17RPT03 DIG-AC
A digital traceability chain for AC voltage and current

Activity A.4.3.2

Deliverable D6: Protocol for a future intercomparison of digital AC voltage and current standards between European NMIs

Leader
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Contributors
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Preface

Objectives of Task 4.3: Protocol for a future intercomparison has been fully met.

CEM, in collaboration with NPL, have used the information obtained in A4.1.7 and A4.2.4, together with information coming from 14RPT01 ACQ-PRO to define the protocol for a future intercomparison of digital AC voltage and current standard between all NMIs participating in the project DIG-AC. All partners will contribute to the protocol and review it. This activity will provide input to A4.3.2.

The activity A4.3.2 has involved the submission of Deliverable 6 to Euramet: “Protocol for a future intercomparison of digital ac voltage and current standards between European National Metrology Institutes (NMIs)”.

Note that some content in this document (participants, time schedule, serial number, etc.) must be updated before carrying out the intercomparison.

1. Introduction

Intercomparisons support mutual recognition agreements between members of the European Community. Regarding ongoing comparisons involving DIG-AC project topic, ac/dc voltage transfer at 3 V, 10 Hz – 1 MHz, 500 V - 1000 V, 10 Hz - 100 kHz (CCEM-K6.a/K9) has been organized under the auspices of the Consultative Committee of Electromagnetism, CCEM, with measurements expected to be completed by May 2022 [2][1]. BIPM onsite comparison covering Josephson Voltage Standards (BIP.EM-K10.a/b) has been going on for some time. Concerning future comparisons, ten laboratories have showed interest on a BIPM onsite Programmable Josephson Voltage Standard (PJVS) ac voltage comparison [1].

At the beginning of DIG-AC project, the analysis carried out between participants showed that a rather small part of ac calibrations is based on sampling and almost none on digital techniques for voltage/current scaling [2]. An intercomparison on these areas is therefore of great importance since it could support future CMCs claims. Digital techniques will allow high accuracy dissemination for complex waveforms that vary with time or have a decent amount of harmonic content. At the same time a digital traceability chain will simplify and shorten calibration procedures.

This intercomparison consists in the measurement of ac voltage and current for different frequencies, voltage/current amplitudes and single/combined waveforms.

The comparison will be carried out in accordance with the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons [3].

All participants to this comparison accept the general instructions and commit themselves to follow the procedures described in this technical report.

Once the protocol and the list of participants have been agreed, no change to the protocol or to the list of participants may be accepted without prior agreement of all the participants.

2. Travelling standard

2.1. General requirements

The quantity to be reported is the measurement error of the travelling standard when measuring current and when measuring voltage, defined as the difference between the measured quantity by the travelling standard and the quantity applied to it, and divided by the quantity applied (voltage or current). The measurement error will be expressed in µV/V and µA/A, respectively.

The current travelling standard is a digitiser Keysight 3458A working in DCV mode together with a 20 mA current shunt.

The same Keysight 3458A digitiser working in DCV mode together with a 4 V resistive voltage divider (RVD) is chosen as voltage travelling standard.

A laptop with the software to be used and connectors are also provided.

The pilot laboratory is responsible for decision about the suitability of the travelling standard for use in the comparison based on its experience and expectation (in some cases a study of the long-term stability and the transport behaviour of the standards will be necessary).

2.2. Description of the standard

The equipment transferred during the intercomparison is shown in Figure 1. Technical details about the digitiser can be found in [4].

The range used in the digitiser is ±1 V. The maximum voltage in the digitiser is 0.8 V_{RMS}.

Figure 1. Components transferred in the intercomparison: digitiser, current shunt and RVD.

2.3. Quantities to be measured

Three ac voltage and three ac current signals at three different frequencies are sampled by the combination digitizer + RVD and digitiser + shunt, respectively. Signals are inputted one by one and in combination (three signals at the same time) as indicated in Figure 2.

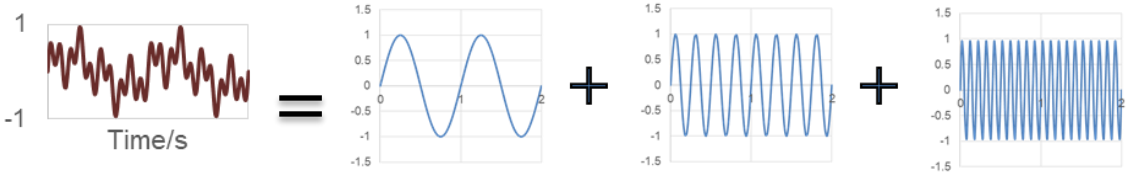

Figure 2. Signal inputs: three waves imputted at the same time and three waves inputted one by one.

The combined waveforms are, in turn, combined in three different ways:

- Same amplitude, same phase
- Different amplitude, same phase
- Same amplitude, different phase

In total, six waveforms are inputted for current and six for voltage as is summarized in Table 1 and 2.

The participating laboratory should report a single measurement result and its uncertainty for each of the testing points represented in the second column of Table 1 and 2. In total, the amount of testing points is 12 values for current and 12 for voltage.

Table 1. Parameters of the current source.

Input #	Testing point	Current source		
		Current RMS/mA	Frequency/Hz	Phase/°
1	1.1	11.00	100	-
2	2.1	11.00	400	-
3	3.1	11.00	1000	-
4	4.1	3.70	100	α
	4.2	3.70	400	α
	4.3	3.70	1000	α
5	5.1	5.55	100	α
	5.2	3.70	400	α
	5.3	1.85	1000	α
6	6.1	3.70	100	α
	6.2	3.70	400	α + 45
	6.3	3.70	1000	α + 90

Table 2. Parameters of the voltage source.

Input #	Testing point	Voltage source		
		Voltage RMS/V	Frequency/Hz	Phase/°
1	1.1	4.000	100	-
2	2.1	4.000	400	-
3	3.1	4.000	1000	-
4	4.1	1.330	100	α
	4.2	1.330	400	α
	4.3	1.330	1000	α
5	5.1	1.995	100	α
	5.2	1.330	400	α
	5.3	0.665	1000	α
6	6.1	1.330	100	α
	6.2	1.330	400	α + 45
	6.3	1.330	1000	α + 90

Measurements should be performed with the environmental/test conditions as follow:

- Voltage: 230 V
- Frequency: 50 Hz ± 0,05 Hz
- Temperature: (23 ± 1) °C
- Humidity: 30% rh - 60% rh

2.4. Method of computation of the reference value

The reference value will be set by the pilot laboratory.

3. Organisation

3.1. Co-ordinator

The co-ordinator and pilot laboratory have to be defined.

3.2. Participants

- TUBITAK
- FER
- CEM
- CMI
- GUM
- Metrosert
- PTB
- INRIM
- IPQ
- JV
- NPL

More details about participants given in Annex A1.

3.3. Time schedule

Participants have 3 weeks for conducting measurements and one week for sending the travelling standard to the next laboratory.

In the case of unexpected delays, the coordinator of the comparison and the next participant should be notified by e-mail. The coordinator will decide about revise the time schedule and inform the other participants.

Annex A2 shows more details about time schedule.

3.4. Transportation

The aim for the time between shipment and reception is one week. Both, standard shipment (road) and expedited transport (plane) are allowed.

Table 3. Time schedule.

NMI	Country	Sending date to the next NMI	Nb open days
Pilot lab			
NMI_1			
…..			
Pilot lab			

An example of a confirmation note of receipt and an example of a confirmation note of dispatch are included in Annex A5 and A6, respectively.

3.5. Unpacking, handling, packing

The travelling standard will be transported in a container, which is designed for safe transportation of the standard. Upon arrival, participants will check the container for external damage, take photos if possible and make sure that all parts are present according to the list.

Opening the corpus of the standards is strictly prohibited.

After the measurements travelling standards will be carefully packed back into the container, in which it arrived. Linear dimensions of container are approximately: 800 mm x 600 mm x 200 mm. The shipping weight is approximately 20 kg.

If damage on the container is detected, the travelling standard will be packed in a new container, which will provide the necessary protection during transportation.

3.6. Failure of the travelling standard

If any defects is found in the travelling standard, the participating laboratory will inform the pilot laboratory immediately. If repair of the travelling standard is needed, the participant will send a travelling standard to the pilot laboratory.

3.7. Financial aspects, insurance

Each participant is responsible for paying the cost for measurements. Each participant is also responsible for arranging shipment to the next participant on his own responsibility and cost, including customs formalities.

4. Measurement instructions

4.1. Test before measurements

Before performing measurements, it is necessary to understand the working principles of travelling standards. Digitiser manual can be found online [4].

Participants will check the standard for external damage, will connect it to mains and will verify that no errors are displayed. If an error appears, it should be easily corrected. If this is not the case the participant will act as indicated in 3.6.

There are no performance tests on the reference standard to be performed before measurements at the participant's laboratory.

4.2. Measurement performance

The standard should be keep at test conditions temperature at least 24 h after arrival. Warm up time is at least 4 hour.

Components will be connected through provided coaxial cables.

The front input terminals of standard must be used for all measurements.

4.3. Method of measurement

The measurement method is that used by the participating laboratory for the provision of a digital calibration.

Make sure that testing voltage and current are within at least 0.2 % of the values shown in Table 1 and 2.

At every testing point shown in Table 1 and 2, make as many independent measurements as stated on the calibration procedures of your laboratory.

Record the data from travelling standard using the software provided in the provided laptop. Calculate current/voltage from recording data with algorithm included in laptop.

Calculate the measurement error (2.1) of the travelling standard for current and voltage at the testing points shown in Table 1 and Table 2. The measurement error is positive if the reference standard's indication is more positive than the applied quantity.

The total estimated expanded uncertainty quoted in the laboratory's report should encompass the Type A and Type B uncertainties of the corresponding NMI calibration service. The expanded uncertainty should be estimated for a level of confidence of 95.45 %.

Report the mean value and spread of the ambient temperature and relative humidity of the laboratory obtained during measurements.

5. Uncertainty of measurement

5.1. Main uncertainty components, including sources and typical values

Participant laboratories are requested to report the main uncertainty components of their measurement systems, identifying all the pertinent uncertainty sources and quantifying their contribution to the expanded uncertainty.

As a guide, uncertainty components can be calculate from DIG-AC Task 3.3 “Report on Uncertainty Estimation for Digital Measurements of Voltage Waveforms”.

5.2. Scheme to report the uncertainty budget

Measurement uncertainty is calculated according to the JCGM 100:2008 (Evaluation of measurement data - Guide to the expression of uncertainty in measurement) [5].

All influencing quantities, their distributions, estimated values, standard uncertainties, degrees of freedom, sensitivity coefficients and components of uncertainty should be given in the uncertainty budget according to The uncertainty of measurement must be determined following the Guide for the Expression of Uncertainty in Measurement [5]. Information of the uncertainty of measurements must be provided in this form.

Participant laboratories are requested to report the main uncertainty components of their measurement systems, identifying all the pertinent uncertainty sources and quantifying their contribution to the expanded uncertainty.

Table 5 in Annex A3.

6. Measurement report

Each participating laboratory will submit a report with measurements results to the pilot laboratory within six weeks after the completion of the measurements. The report should be sent to the pilot laboratory by e-mail.

The report contents are included in Annex A4.

7. Report of the comparison

Pilot laboratory will prepare draft A report and will send it to the participating laboratories for comments.

The participating laboratory will be informed if the significant difference between its results of measurements and preliminary reference value is found, in order to verify any numerical error in the reported results

Participating institutes will send back their comments to the pilot laboratory within 6 weeks.

After that, pilot laboratory will prepare the final report.

References

[1] Consultative Committee for Electricity and Magnetism (CCEM), Report of the 32nd meeting (14-15 April 2021) to the International Committee for Weights and Measures

[2] 17RPT03 DIG-AC, Digital techniques for quantum-traceable ac scaling, A. Sosso, Activity A2.1.4, February 2022

[3] CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons, Version 2.1 (June 2017)

[4] Keysight 3458A Multimeter, Quick Reference Guide, August 2017, https://www.keysight.com/es/en/assets/9018-14517/quick-start-guides/9018-14517.pdf

[5] Guide to the Expression of Uncertainty in Measurement, 1999. International Organization of Standards, Geneva, Switzerland. ISO ENV 13005:1999.

Annexes

Annex A1 – Detailed list of participants

Table 4. List of participants

Organisation	Country	Contact person	E-mail	Shipping address
TUBITAK	Turkey	Tezgül Oztürk		
FER	Croatia	Damir Ilic		
CEM	Spain	Javier Díaz de Aguilar		
CMI	Czech Republic	Martin Sira		
GUM	Poland	Witold Rzodkiewicz		
Metrosert	Estonia	Andrei Pokatilov		
PTB	Germany	Ralf Behr		
INRIM	Italy	Andrea Sosso		
IPQ	Portugal	Vitor Cabral		
JV	Norway	Helge Malmbekk		
NPL	United Kingdom	Jane Ireland		

Annex A2 – Schedule of the measurements

The pattern of the full scale comparison with the allocated time-slots is (examples):

- Single loop: (pilot → NMI_1 → NMI_2 →... → NMI_N → pilot),
- Multiple loop: (pilot → NMI_1 → NMI_2 → pilot → NMI_3 →... → pilot),
- Star configuration: (pilot → NMI_1 → pilot → NMI_2... → pilot).)

Annex A3 – Typical scheme for an uncertainty budget

The uncertainty of measurement must be determined following the Guide for the Expression of Uncertainty in Measurement [5]. Information of the uncertainty of measurements must be provided in this form.

Participant laboratories are requested to report the main uncertainty components of their measurement systems, identifying all the pertinent uncertainty sources and quantifying their contribution to the expanded uncertainty.

Table 5. Uncertainty budget

Uncertainty Budget: ***Title***

i	**Quantity (unit)**	**Distribution**	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$
1							
2							
…							
n							
y		Normal					
		Conf. level = 95.45%		*k* =			
		Result =		*U* =			

Model: Y = ……

Annex A4 – Layout of the measurement report

The report will contain:

1. Identification of the travelling standard;
2. Identification of the participant laboratory and its representative;
3. Description of the method of measurement;
4. Description of the measuring scheme;
5. Confirmation of the traceability of measurements performed.
6. Temperature and relative humidity in the laboratory during the measurements;
7. Measurement data;
8. Results;
9. A detailed uncertainty budget;
10. Signature and title of the laboratory representative.

Other information about the measurement results will not be reported.

Annex A5 – Confirmation note of receipt

Participants have to inform the pilot laboratory and the sending laboratory by e-mail about the arrival of the travelling standard. The form shown on Table 6 can be used for that end.

Table 6. Travelling standards arrival form

Receipt confirmation note		
Arrival date		
NMI		
Person in charge		
Status	□ Damaged	□ Non damaged
Notes		

Annex A6 - Confirmation note of dispatch

The participating laboratory should inform the pilot laboratory and the next laboratory by e-mail about departure of the travelling standard. The form shown on Table 7 can be used for that end.

Table 7. Travelling standards dispatch form

Dispatch confirmation note	
Shipment date	
NMI	
Person in charge	
Carrier information	
Notes	