

Validation Of The New Automatic System For AC Voltage Comparisons

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Abstract- A system for the automatic comparisons of ac voltage, ac current and ac-dc transfer has been built, which simplifies the management of the whole traceability chain from national standards to the instruments under test. The validation process for ac-voltage and ac-dc transfer has shown the functionality of the system, a high repeatability and self-consistency of the results and a full compatibility with measurements made manually and by the previous automatic system.

I. Introduction

A new generalized automatic system for the dissemination activity has been built recently at Istituto Elettrotecnico Nazionale "Galileo Ferraris" (IEN), which takes full advantage of programmable instruments for the time-consuming operations required in calibration activity. This system can be employed for high accuracy measurements for ac voltage, ac current and ac-dc transfer, both in voltage and current. It has been built as a coherent structure that, from the national standards, can disseminate the traceability to all the instruments under calibration. This system, which is described in detail in [1], is an evolution and an extension of a previous one built some years ago and devoted mainly to voltage calibration [2]. So, it is supposed to be employed more widely and in the whole traceability chain. The verification and validation of the system described has been carried out by a preliminary assessment of its functionality, a test for the consistency of the results and a comparison with measurements performed manually or by the previous automatic systems.

II. The system

The system consists of a set of instruments and a proper software for controlling the measurements. The hardware is configurable by the operator on the basis of the specific calibration to be performed and allows several types of instruments to be used both as reference units and as units under test. The main operative instrument is a calibrator, which can be chosen between three models of different manufacturers.

The standards for the ac voltage calibration, from which the traceability is derived are:

- a multirange ac-dc transfer standard for voltages read by a multimeter;
- a suitable thermal converter, with the thermal element (single junction or planar multijunction [2]) read by a nanovoltmeter or a multimeter;
- a programmable ac-dc transfer standard.

Other instruments can be also used both as reference standards or instruments under test for the measurements, such as calibrators, programmable ac/dc transfer standard, ac measuring devices and multimeters in the ac voltage function.

The system can be configured for the specific operative needs and the software is organized in a modular way. On the basis of the type of instruments and the measurements to be performed the selected modules are activated in a proper sequence.

The software program can be subdivided in three main modules for controlling:

- the measurement sequence;
- the IEEE-488 interface;
- the settings and the output of the calibrator.

Depending on the particular instruments selected for comparison the suitable modules for introducing and programming the setting of the instruments and for reading their data are involved.

The last module is for the computation of the results that are stored in suitable files. For aim of generality and for future expansions a particular communication language between the modules has been developed for describing the types of operations.

III. Test of the software functionality

Software verification and validation process determines whether the system is suitable for the activity for which has been developed. This determination may include analysis, evaluation, review, inspection, assessment, and testing of software products and processes, including the operational environment, hardware, interfacing software [3].

Specifically, the system, which has been built in separate modules that are called in sequence, has been tested first for its functionality. The main advantage of this modular structure is an easier investigation, because each function can be tested separately in independent steps.

The module that controls the sequence has been tested by preliminary connecting, instead of the other operative modules, only small tests modules that simply write both on the printer and on the screen the time and a short description of the operation to be performed.

The correct sequence of the IEEE-488 interface instructions has been tested by means of the specific software for visualizing them, while the operative module that controls the calibrator by checking, for given series of commands covering all the ranges and the functions in ac and dc voltage and current, the correspondent output values by means of a multimeter.

Similar tests have been made for the instruments employed for acquisition. However, as such instruments are not uniquely identified and owned by IEN, but they can belong to different owners that send them to IEN for calibration, the verification has been made only by means of specific sample instruments. The implicit assumption is that if an instrument of the same model is working properly, it would answer to the same commands in the same way. However, after a preliminary test, suitable delays have introduced to all time periods identified as critical.

Furthermore, in the modules there is, where possible, a well defined time sequence of the operations and structural separation of the module functions. The only exception is given by the reading and the registration of the results of a comparison between two instruments, where the readings are alternated in order to simulate two means values over almost simultaneous period. Also in this case additional delays have been included to avoid any possible interference between the modules.

IV. Self-consistency of the results

A verification of the metrological capability of the system has been performed by checking first the self-consistency of the results. This means that the measurements, within the limit of the uncertainties, should give the same results over time, maintain their value independently of the instrument position (standard or unknown) and be compatible when derived from a combination of them.

A. Repeteability of the results

The automatic system has been tested in several configurations.

The repeatability of the measurements has been evaluated by repeating the same measurement for at least three times, in different days and by disconnecting and reconnecting the wires and the connectors. The repeatability evaluated as a (1σ) is satisfactory and some examples of them are given in Table 1.

B. Consistency of derived measurements

Another verification was made about the repeatability of the result when the devices are considered in a different role in the system. The inversion of the attribution of standard or unknown for the instruments does not change the results over the limit of the repeatability. Instead, for current measurements, Table 2 shows some differences in the current measurements due to the inversion of the instruments to the current node. This effect more evident at higher frequencies, however, does not depend on the system but is related to the different currents that flow into the two shunts (low-currents) or to a different contribution of the mutual inductances (high currents).

The effect of combined measurements has not been tested extensively yet. For voltage measurements, for example, a thermal converter, a multirange transfer standard and a programmable transfer standard have been compared each against the others up to frequencies of 100 kHz. The cyclic sum of the differences has been evaluated and is within the quadratic sum of the uncertainties.

Table 1 Examples of repeatability of results

Type of calibration	C side	X side	Value	Frequency	Repeat. (1σ) 10^{-6}
Calibrator (Voltage)	Multirange programmable transfer standard		10 V	1 kHz	0.5
			10 V	20 kHz	0.3
			10 V	100 kHz	1.1
			10 V	1 MHz	1.7
			100V	20 kHz	0.4
			200 V	20 kHz	0.2
Calibrator (Current)	Shunt + Thermal element		0.1 A	40 Hz	1.1
			0.1 A	5 kHz	0.8
Calibration of shunt + multirange transfer stand.	Shunt + Multirange transfer stand.	Shunt + Multirange transfer stand	1 A	40 Hz	0.5
			1 A	1 kHz	0.9
			1 A	5 kHz	1.8

Table 2 Examples of differences with an inversion at the current node

Type of calibration	C side	X side	Value	Frequency	Difference 10^{-6}
Calibration of shunt + multirange transfer stand	Shunt + Multirange transfer stand	Shunt + Multirange transfer stand	10 mA	40 Hz	-2.9
				1 kHz	-1.9
				5 kHz	-1.6
			50 mA	40 Hz	-0.8
				1 kHz	-0.8
				5 kHz	-3.4
			100 mA	40 Hz	-0.7
				1 kHz	2.6
				5 kHz	3.2
			500 mA	40 Hz	2.2
				1 kHz	1.1
				5 kHz	6.9

V. Compatibility with measurements differently performed

A. Compatibility with manual measurements

In particular cases, which were thought as more critical, the automatic procedure has been verified by using a manual procedure. with the instruments detached from the interface but working in the same environment. This verification has been made mainly for high voltages and high currents where the settling time was particularly critical for the automatic system. Verification has shown the compatibility of the results, even if, for the fact that the timing was quite different, the repeatability of the manual system were higher than those of the automatic one.

B. Comparison between a previous automatic systems

In order to be validated for its specific purposes, the new system has been utilized for the measurements and the results have been compared with those obtained by the previous system.

The starting point for the previous system was the calibration of the programmable ac-dc transfer standard by means of the thermal converters of the national standard made by the primary system [3]. By means of the system described in [1] the calibrator was characterized in all ranges at several frequencies, using as reference the programmable ac-dc transfer standard.

For the new system, the starting point was instead a multirange ac-dc transfer standard, calibrated in comparison with the national standard. By means of this standard, the calibration of the programmable ac-dc transfer standard and the characterization of the calibrator was obtained for the same voltages and frequencies.

The structures of the measurements performed by the two methods, with the traceability link between the instruments, are represented schematically in Fig.1.

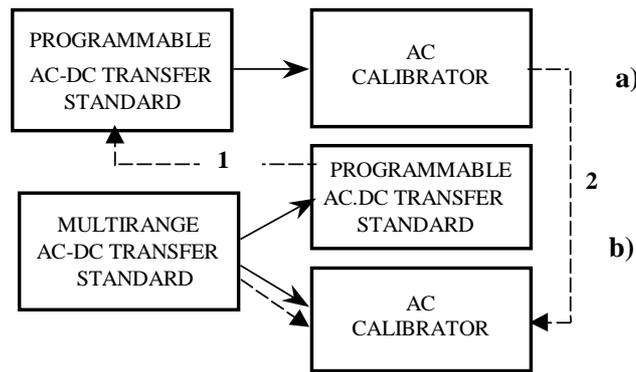


Fig. 1 Schematic representation of the measurement performed
a) by the previous system b) by the new system

Table 3 Repeatability of the comparisons (link 1 in the schematic representation) and difference between the characterization of the ac calibrator by the two methods (link 2).

	1 kHz		20 kHz		50 kHz		100 kHz		500 kHz		1 MHz	
	Reap.	Diff.	Reap.	Diff.	Reap.	Diff.	Reap.	Diff.	Reap.	Diff.	Reap.	Diff.
0.5 V	0.1	0.5	0.2	0.1	0.7	1.4	1.0	1.5	11.8	4.6	32.5	10.9
2 V	0.3	0.4	0.4	0.4	1.7	1.6	5.1	0.1	8.2	7.5	13.8	40.0
10 V	0.1	1.1	0.2	0.9	1.0	1.3	0.7	0.4	6.3	5.9	29.4	17.4
100 V	1.3	0.6	0.4	0.3	2.2	1.4	3.6	1.9				
600 V	0.2	1.0	0.9	0.3	1.7	0.4	7.2	1.9				
	1 kHz		10 kHz		20 kHz		30 kHz					
1000 V	0.1	1.7	-1.4	-1.0	0.4	0.5	0.4	0.5				

As it can be seen in Table 3 the spread of the results and the differences between different methods are in all points within 40 parts in 10^6 and generally less than 5 parts in 10^6 up to 100 kHz.

V. Conclusions

The system for calibration has been built and it is now in use for calibration of both the internal and customer's instruments. The system allows the almost automatic calibration of the reference calibrator in the function ac voltage and ac current and the parallel calibration of several types of ac-dc transfer, ac voltage and ac current measurements.

The modular structure allows an easy extension of the software to new instruments and devices and by means of some further improvements the system can also be used for primary comparison, covering all the chain from primary standard to instruments under test.

Verification of the system for ac voltage has shown the functionality of the system. The repeatability and the consistency of the measurements and the differences between the differences obtained by using different methods fully support the uncertainty claims for the new system.

References

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