in [1]-[3], the Instituto Nacional de Metrologia, Qualidade e Tecnologia (Inmetro), in Brazil, the Instituto Nacional de Tecnología Industrial (INTI), in Argentina, and the Administración Nacional de Usinas y Trasmisiones Eléctricas (UTE), in Uruguay, are jointly developing a reference system for measuring electric power up to 100 kHz. The objective is the construction of three similar measuring systems, one for each institute. The project was supported in part by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), in Brazil.

The project is coordinated by Inmetro, who purchased and transported the components and parts needed to the assembly of the measuring systems in each participating country. Apart from coordinating this project, Inmetro is also responsible for the development of the power amplifiers and the transconductance amplifiers. INTI is responsible for the development of the arbitrary waveform function generators, the dual-channel digitizers and the current shunts (and their calibration). UTE is responsible for the development of the resistive voltage dividers (and their calibration). The integration and testing of the measuring systems are to be performed by the three institutes.

The current status of this development is described in this article.

2. Major developments

The reader is urged to consult [1] for a description of the measuring system. It comprises: an arbitrary waveform function generator with two synchronized channels, a power amplifier, a transconductance amplifier, a resistive voltage divider, a current shunt, and a digitizer with two synchronized channels.
2.1 Arbitrary waveform function generator
One two-channel arbitrary waveform function generator was constructed and tested at INTI (Figure 1). It is based on Direct Digital Synthesis (DDS). The design requirements for such generator were presented in [1]. A two-channel version of the design described in [4]-[6] was implemented. The input buffer and analog-to-digital converter (ADC) were doubled and two power supplies for the ADC modules were used.

![Figure 1. Arbitrary waveform function generator constructed at INTI (placed on top of the digitizer).](image1.png)

2.2 Power amplifier
The design requirements for such amplifier were presented in [1]. The design is based on a one-stage version of [7]. Four units of the amplifier using surface-mount-device (SMD) technology were assembled at Inmetro (Figure 2). The National Institute of Standards and Technology (NIST) collaborated in this development. The power amplifier boosts one of the outputs of the arbitrary waveform function generator to provide the nominal voltages (up to 240 V rms) required for calibrating the device under test. The prototype of the power amplifier is shown in Figure 3. The photo also shows two linear power supplies that supply +500 V / −500 V to the two output power MOSFETs in push-pull configuration which are fixed on two heat sinks on the circuit board.

![Figure 2. Four units of the power amplifier module assembled at Inmetro.](image2.png)
2.3 Transconductance amplifier

A total of 3 (three) transconductance amplifiers are being constructed each covering the following ranges: 40 mA, 400 mA, and 12 A. One additional 24 A transconductance amplifier has been already constructed (we could not construct three units of the latter due to budget restrictions).

The design requirements for such amplifiers were presented in [1]. The amplifier design is based on [8]. The transconductance amplifier boosts the other output of the arbitrary waveform function generator to provide the nominal currents (up to 24 A rms) required for calibrating the device under test. The amplifier contains only analog circuits to reduce electrical noise. Linear power supplies are utilized in the low-current amplifiers (40 mA and 400 mA) also to reduce electrical noise. 500 W and 1500 W switched-mode power supplies (SMPS) are used in the 12 A and 24 A amplifiers, respectively, to provide stable voltage rails for the output power circuits. The latter need adequate means to dissipate power while having a small physical geometry to maintain a low inductance in the output current circuit. Vishay Z-Foil resistors (VTA) with low temperature coefficient of resistance (TCR) are employed in critical circuit nodes to increase the output stability of the amplifier [9].

Figure 3. Prototype of the power amplifier.

Figure 4. 24 A, 100 kHz transconductance amplifier constructed at Inmetro.
The 24-A, 100 kHz transconductance amplifier constructed and tested at Inmetro is shown in Figure 4. It was approved in the stability, harmonic distortion and bandwidth tests. The amplifier is now being used for ac-dc current transfer measurements. It comprises one preamplifier/buffer and six 4 A modules (each with transconductance of 1 S) that are connected in parallel to provide up to 24 A (the 12 A amplifiers to be constructed each have three 4 A modules to provide up to 12 A). Each module is a class AB amplifier containing 5+5 output transistors in push-pull configuration. All the 60 (30) output transistors are fixed to a common wind-tunneled heat sink to dissipate up to 360 W (180 W).

2.4 Resistive voltage divider
Three sets of nine resistive voltage dividers with binary nominal values from 4 V to 1024 V were constructed and tested at UTE [10]. One such set is shown in Figure 5. Each divider comprises two cascaded, independently shielded sections: a range resistor and a shunt resistor. The two sections can be calibrated together as a voltage divider or separately as resistors. This provides flexibility in testing. Low-dissipation-factor Vishay Z-Foil audio resistors (VAR) are employed [11][12]. It was confirmed by UTE that nonlinear effects are reduced considerably by soldering such resistors on PTFE boards [11]. Such boards have a very low dissipation factor. Once nonlinear effects have been minimized, stray capacitances are the most relevant linear parasitic effect. A special shielding technique for nulling radial electric fields is employed for the dividers from 64 V to 1024 V [13]. Fans were installed in the 512 V and 1024 V dividers to cope with stability requirements.

![Figure 5. One of the three sets of resistive voltage dividers constructed at UTE.](image)

2.5 Current shunt
Three sets of current shunts with nominal values 20 mA, 50 mA, 100 mA, 200 mA, 0.5 A, 1 A, 2 A, 5 A, 10 A, 20 A, 50 A and 100 A were constructed at INTI [14][15]. One such set is shown in Figure 6. Two additional sets were independently constructed and tested at Inmetro for ac-dc current transfer measurements and instrument calibration purposes (Figs. 7 and 8). The shunts employ Vishay Z-Foil resistors (Z201) with low TCR to satisfy stability requirements.

Inmetro has already tested all the shunts (with partial results published in [16]). An M. Sc. dissertation [17] was published under Inmetro’s metrology postgraduate program to document the experimental characterization of the shunts constructed at Inmetro. A model was proposed to predict the ac-dc current transfer differences for cage-type shunts from 0.5 A to 20 A. The measured ac-dc current transfer differences agree with the predicted values within the standard uncertainties [18].
new design for low-current shunts (from 20 mA to 200 mA) was proposed and a model used to predict their ac-dc current transfer differences [19].

![Figure 6. One of the three sets of current shunts constructed at INTI.](image)

![Figure 7. Two sets of current shunts from 20 mA to 20 A constructed at Inmetro.](image)

![Figure 8. Two sets of 50 A and 100 A current shunts constructed at Inmetro.](image)
2.6 Dual-channel digitizer

One dual-channel digitizer was constructed and tested at INTI (Figure 9). It is based on a Sigma-Delta analogue-to-digital converter (ADC). The design requirements for such digitizer were presented in [1]. The original design in [20] was modified by adding a second channel, extending the input bandwidth up to 100 kHz, and splitting the master clock into two signals. The digitizer design is briefly described in [21].

![Dual-channel digitizer constructed at INTI.](image)

3. Project management

The project is coordinated by Inmetro, who was responsible for the purchase and transportation of the components and parts needed to the construction of the modules, and for the transportation of the modules needed to the assembly of the measuring systems, in each partner country.

The project activities include the design, layout and documentation of the printed circuit boards, the design and documentation of the electronic packaging of the modules, the calibration certificates of resistive voltage dividers and current shunts, the design and documentation of the software and firmware, and the measuring system integration, testing and documentation.

The following modules are currently under construction: (a) 40 mA, 400 mA and 12 A transconductance amplifiers (three units of each range) by Inmetro, (b) power amplifiers (three units) by Inmetro, (c) dual-channel digitizers (additional two units) by INTI, and (d) two-channel arbitrary waveform function generators (additional two units) by INTI. The partner institutes will start transporting among them the modules already constructed. The Covid-19 pandemic has caused a severe delay in the project schedule.

Acknowledgments

This work was supported in part by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) of the Ministry of Science, Technology and Innovations of Brazil, under Grant CNPq/Prosul Processo Nº 490271/2011-1.

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