Final Report

AFRIMETS.EM-S2: Comparison On
Digital Multimeter for DC Voltage, DC Current, DC
Resistance, AC Voltage and AC Current parameters

Authors
Michael Khoza[1], Marcus Hlakola[1], Prof. Dr. Rasha Sayed[2] and Hala M. Abdel Mageed[2]

[1]National Metrology Institute of South Africa (NMISA), South Africa
[2]National institute of Standards (NIS), Egypt

CONTENTS

1 Introduction

During the 13th an intra-Africa metrology system (AFRIMETS) technical committee on electricity and magnetism (TCEM) meeting held on 8th to 9th of July 2019 at Giza, Egypt, a supplementary comparison was approved on digital multimeter. The primary aim of the comparison is to support the calibration measurement capabilities of the national metrology institutes in measuring DC voltage, DC current, DC resistance, AC voltage and AC current parameters. The National Institute of Standards, Egypt (NIS) piloted the comparison and National Metrology Institute of South Africa (NMISA) provided the comparison reference values and eight AFRIMETS national metrology designated institutes participated. The comparison commenced in January 2020 and completed in August 2021. This report describes the behaviour of the comparison standard, participants reported corrections and calculated comparison reference values with associated uncertainties of measurements at 95% confidence level, normalized errors and degrees of equivalence.

2 Organisation of the comparison

The supplementary comparison was prepared in accordance with the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons [1] [2].

2.1 Participants

Table 1. List of participants

Country	Institute	Acronym	Contact person	Shipping address
South Africa	National Metrology Institute of South Africa	NMISA	Marcus Hlakola mhlakola@nmisa.org	Building 5, CSIR Scientia campus, Meiring Naude Road, Pretoria, 0001, South Africa
Egypt	National Institute of Standards, Egypt (Pilot)	NIS	Prof. Dr. Hala Abd El Megeed hala.mohamed@nis.sci.eg, Prof. Dr. Rasha Sayed, Prof. Dr. Mohammed Helmy, Dr. Ahmed Aliwa, Dr. Heba Ahmed and Eng. Omar Aladdin	M. A. El-Sadat (Tersa) Street, El Haram, El Giza, Egypt. P.O. Box: 136 Giza, Code No: 12211

Morocco	Laboratoire Public d'Essais et d'Etudes / Laboratoire National de Métrologie	LPEE-LNM	Mr Abdellah ZITI ziti@lpee.ma	Km 7, Route d'El Jadida, Oasis – Casablanca Morocco
Tunisia	Designated National Institute DEFNAT	DEFNAT/ANM	Ms Zouaoui Jihène, Mr Louhichi Youssef and Mrs Saiida JBILI metrologie@defense.tn	Base militaire Mefteh Saad Allah 1068 Cité Errommana BP 81 Tunis
Kenya	Kenya Bureau of Standards	KEBS	Nyambura Catherine nyamburac@kebs.org	Popo Road, Off Mombasa Road, P.O. BOX 54974-00200, Nairobi, Kenya
Uganda	Uganda National Bureau of Standards	UNBS	Mr. Patrick Kizito Musaazi patrick.kizito@unbs.go.ug	Plot M217 Nakawa Industrial Area, Kampala, Uganda
Ethiopia	National Metrology Institute of Ethiopia	NMIE	Mr. Nesredin Nezir Hassen nesredin03@gmail.com	B67, street 1405, Woreda 06, Bole Sub City, Addis Ababa, Ethiopia
Zimbabwe	Scientific and Industrial Research and Development Centre, National Metrology Institute	SIRDC-NMI	Mr. Raban Chikwanha rchikwanha@sirdc.ac.zw rchikwanha@gmail.com	1574 Alpes Road. Hatcliffe. Harare. Zimbabwe

2.2 Measurement schedule

The travelling standard was circulated to the participating laboratories in a two loops configuration from January 2020 and ended in August 2021 as shown in Table 2.

Table 2. Comparison measurement schedule

Participants	Measurement date of Travelling Standard (DD/MM/YY)
Loop 1	
South Africa	25-01-2020
Egypt	27-02-2020
Morocco	08-05-2020
Tunisia	22-06-2020
South Africa	20-09-2020
Loop 2	
South Africa	20-09-2020
Uganda	30-11-2020
Kenya	16-12-2020
Ethiopia	05-02-2021
South Africa	13-03-2021
Zimbabwe	10-07-2021
South Africa	28-08-2021

2.3 Unexpected incidents

No incidents involving the travelling standard was reported and due to customs regulations, the circulation of the travelling standard was delayed between some participants.

3 Travelling standard and required measurements.

3.1 Description of travelling standard

The travelling standard is a 6½ digit multimeter (Fluke model 8846A) provided by Laboratoire de Metrologia de la Direction Generale des Transmissions et de l'Informatique, Tunisia (DEFNAT). This instrument can measure DC voltage up to 1000 V, DC current up to 10 A, resistance up to 1 GΩ, AC voltage up to 1 000 V, and AC current up to 10 A. The details of the digital multimeter are listed in Table 3 and the picture is shown in figure1.

Table 3. Description of the travelling standard 6½ digit Fluke 8846A multimeter [3]

General Information	
Power supply requirement	100 V / 120 V / 220 V / 240V ± 10 %
Power line frequency	50 Hz to 60 Hz
Power consumption	28 VA peak (12 W average)
Warm-up time	1 Hour to get full specification
Operating temperature range	0 °C to 50 °C
Operating humidity range	0 % to 80 % relative humidity
Temperature coefficient (18 °C - 28 °C)	See pages from 1-11 to 1-17, in the DMM user's manual
Transport Information	
Storage temperature range	–40 °C to 70 °C
Dimensions (H × W × D)	89 mm (H) × 217 mm (W) × 297 mm (D)
Shipping container (H × W × D)	167 mm (H) × 470 mm (W) × 360 mm (D)
Weight	3.6 kg
Shipping Weight	6.0 kg

Figure 1. 6½ Digit Multimeter Fluke model 8846A [3]

3.2 Quantities to be measured.

The quantities to be measured are DC voltage, DC current, DC resistance, AC voltage and AC current are listed in Table 4 [2].

Table 4. Quantities to be measured.

Parameter	Nominal value
DC Voltage	100 mV, 10 V and 1000 V
DC Current	10 mA, 1 A and 10 A
DC Resistance	100 kΩ, 1 MΩ and 100 MΩ
AC Voltage	100 mV, 100 V and 1000 V at 40 Hz and 1 kHz
AC Current	10 mA, 1 A and 10 A at 40 Hz and 1 kHz

3.3 Environmental conditions

The temperature and relative humidity conditions which the participants performed the measurement are listed in table 5.

Table 5. Environmental conditions by participants

Participants	Temperature (°C)	Relative Humidity (%)
NMISA	23,05	48,3
NIS	22,03	44,6
LPEE-LNM	23,00	48,0
DEFNAT/ANM	23,0	50,0
KEBS	22,6	40,9
UNBS	21,5	50,0
NMIE	23,4	50,2
SIRDC-NMI	23,1	51,0

3.4 Measurement methods and traceability

NMISA

- The digital multimeter was measured in accordance with the fluke 8846A digital multimeter user's manual, July 2006, Rev.2, 6/08 [3].
- The digital multimeter was calibrated by direct method against the Fluke 5730A multifunction calibrator, Fluke 732B and standards resistors.
- The Fluke 5730A multifunction calibrator, Fluke 732B and standard resistors are traceable calibrated at NMISA.

NIS

- The digital multimeter was calibrated by direct and differential methods against the multifunction calibrator, Fluke 732B and standards resistors.
- The multifunction calibrators, Fluke 732B and standard resistors are traceable calibrated at CMI, Czech, NIS DC JVAS and BIPM respectively.

LPEE-LNM

- The digital multimeter was calibrated by direct comparison with Multifunction calibrators Fluke 5700A & Fluke 5500A, DC Standards Resistors Fluke 742A-100 kΩ, 742A-1MΩ, and IET SRL-100MΩ.
- The Multifunction calibrators Fluke 5700A & Fluke 5500A were calibrated by LPEE-LNM using Fluke 732B, IET KVD 700, Fluke 752A, Fluke 792A associated to A40 current shunts, and DC Standards Resistors from 1 mW to 10 kW.
- The Fluke 732B, Fluke 742A-1 Ω, Fluke 742A-100 Ω and Fluke 742A-10 kΩ are traceable calibrated at BIPM.
- The Kelvin-Varley Divider IET KVD 700, Fluke 752A, Fluke 792A associated to A40 current shunts, DC Standards Resistors from 1 mW to 100 MW are traceable calibrated at LNE-France.

DEFNAT/ANM

- The digital multimeter is calibrated by direct and differential methods against the multifunction calibrator.
- The multifunction calibrator is calibrated using the DC voltage with Fluke 732B Zener, precision meter Agilent 34420A and standard divider Fluke 752A, AC voltage with AC/DC Transfer Fluke 792A, Direct current with the Guildline 9211A DC shunt and Alternating current by AC/DC transfer method with Fluke A40A current shunt resistor.
- The Fluke 732B Zener and the Agilent 34420A meter are calibrated with DEF-NAT JVS. The Fluke 792A, Guildline 9211A, standard divider Fluke 752A and standard resistors are traceable to France, LNE.

KEBS

- The digital multimeter is calibrated by directly against the 5730A multifunction calibrator
- The direct comparison method used for DC Resistance, DC Voltage and AC Voltage and indirect comparison method by Ohm's law used for DC and AC Current.
- The digital multimeter DC resistance, DC Voltage and AC Voltage measurements were realized using standard resistors and multifunction calibrator 5730A respectively, whose traceability obtained from KEBS laboratory and UME, Turkey.
- The indirect comparison method by Ohm's law used for DC and AC Current measurements were realized using AC/DC Calibrator Valhalla 2555A whose traceability is obtained from UME, Turkey.

UNBS

- The digital multimeter was calibrated by substitution and direct comparison methods using the Fluke 5500A and Keithley 2010.
- The Fluke 5500A and Keithley 2010 laboratory standards are traceable calibrated at NMISA.

EMI

- The calibration was performed by direct comparison with the FLUKE 5730A calibrator.
- The FLUKE 5730A calibrator has been calibrated using the 792A AC/DC transfer standard, the Fluke A40 current shunt resistor, the Fluke 732B Zener DC voltage standard, and the Fluke 742A and Y5020 DC resistors.
- The 792A AC/DC transfer standard, the Fluke A40 current shunt resistor, the Fluke 732B Zener DC voltage standard, and the Fluke 742A and Y5020 DC resistors are traceable to NMISA.

SIRDC-NMI

- The calibration was performed by direct comparison against the Fluke 5080A multifunction calibrator.
- The Fluke 5080A laboratory standard is traceable calibrated at NMISA.

3.5 Deviation(s) from the protocol

There were no deviations from the participants, the measurements were undertaken as per the protocol [2]

4 Stability of the travelling standards

The stability of the travelling standard was determined from NMISA measurements dated from 25 January 2020 to 28 August 2021. The linear fit equation (1) below used to calculate the drift (m) of the travelling standard.

$$(y - y_0) = m(x - x_0) \qquad (1)$$

Where:

- x is a selected NMISA measurement date.
- x_0 is the average of the NMISA measurement dates.
- y is the correction value given by the linear fit on a selected date.
- y_0 is the average correction of the NMISA measurements.
- m is the calculated drift of the correction per day.

For each of the measured corrections, x_0, y_0 and m are given in table 6 below.

Table 6. Parameters for drift ($\boldsymbol{m}$) analysis of travelling standard.

Parameter	Range	x_o	y_o	m
DC Voltage	100 mV	28/11/2020	-0.0005 mV	7.33E-07 mV/day
	10 V		-0.0000735 V	-2.38E-08 V/day
	1000 V		-0.01075 V	-4.58E-06 V/day
DC Resistance	100 kΩ		0.009225 kΩ	1.13E-05 kΩ/day
	1 MΩ		0.000086 MΩ	8.80E-08 MΩ/day
	100 MΩ		0.12395 MΩ	1.68E-04 MΩ/day
DC Current	10 mA		0.0025675 mA	-2.63E-06 mA/day
	1 A		0.00005925 A	-4.12E-08 A/day
	10 A		-0.0013575 A	-4.49E-07 A/day
AC Voltage	100 mV at 40 Hz		0.017525 mV	4.67E-06 mV/day
	100 mV at 1000 Hz		0.0116 mV	3.67E-06 mV/day
	100 V at 40 Hz		0.060625 V	9.81E-06 V/day
	100 V at 1000 Hz		0.052025 V	1.13E-05 V/day
	1000 V at 40 Hz		0.65525 V	1.38E-04 V/day
	1000 V at 1000 Hz		0.65525 V	1.38E-04 mV/day
AC Current	10 mA at 40 Hz		0.0021075 mA	-1.79E-06 mA/day
	10 mA at 1000 Hz		0.001475 mA	-1.85E-06 mA/day
	1 A at 40 Hz		0.00015875 A	4.86E-08 A/day
	1 A at 1000 Hz		0.0000735 A	6.42E-08 A/day
	10 A at 40 Hz		0.00177 A	1.39E-06 A/day
	10 A at 1000 Hz		0.0003125 A	9.07E-07 A/day

The behaviour of the travelling standard using the NMISA measurements are plotted on the graphs shown in figure 2 to 22 below.

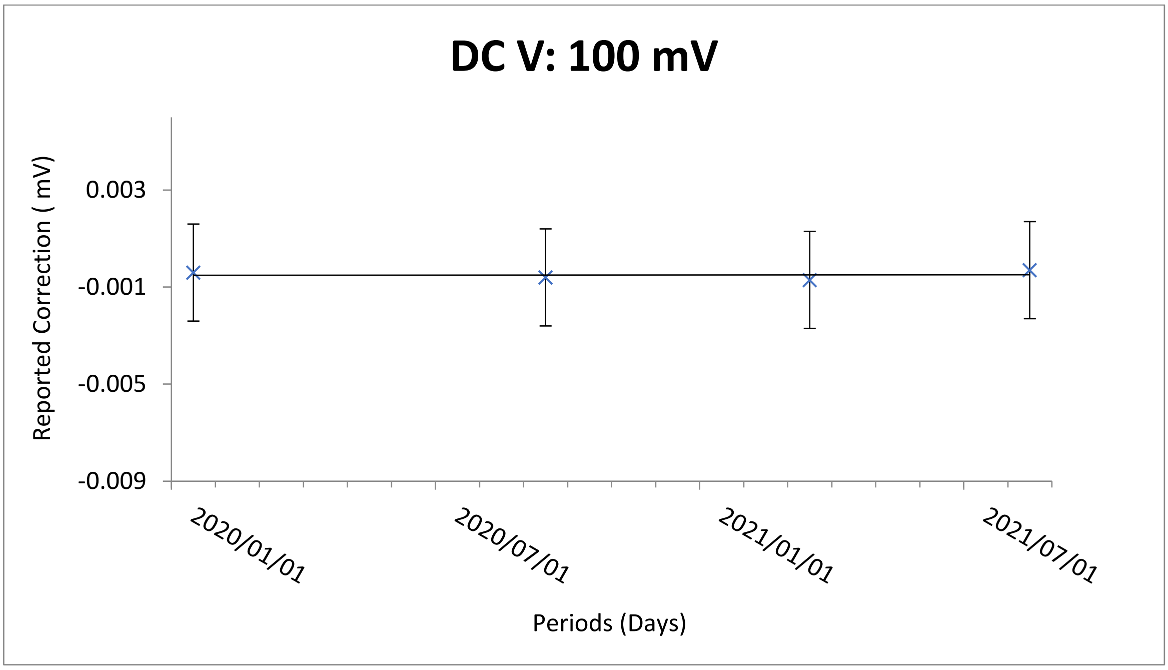

Figure 2. Stability of dc voltage 100 mV

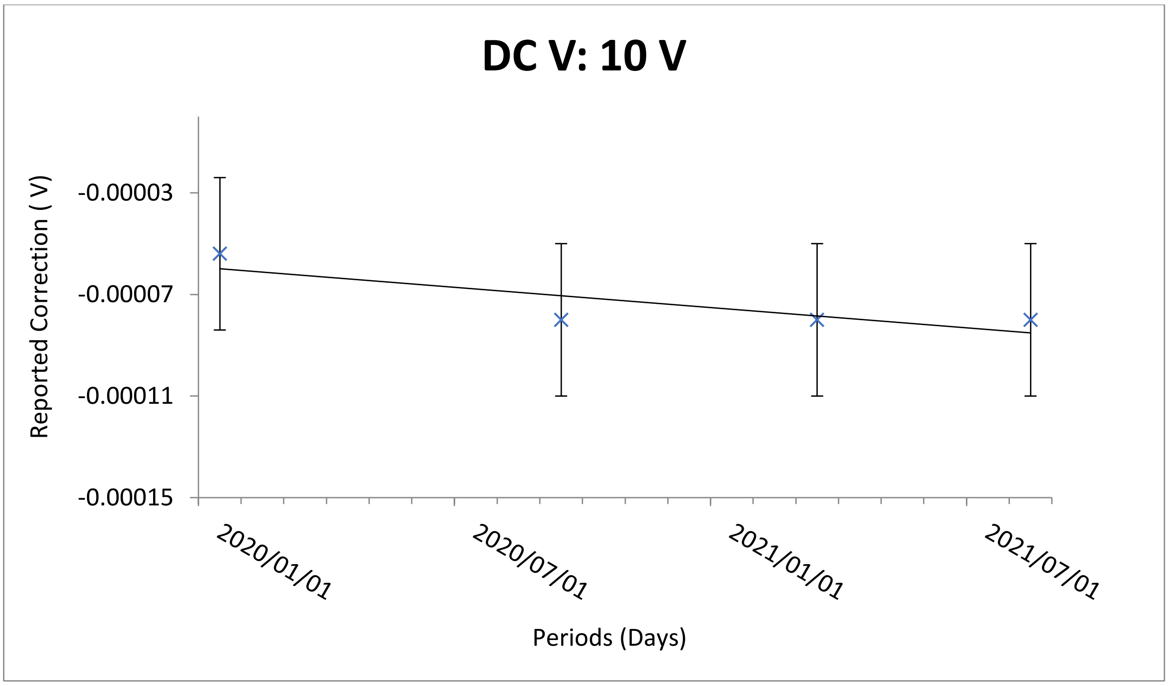

Figure 3. Stability of dc voltage 10 V

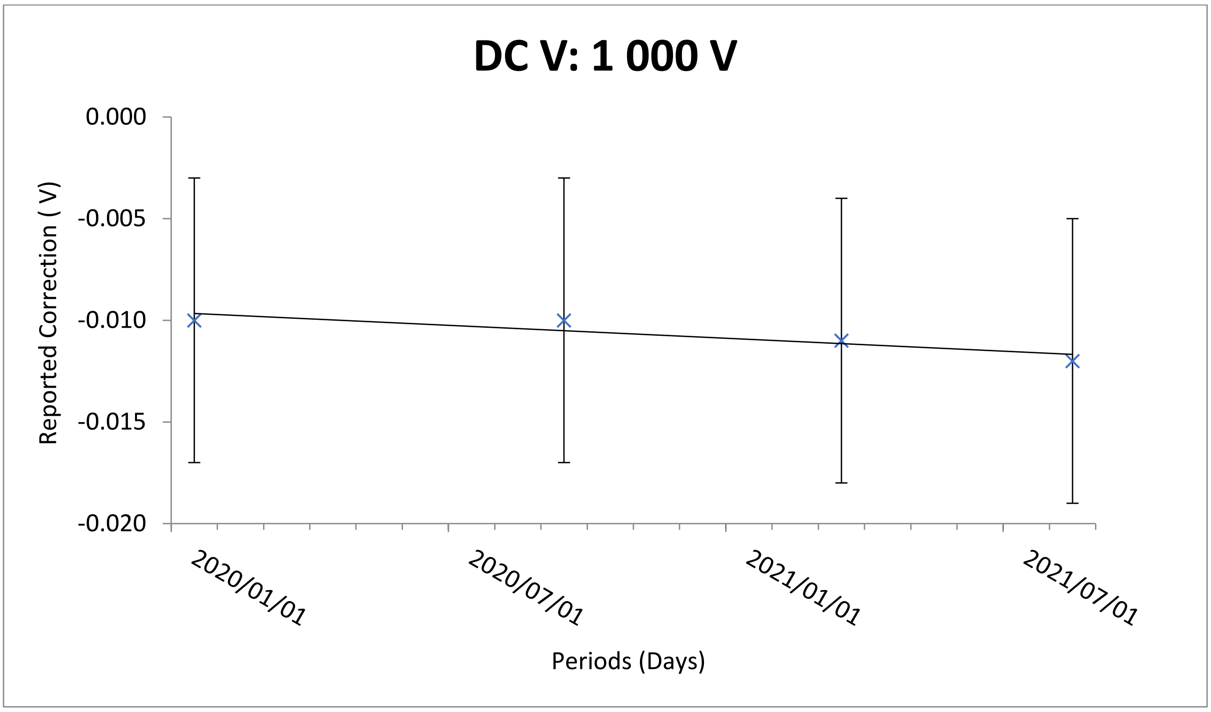

Figure 4. Stability of dc voltage 1 000 V

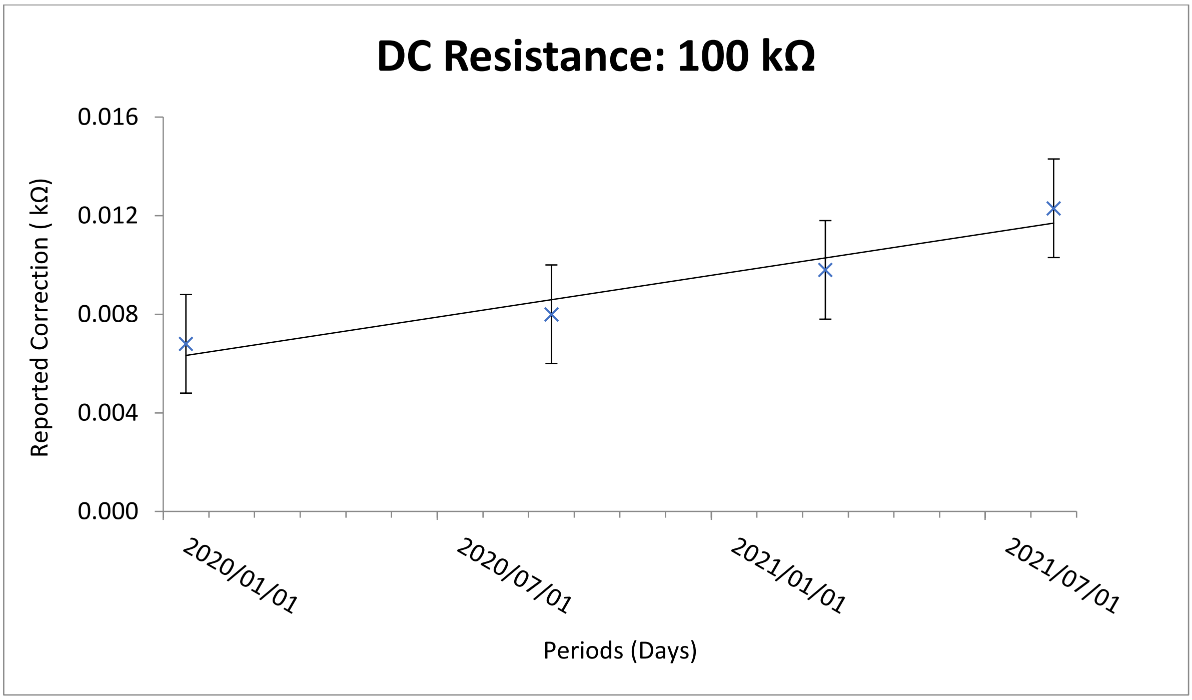

Figure 5. Stability of dc resistance 100 kΩ

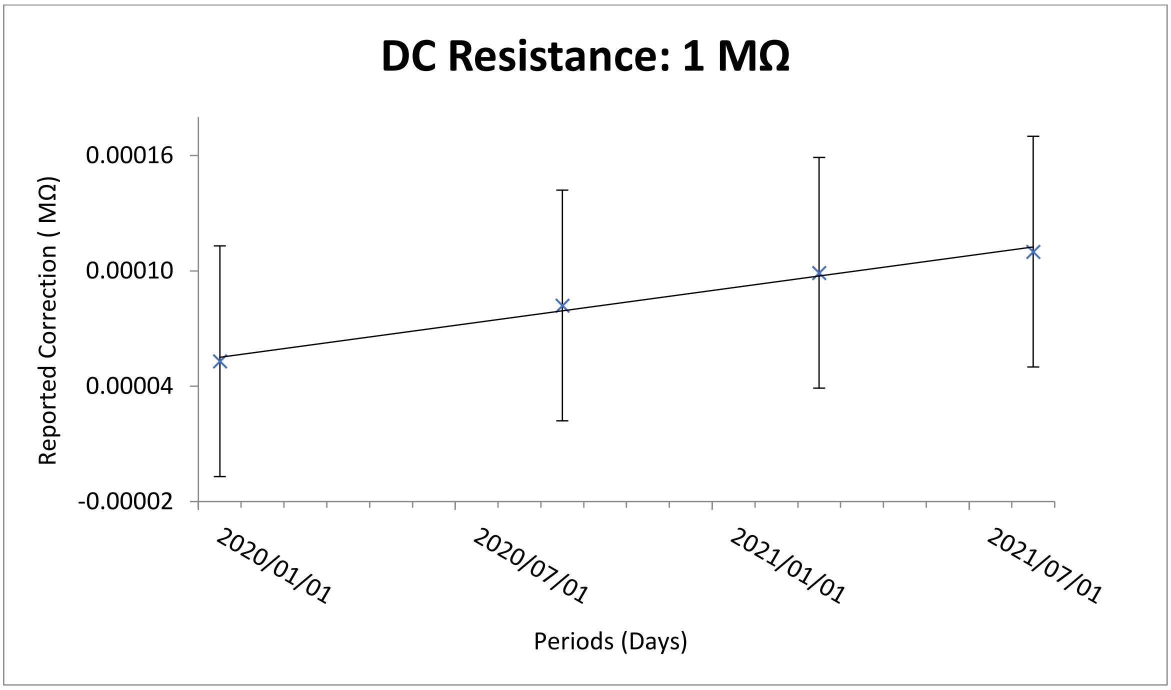

Figure 6. Stability of dc resistance 1 MΩ

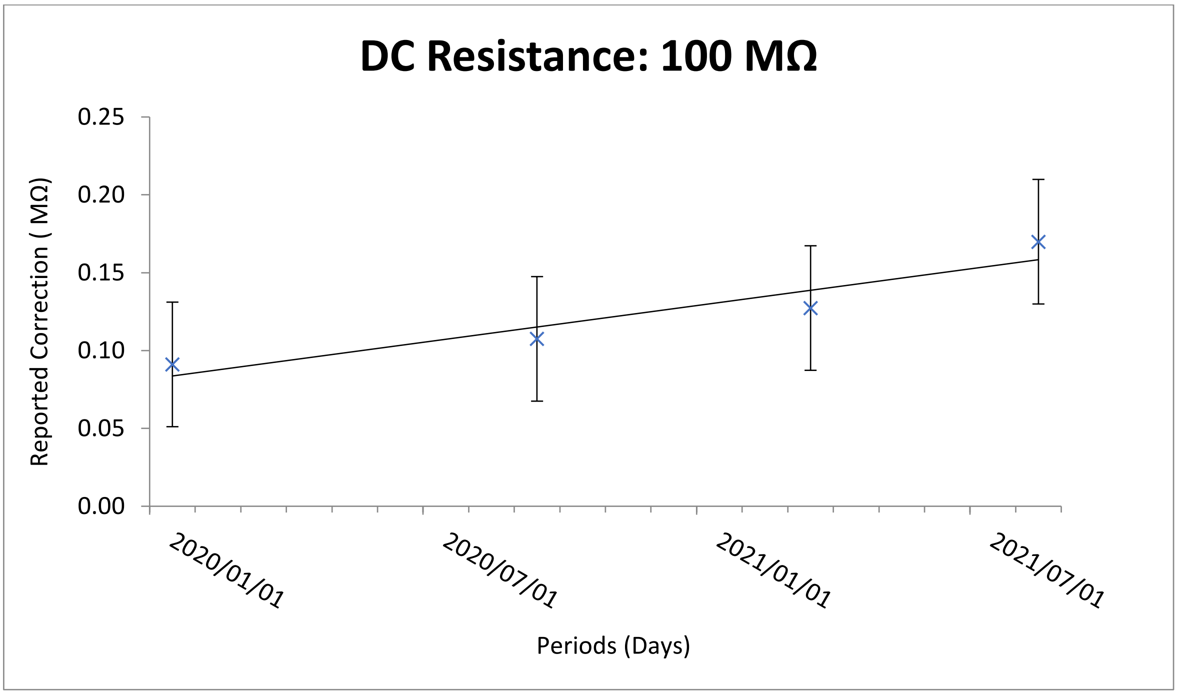

Figure 7. Stability of dc resistance 100 MΩ

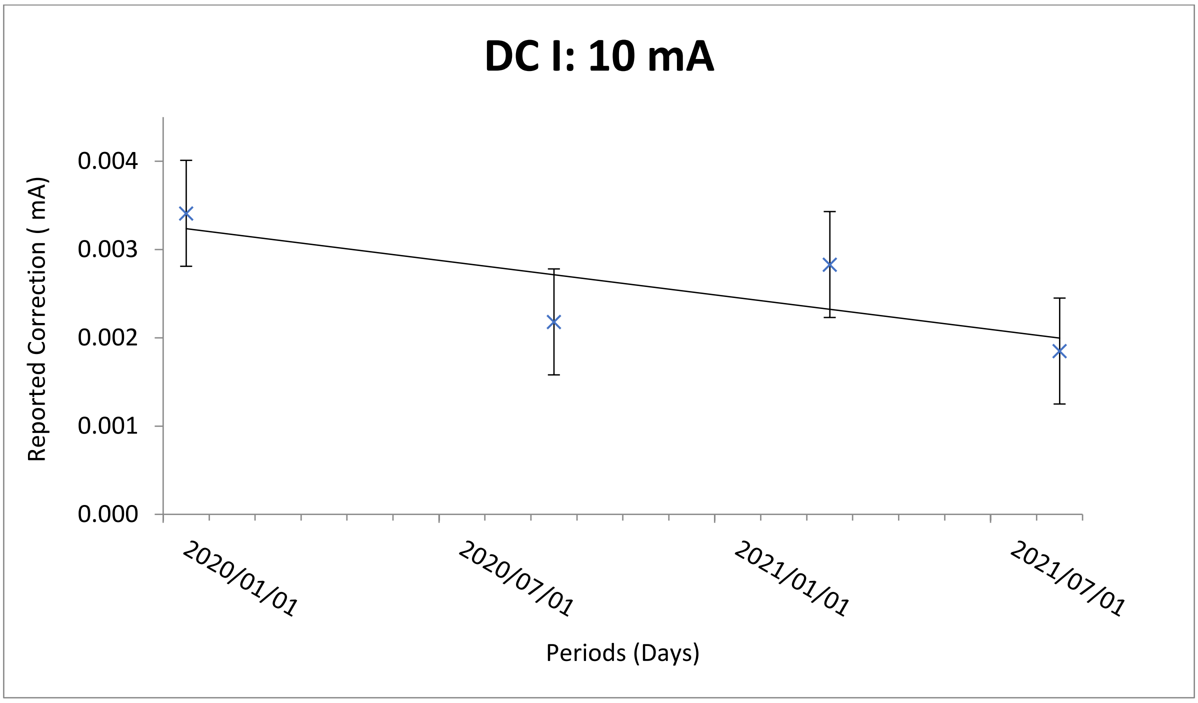

Figure 8. Stability of dc current 10 mA

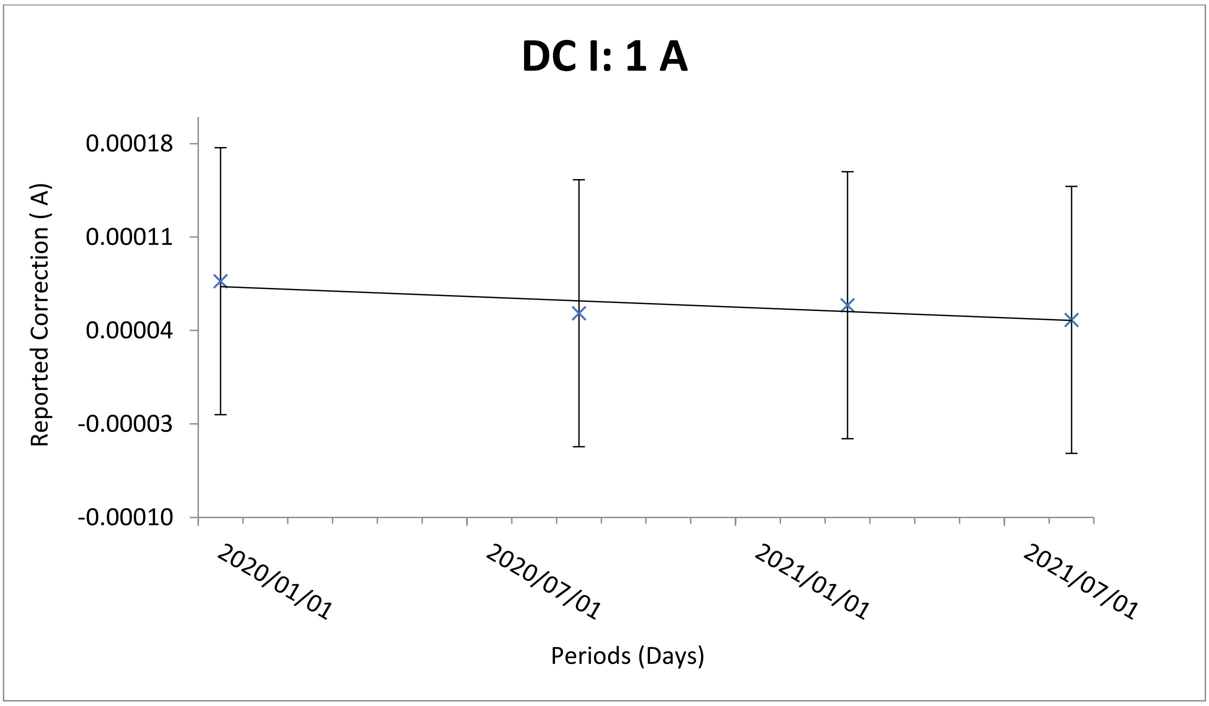

Figure 9. Stability of dc current 1 A

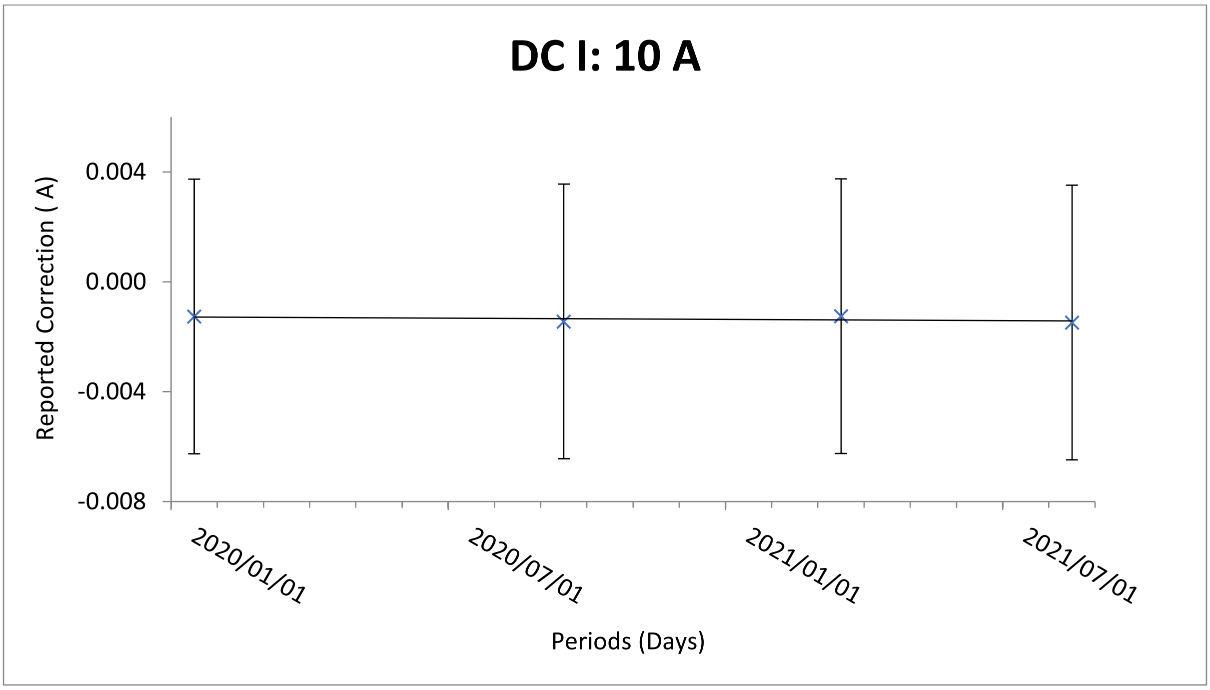

Figure 10. Stability of dc current 10 A

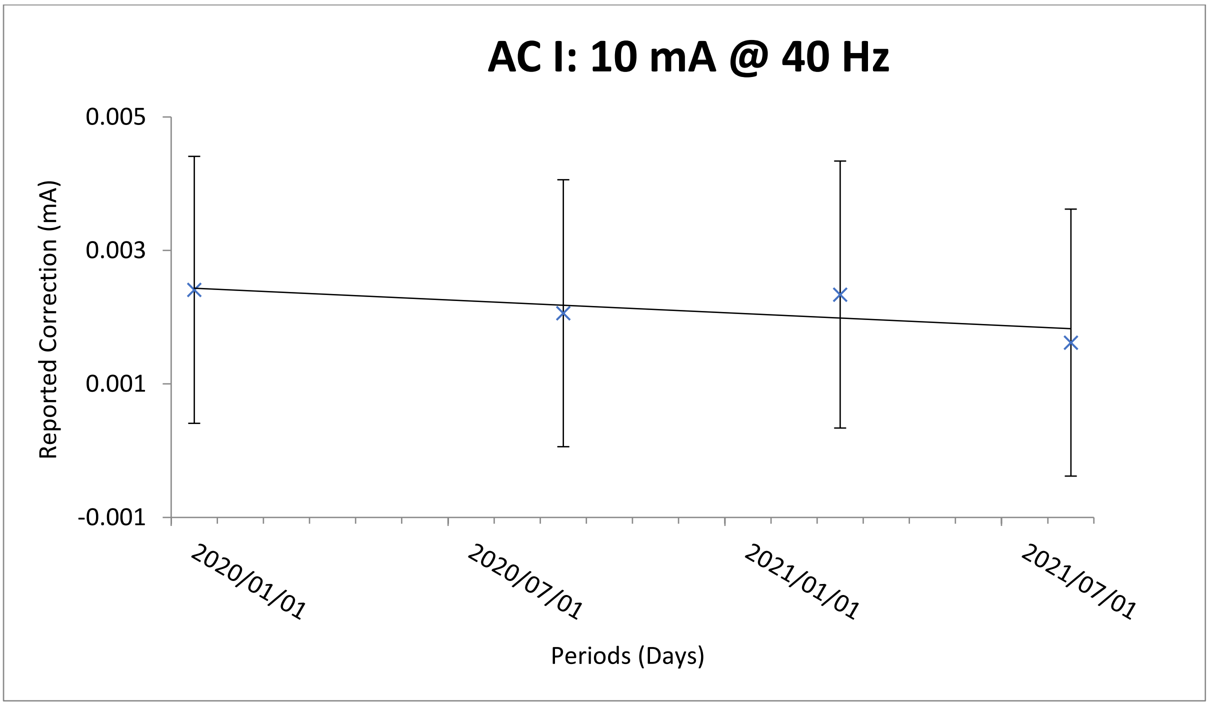

Figure 11. Stability of ac current 10 mA @ 40 Hz

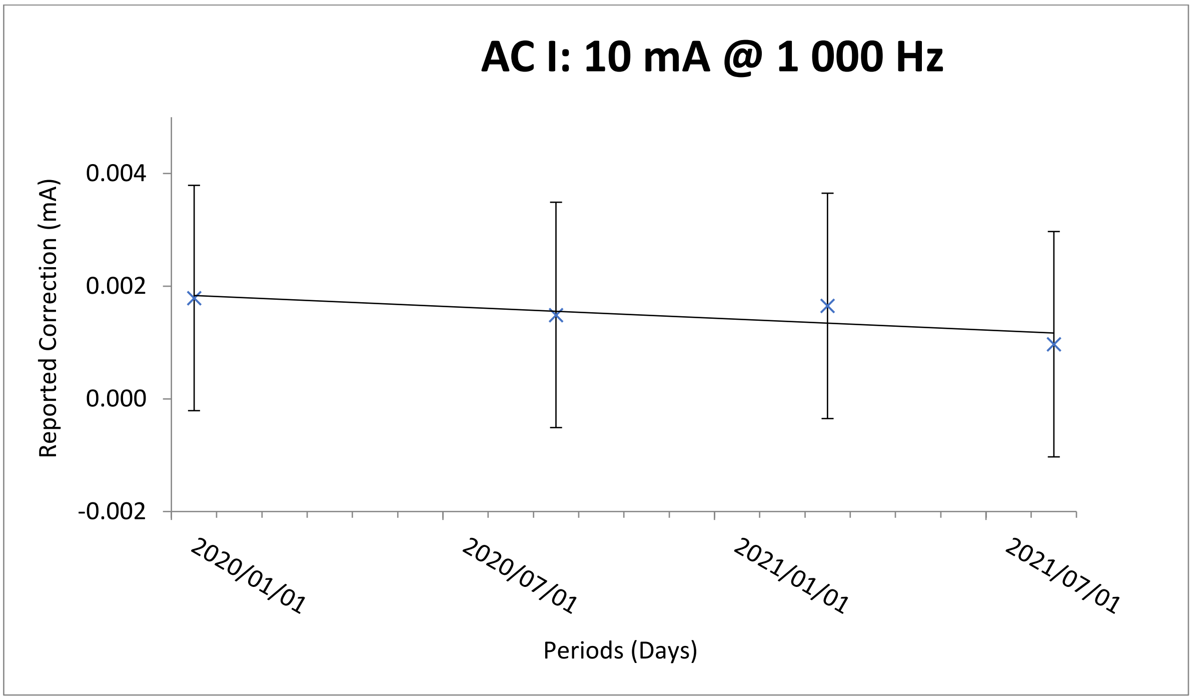

Figure 12. Stability of ac current 10 mA @ 1 000 Hz

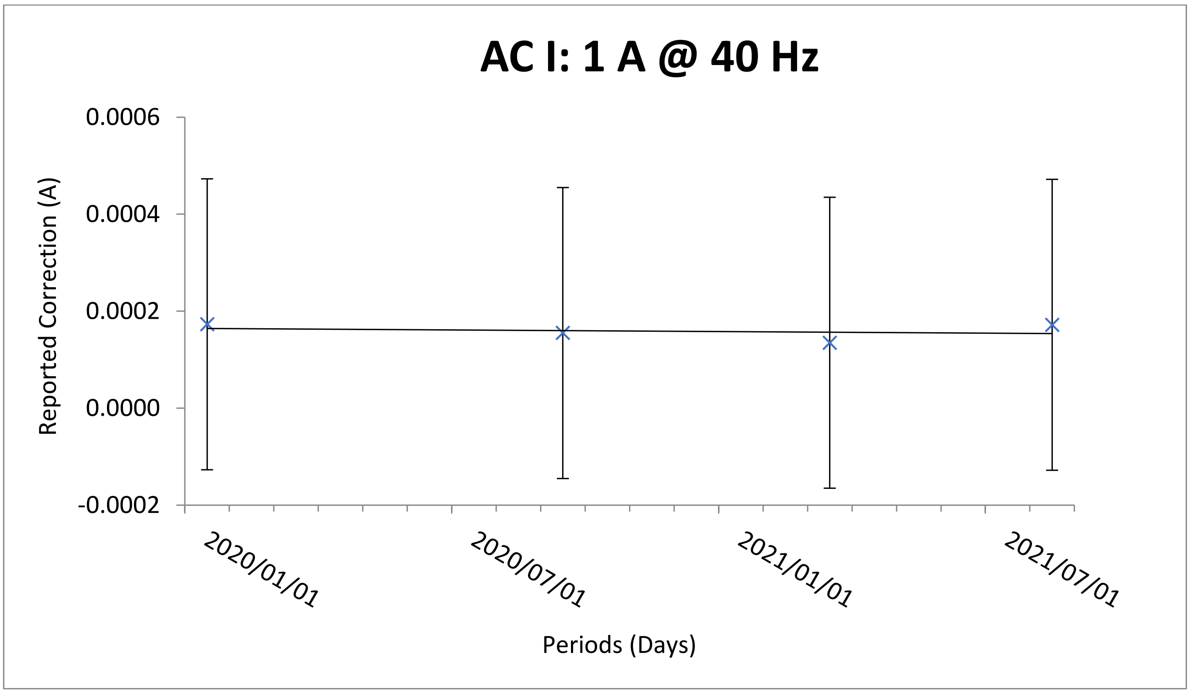

Figure 13. Stability of ac current 1 A @ 40 Hz

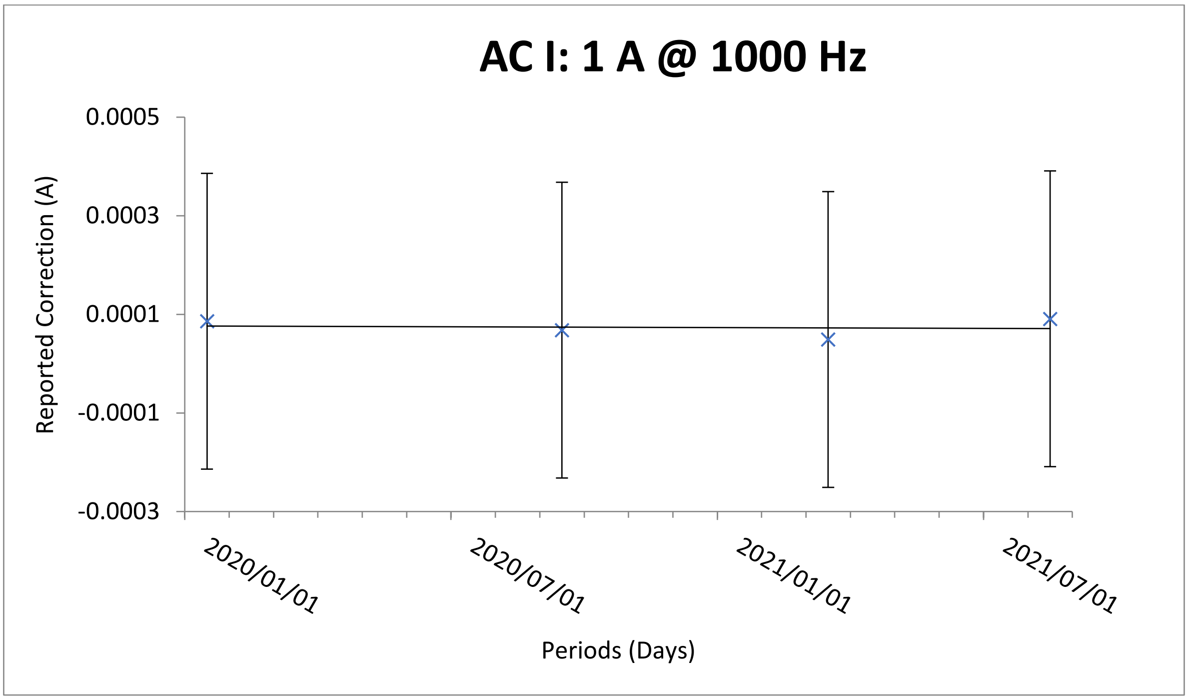

Figure 14. Stability of ac current 1 A @ 1 000 Hz

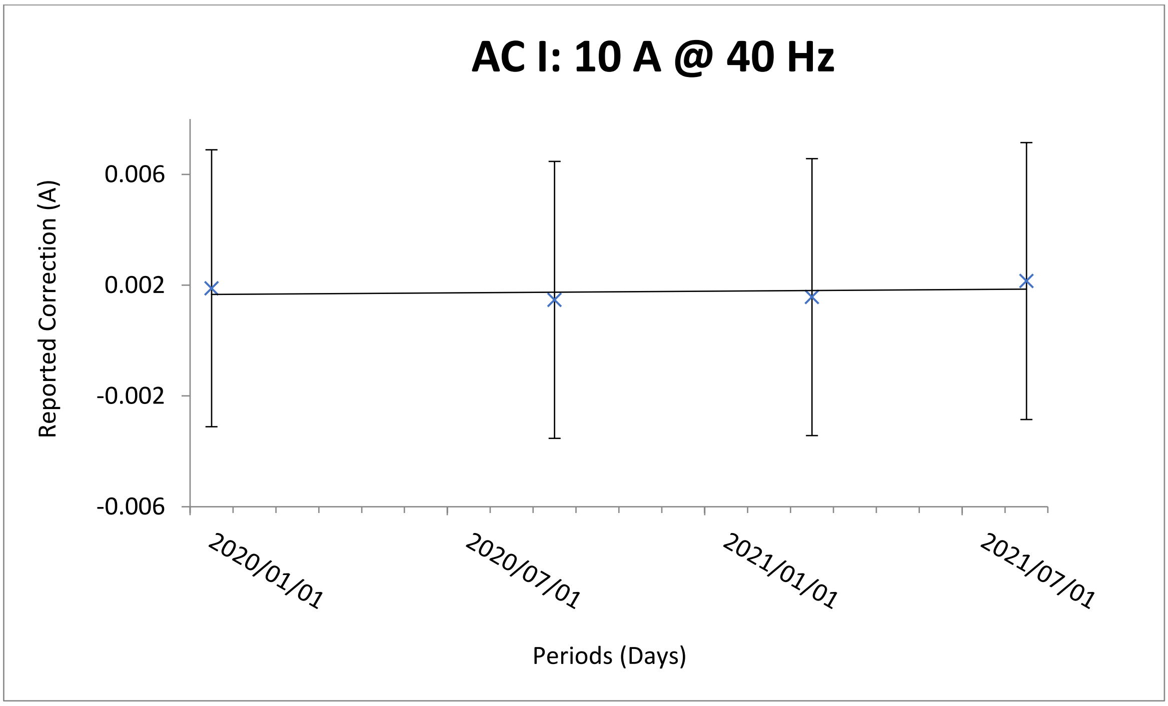

Figure 15. Stability of ac current 10 A @ 40 Hz

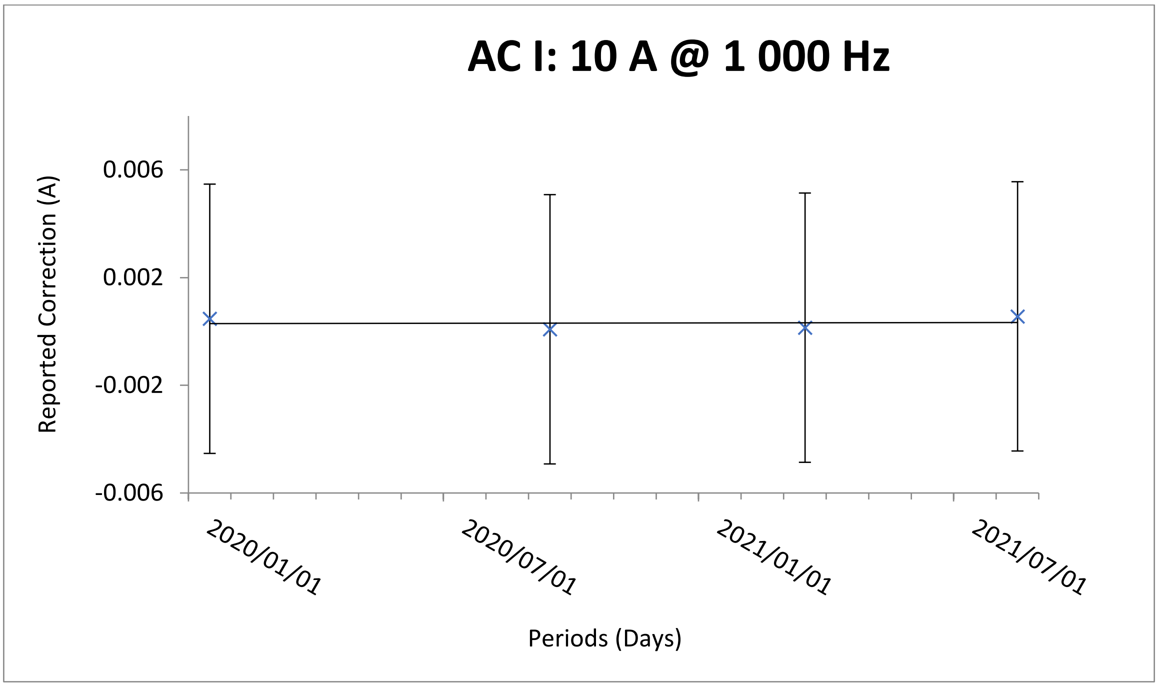

Figure 16. Stability of ac current 10 A @ 1 000 Hz

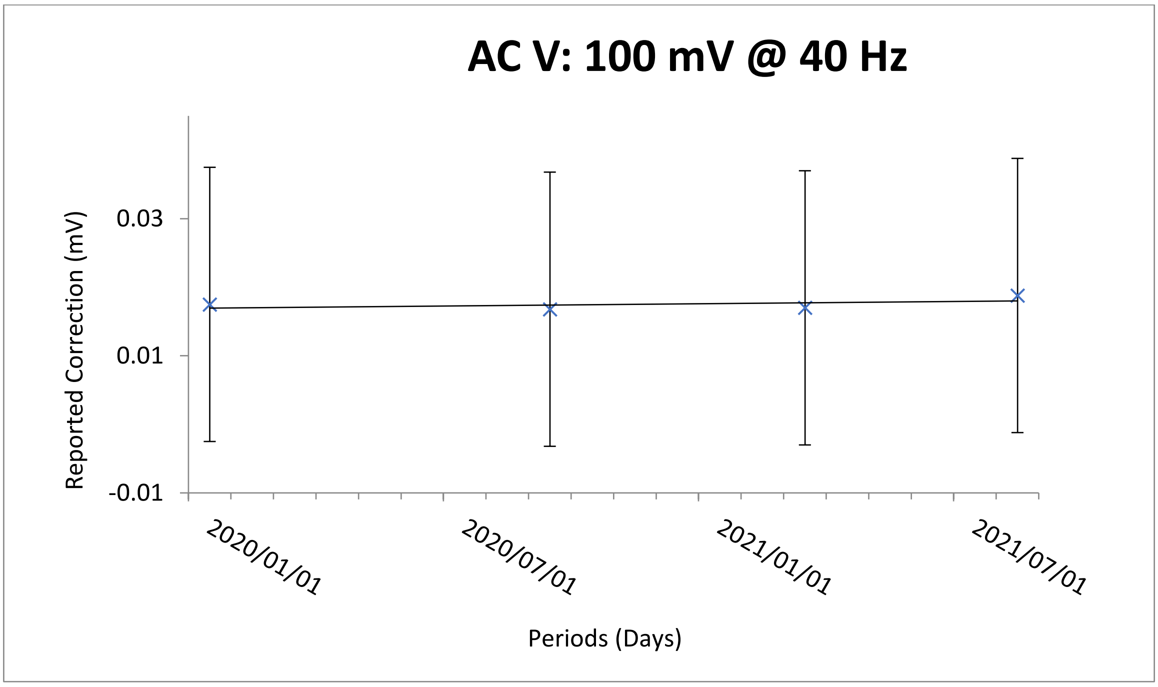

Figure 17. Stability of ac voltage 100 mV @ 40 Hz

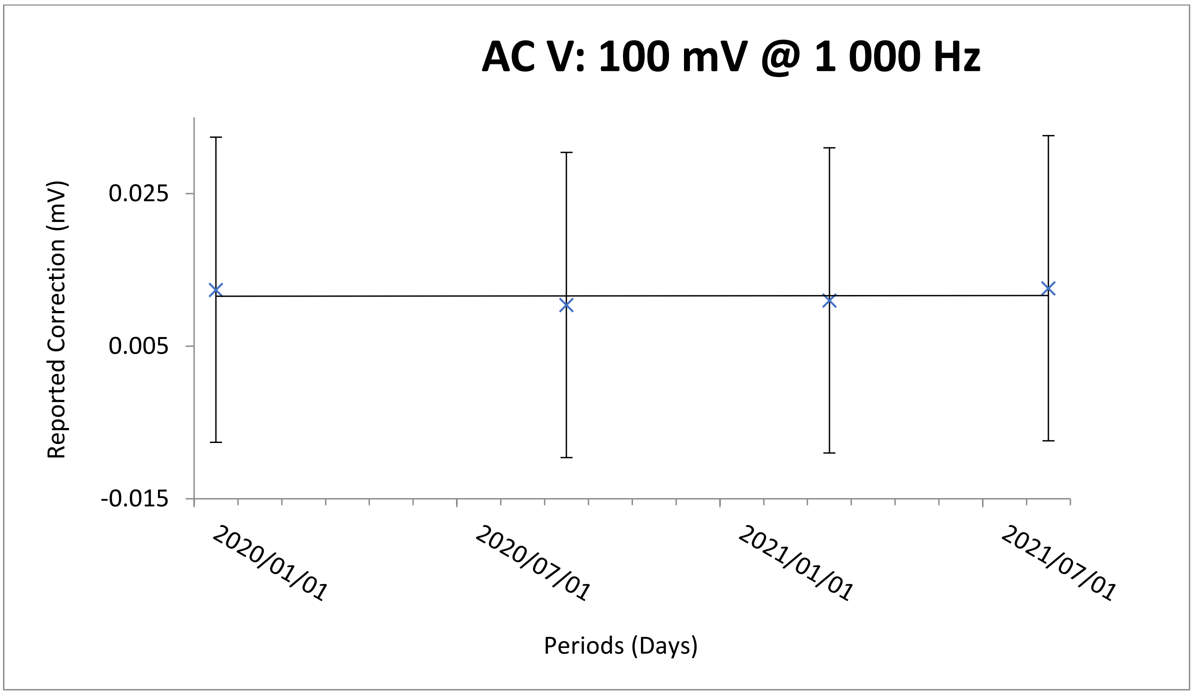

Figure 18. Stability of ac voltage 100 mV @ 1 000 Hz

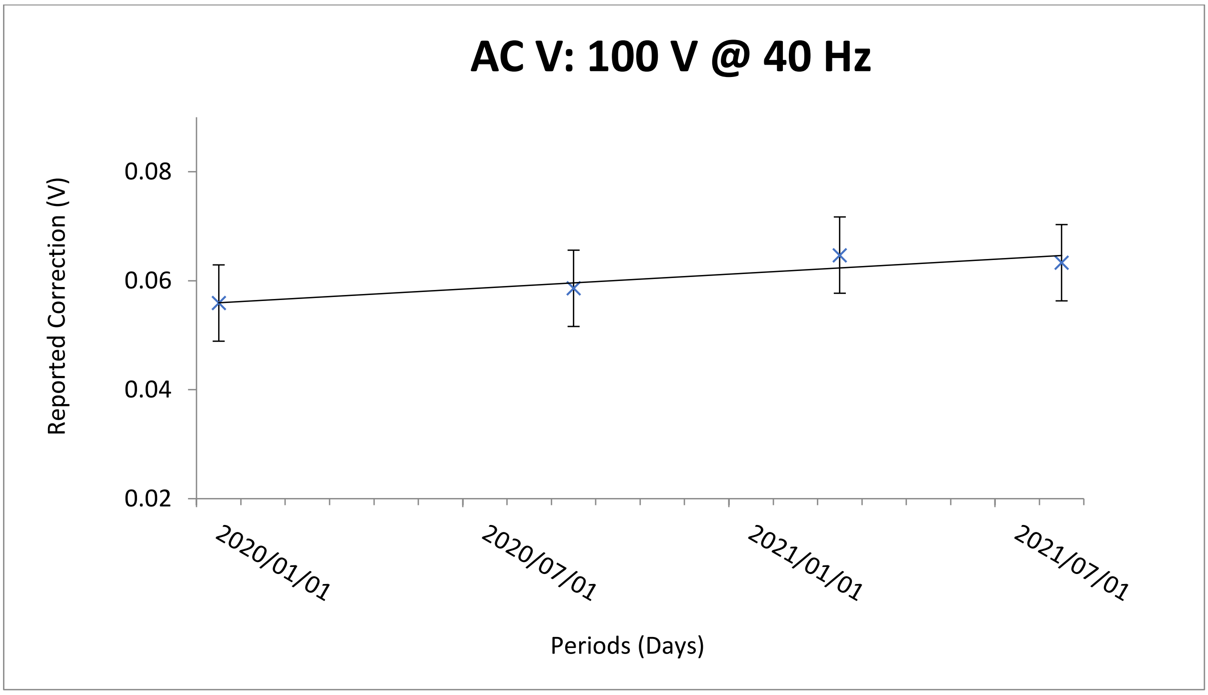

Figure 19. Stability of ac voltage 100 V @ 40 Hz

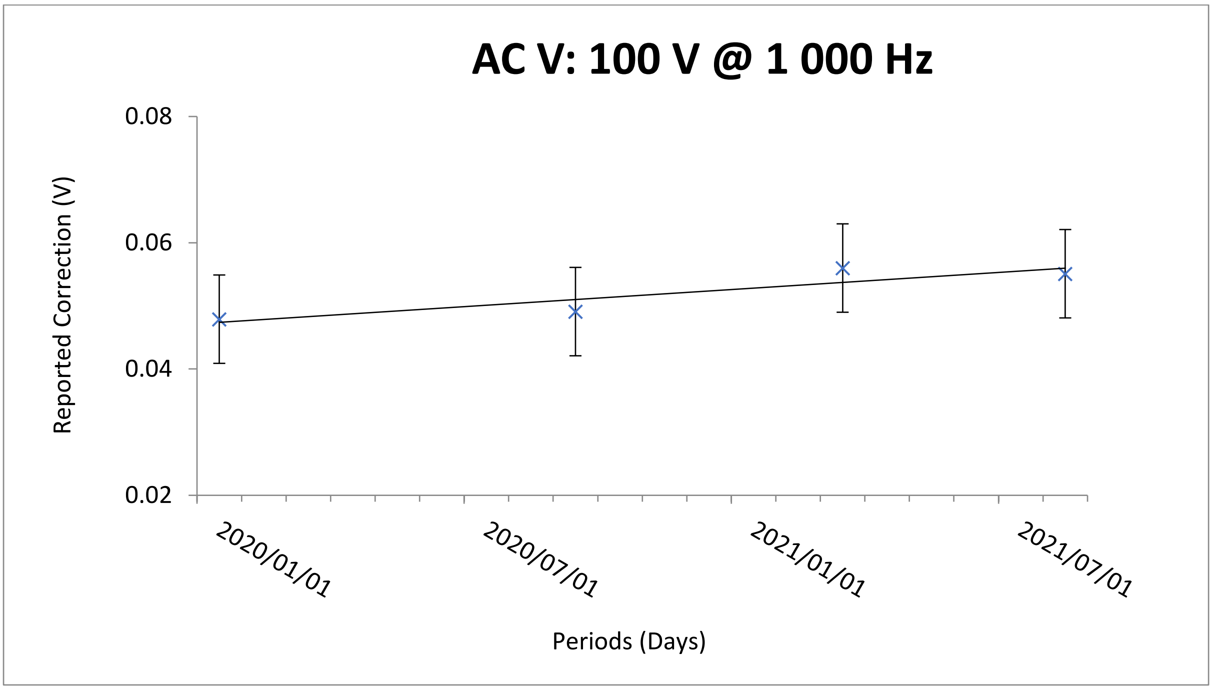

Figure 20. Stability of ac voltage 100 V @ 1 000 Hz

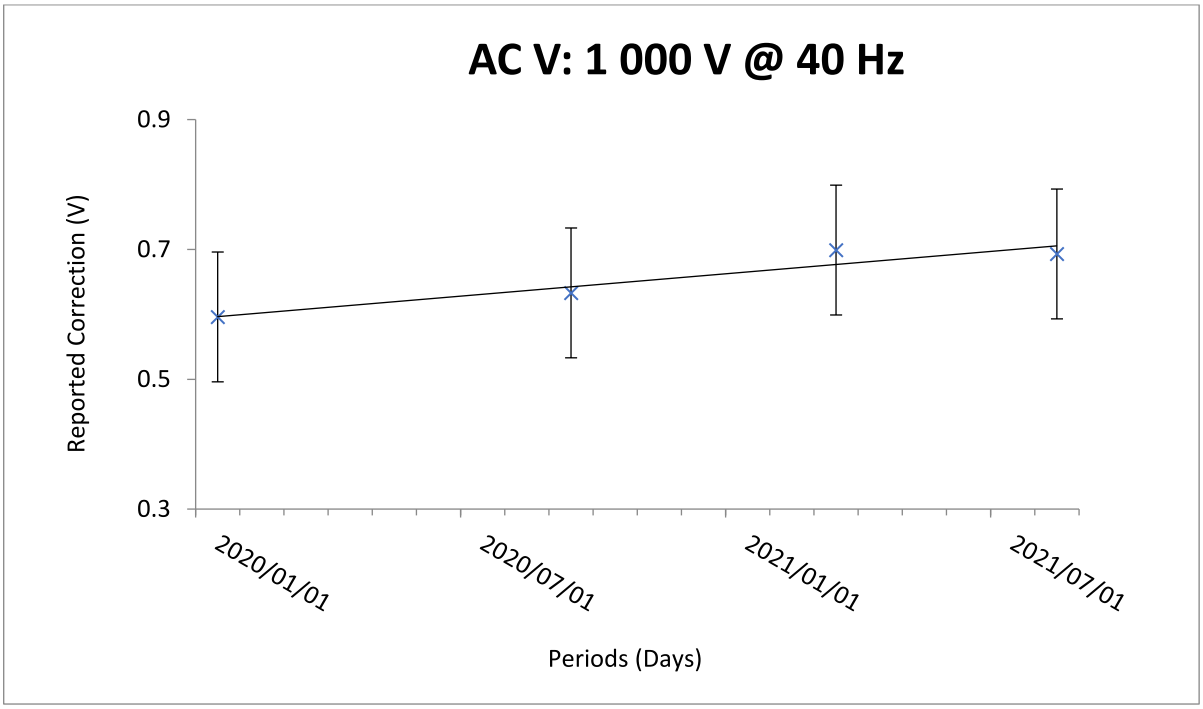

Figure 21. Stability of ac voltage 1 000 V @ 40 Hz

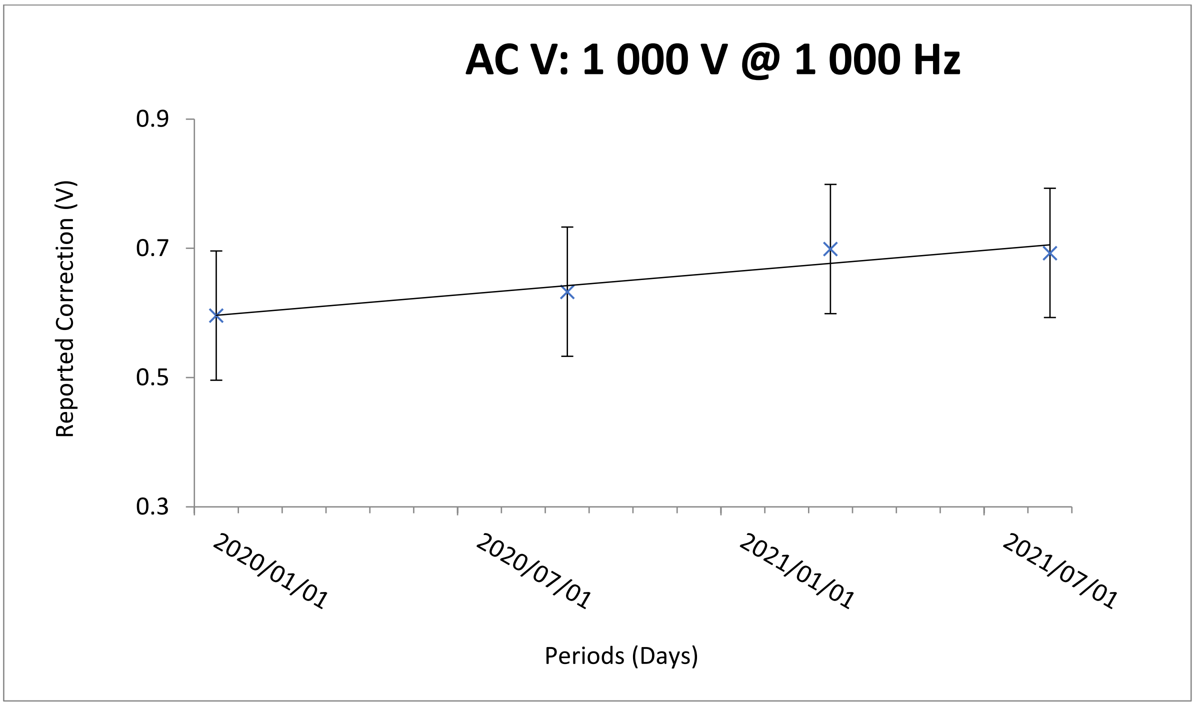

Figure 22. Stability of ac voltage 1 000 V @ 1 000 Hz

5 Comparison results

5.1 Drift corrections

The drift (m) component determined using the equation (1) in paragraph 4 above is used to apply correction to the participants reported value to the comparison reference value dated 28 November 2020 using the equation (2).

$$C_x = C_r + (m * D_y) \qquad (2)$$

Where:

C_x is the corrected reported correction value of the participant.

C_r is the reported correction value by participant.

m is the estimated correction drift per day of the travelling standard.

D_y is the period lapsed in days with respect to comparison reference value, 28 November 2020.

5.2 Calculation of comparison reference value, CRV

Accordingly, the comparison reference value R_{CRV} is determined by averaged of the NMISA measurements ($\bar{X}$), using Equation (3) and the uncertainty of the reference value U_{RCV} is the uncertainty of $\bar{X}$ [4] [5] [6].

$$\overline{X} = \frac{\sum_{i=1}^{N} X_i}{N} \qquad (3)$$

Where:

$\overline{X}$ is the (R_{CRV}) averaged of (NMISA) measurements.

X_i is the measurements performed by NMISA

N is the number of measurements performed by NMISA

The uncertainty of the reference value (U_{RCV}) is the reported NMISA expanded uncertainty of measurement. The R_{CRV} values and their associated uncertainties (k = 2) are as shown in Table 7.

Table 7: Comparison Reference values (R_{CRV})

Parameter	Range	Comparison Reference Value	Uncertainty (k=2)
DC Voltage	100 mV	-0.00073 mV	0.002 mV
	10 V	-0.00007 V	0.00003 V
	1 000 V	-0.00934 V	0.007 V
DC Resistance	100 kΩ	0.00575 kΩ	0.002 kΩ
	1 MΩ	0.00006 MΩ	0.00006 MΩ
	100 MΩ	0.07202 MΩ	0.04 MΩ
DC Current	10 mA	0.00338 mA	0.0006 mA
	1 A	0.00007 A	0.0001 A
	10 A	-0.00122 A	0.005 A
AC Voltage	100 mV at 40Hz	0.01608 mV	0.02 mV
	100 mV at 1000 Hz	0.01047 mV	0.02 mV
	100 V at 40 Hz	0.05760 V	0.007 V
	100 V at 1000 Hz	0.04855 V	0.007 V
	1000 V at 40 Hz	0.61259 V	0.1 V
	1000 V at 1 000 Hz	0.53509 V	0.1 V
AC Current	10 mA at 40 Hz	0.00266 mA	0.002 mA
	10 mA at 1 000 Hz	0.00205 mA	0.002 mA
	1 A at 40 Hz	0.00014 A	0.0003 A
	1 A at 1 000 Hz	0.00005 A	0.0003 A
	10 A at 40 Hz	0.00134 A	0.005 A
	10 A at 1 000 Hz	0.00003 A	0.005 A

5.3 Normalised error (E_n)

The normalised errors of the corrected reported values have been calculated using Equation (4),

$$E_N = \frac{R_x - R_{\mathrm{CRV}}}{\sqrt{(U_{CRV})^2 + (U_{Rx})^2}} \qquad (4)$$

where:

E_n is the normalised error.
R_X is the corrected value reported by participant.
R_{CRV} is the comparison reference value.
U_{RX} is the uncertainty reported by participant.
U_{CRV} is the uncertainty of the reference value.

5.4 Deviation from R_{CRV}

The deviation from R_{CRV}, D_i is determined the using the Equation (5) [5] [6].

$$D_i = R_X - R_{\mathrm{CRV}} \qquad (5)$$

Where R_X is the corrected reported value by participant and R_{CRV} is the comparison reference value.

5.5 Participants reported results

Table 8 to 28 presents the corrected measurement results associated with their uncertainties, R_{CRV}, U_{CRV} , E_n values and the deviation from R_{CRV} (D_i) for the travelling standard. Graphical representations of the comparison results are shown in Figure 23 to 42.

Table 8. Participants corrected measurements dc voltage 100 mV

Name of Participant	Parameter: DC V	Reported Correction (mV)	Applied Drift Correction (mV)	Uncertainty of Measurement (±mV)	Calculated E_N Value	Degrees of Equivalent (mV)
CRV	100 mV		-0.00050	0.002		
NMISA		-0.0004	-0.00017	0.002	-0.12	0.0003
NIS		-0.0006	-0.00040	0.00052	-0.05	0.0001
LPEE-LNM		-0.0004	-0.00025	0.0019	-0.09	0.0002
DEFNAT/ANM		-0.0007	-0.00058	0.0012	0.04	-0.0001
NMISA		-0.0006	-0.00055	0.002	0.02	0.0000
UNBS		0.0004	0.00040	0.00203	-0.32	0.0009
KEBS		-0.00026	-0.00027	0.00058	-0.11	0.0002
EMI		-0.0002	-0.00025	0.0011	-0.11	0.0002
NMISA		-0.0007	-0.00078	0.002	0.10	-0.0003
SIRDC-NMI		-0.0006	-0.00076	0.0068	0.04	-0.0003
NMISA		-0.0003	-0.00050	0.002	0.00	0.0000

Table 9. Participants corrected measurements dc voltage 10 V

Name of Participant	Parameter: DC V	Reported Correction (V)	Applied Drift Correction (V)	Uncertainty of Measurement (±V)	Calculated E_N Value	Degrees of Equivalent (V)
CRV	10 V		-0.00007	0.00003		
NMISA		-0.000054	-0.00006	0.00003	-0.29	0.00001
NIS		-0.00007	-0.00008	0.00014	0.02	0.00000
LPEE-LNM		-0.00008	-0.00008	0.00009	0.12	-0.00001
DEFNAT/ANM		-0.00008	-0.00008	0.00004	0.21	-0.00001
NMISA		-0.00008	-0.00008	0.00003	0.19	-0.00001
UNBS		0.00002	0.00002	0.0001	-0.90	0.00009
KEBS		-0.000071	-0.00007	0.000018	-0.08	0.00000
EMI		-0.00007	-0.00007	0.000094	-0.05	0.00001
NMISA		-0.00008	-0.00008	0.00003	0.09	0.00000
SIRDC-NMI		-0.0001	-0.00009	0.0005	0.04	-0.00002
NMISA		-0.00008	-0.00007	0.00003	0.00	0.00000

Table 10. Participants corrected measurements dc voltage 1 000 V

Name of Participant	Parameter: DC V	Reported Correction (V)	Applied Drift Correction (V)	Uncertainty of Measurement (±V)	Calculated E_N Value	Degrees of Equivalent (V)
CRV	1000 V		-0.01106	0.007		
NMISA		-0.01	-0.01141	0.007	0.04	-0.0003
NIS		-0.012	-0.01326	0.00290	0.29	-0.0022
LPEE-LNM		-0.006	-0.00693	0.014	-0.26	0.0041
DEFNAT/ANM		-0.007	-0.00773	0.009	-0.29	0.0033
NMISA		-0.01	-0.01032	0.007	-0.08	0.0007
UNBS		-0.001	-0.00099	0.0112	-0.76	0.0101
KEBS		-0.0051	-0.00502	0.0032	-0.79	0.0060
EMI		-0.0084	-0.00808	0.015	-0.18	0.0030
NMISA		-0.011	-0.01052	0.007	-0.05	0.0005
SIRDC-NMI		-0.011	-0.00997	0.05	-0.02	0.0011
NMISA		-0.012	-0.01200	0.007	0.09	-0.0009

Table 11. Participants corrected measurements dc resistance 100 kΩ

Name of Participant	Parameter: DC Resistance	Reported Correction (kΩ)	Applied Drift Correction (kΩ)	Uncertainty of Measurement (±kΩ)	Calculated E_N Value	Degrees of Equivalent (kΩ)
CRV	100 kΩ		0.00922	0.002		
NMISA		0.0068	0.01027	0.002	-0.37	0.0011
NIS		0.0059	0.00900	0.00073	0.10	-0.0002
LPEE-LNM		0.0067	0.00900	0.0006	0.11	-0.0002
DEFNAT/ANM		0.0071	0.00889	0.0016	0.13	-0.0003
NMISA		0.0080	0.00878	0.002	0.16	-0.0004
UNBS		-0.0050	-0.00502	0.00112	6.21	-0.0142
KEBS		0.0085	0.00835	0.00018	0.44	-0.0009
EMI		0.0071	0.00632	0.011	0.26	-0.0029
NMISA		0.0098	0.00862	0.002	0.21	-0.0006
SIRDC-NMI		0.0120	0.00947	0.041	-0.01	0.0003
NMISA		0.0123	0.00922	0.002	0.00	0.0000

Table 12. Participants corrected measurements dc resistance 1 MΩ

Name of Participant	Parameter: DC Resistance	Reported Correction (MΩ)	Applied Drift Correction (MΩ)	Uncertainty of Measurement (±MΩ)	Calculated E_N Value	Degrees of Equivalent (MΩ)
CRV	1 MΩ		0.00009	0.00006		
NMISA		0.000053	0.00008	0.00006	0.07	-0.00001
NIS		0.000058	0.00008	0.00005	0.05	0.00000
LPEE-LNM		0.000058	0.00008	0.00001	0.16	-0.00001
DEFNAT/ANM		0.000083	0.00010	0.000028	-0.17	0.00001
NMISA		0.000082	0.00009	0.00006	-0.02	0.00000
UNBS		0.0007216	0.00072	0.000039	-8.88	0.00064
KEBS		0.0000082	0.00001	0.0000072	1.31	-0.00008
EMI		0.000119	0.00011	0.0012	-0.02	0.00003
NMISA		0.000099	0.00009	0.00006	-0.04	0.00000
SIRDC-NMI		0.0001	0.00008	0.0004	0.01	-0.00001
NMISA		0.00011	0.00009	0.00006	0.00	0.00000

Table 13. Participants corrected measurements dc resistance 100 MΩ

Name of Participant	Parameter: DC Resistance	Reported Correction (MΩ)	Applied Drift Correction (MΩ)	Uncertainty of Measurement (±MΩ)	Calculated E_N Value	Degrees of Equivalent (MΩ)
CRV	100 MΩ		0.12391	0.04		
NMISA		0.0911	0.14299	0.04	-0.34	0.0191
NIS		0.0671	0.11343	0.09160	0.10	-0.0105
LPEE-LNM		0.088	0.12237	0.015	0.04	-0.0015
DEFNAT/ANM		0.098	0.12479	0.013	-0.02	0.0009
NMISA		0.1075	0.11912	0.04	0.08	-0.0048
UNBS		-0.1891	-0.18944	0.1066	2.75	-0.3133
KEBS		0.067762	0.06473	0.00162	1.48	-0.0592
EMI		0.18672	0.17510	0.11	-0.44	0.0512
NMISA		0.1273	0.10961	0.04	0.25	-0.0143
SIRDC-NMI		0.11	0.07226	0.67	0.08	-0.0516
NMISA		0.1699	0.12391	0.04	0.00	0.0000

Table 14. Participants corrected measurements dc current 10 mA

Name of Participant	Parameter: DC Current	Reported Correction (mA)	Applied Drift Correction (mA)	Uncertainty of Measurement (±mA)	Calculated E_N Value	Degrees of Equivalent (mA)
CRV	10 mA		0.00257	0.0006		
NMISA		0.0034	0.00260	0.0006	-0.04	0.0000
NIS		-0.0013	-0.00202	0.00010	7.55	-0.0046
LPEE-LNM		0.0018	0.00124	0.0007	1.44	-0.0013
DEFNAT/ANM		0.0019	0.00148	0.0003	1.62	-0.0011
NMISA		0.0022	0.00200	0.0006	0.67	-0.0006
UNBS		0.0002	0.00021	0.00035	3.40	-0.0024
KEBS		-0.0001	-0.00009	0.008	0.33	-0.0027
EMI		-0.0002	0.00001	0.006	0.42	-0.0026
NMISA		0.0028	0.00311	0.0006	-0.63	0.0005
SIRDC-NMI		0.0160	0.01659	0.094	-0.15	0.0140
NMISA		0.0019	0.00257	0.0006	0.00	0.0000

Table 15. Participants corrected measurements dc current 1 A

Name of Participant	Parameter: DC Resistance	Reported Correction (A)	Applied Drift Correction (A)	Uncertainty of Measurement (±A)	Calculated E_N Value	Degrees of Equivalent (A)
CRV	1 A		0.00006	0.0001		
NMISA		0.000077	0.00006	0.0001	-0.04	0.0000
NIS		-0.000119	-0.00013	0.00002	1.86	-0.0002
LPEE-LNM		0.000045	0.00004	0.00013	0.14	0.0000
DEFNAT/ANM		0.000051	0.00004	0.000028	0.14	0.0000
NMISA		0.000053	0.00005	0.0001	0.06	0.0000
UNBS		0.000065	0.00007	0.00003	-0.06	0.0000
KEBS		-0.00041	-0.00041	0.0008	0.58	-0.0005
EMI		0.000193	0.00020	0.00047	-0.28	0.0001
NMISA		0.000059	0.00006	0.0001	-0.03	0.0000
SIRDC-NMI		0.0000	0.00001	0.0035	0.01	-0.0001
NMISA		0.000048	0.00006	0.0001	0.00	0.0000

Table 16. Participants corrected measurements dc current 10 A

Name of Participant	Parameter: DC Resistance	Reported Correction (A)	Applied Drift Correction (A)	Uncertainty of Measurement (±A)	Calculated E_N Value	Degrees of Equivalent (A)
CRV	10 A		-0.00136	0.005		
NMISA		-0.00126	-0.00140	0.005	0.01	0.0000
NIS		-0.0008	-0.00092	0.00079	-0.09	0.0004
LPEE-LNM		-0.001	-0.00109	0.0046	-0.04	0.0003
DEFNAT/ANM		-0.0005	-0.00057	0.0099	-0.07	0.0008
NMISA		-0.00144	-0.00147	0.005	0.02	-0.0001
UNBS		0.00214	0.00214	0.0005	-0.70	0.0035
KEBS		0.00035	0.00036	0.008	-0.18	0.0017
EMI		-0.00078	-0.00075	0.0064	-0.07	0.0006
NMISA		-0.00125	-0.00120	0.005	-0.02	0.0002
SIRDC-NMI		-0.001	-0.00090	0.034	-0.01	0.0005
NMISA		-0.00148	-0.00136	0.005	0.00	0.0000

Table 17. Participants corrected measurements ac voltage 100 mV @ 40 Hz

Name of Participant	Parameter: AC Voltage	Reported Correction (mV)	Applied Drift Correction (mV)	Uncertainty of Measurement (±mV)	Calculated E_N Value	Degrees of Equivalent (mV)
CRV	100 mV at 40 Hz		0.01752	0.02		
NMISA		0.0175	0.01894	0.02	-0.05	0.0014
NIS		0.0180	0.01929	0.01310	-0.07	0.0018
LPEE-LNM		0.0160	0.01695	0.008	0.03	-0.0006
DEFNAT/ANM		0.0180	0.01874	0.091	-0.01	0.0012
NMISA		0.0168	0.01712	0.02	0.01	-0.0004
UNBS		-0.0052	-0.00521	0.05	0.42	-0.0227
KEBS		0.0431	0.04302	0.012	-1.09	0.0255
EMI		0.0150	0.01463	0.5	0.01	-0.0029
NMISA		0.0170	0.01651	0.02	0.04	-0.0010
SIRDC-NMI		0.0070	0.00595	0.081	0.14	-0.0116
NMISA		0.0188	0.01752	0.02	0.00	0.0000

Table 18. Participants corrected measurements ac voltage 100 mV @ 1 000 Hz

Name of Participant	Parameter: AC Voltage	Reported Correction (mV)	Applied Drift Correction (mV)	Uncertainty of Measurement (±mV)	Calculated E_N Value	Degrees of Equivalent (mV)
CRV	100 mV at 1000 Hz		0.01160	0.02		
NMISA		0.0124	0.01353	0.02	-0.07	0.0019
NIS		-0.0018	-0.00079	0.00146	0.62	-0.0124
LPEE-LNM		0.01	0.01075	0.009	0.04	-0.0009
DEFNAT/ANM		0.009	0.00958	0.079	0.02	-0.0020
NMISA		0.0104	0.01065	0.02	0.03	-0.0009
UNBS		-0.0131	-0.01311	0.05	0.46	-0.0247
KEBS		0.0412	0.04113	0.012	-1.27	0.0295
EMI		0.0096	0.00935	0.5	0.00	-0.0023
NMISA		0.011	0.01062	0.02	0.03	-0.0010
SIRDC-NMI		0.007	0.00618	0.081	0.06	-0.0054
NMISA		0.0126	0.01160	0.02	0.00	0.0000

Table 19. Participants corrected measurements ac voltage 100 V @ 40 Hz

Name of Participant	Parameter: AC Voltage	Reported Correction (V)	Applied Drift Correction (V)	Uncertainty of Measurement (±V)	Calculated E_N Value	Degrees of Equivalent (V)
CRV	100 V at 40 Hz		0.06062	0.007		
NMISA		0.0559	0.05892	0.007	0.17	-0.0017
NIS		0.0498	0.05250	0.00063	1.16	-0.0081
LPEE-LNM		0.054	0.05600	0.005	0.54	-0.0046
DEFNAT/ANM		0.055	0.05656	0.01	0.33	-0.0041
NMISA		0.0586	0.05928	0.007	0.14	-0.0013
UNBS		0.0057	0.00568	0.00751	5.35	-0.0549
KEBS		0.0663	0.06612	0.0031	-0.72	0.0055
EMI		0.06774	0.06706	0.032	-0.20	0.0064
NMISA		0.0647	0.06367	0.007	-0.31	0.0030
SIRDC-NMI		0.058	0.05580	0.066	0.07	-0.0048
NMISA		0.0633	0.06062	0.007	0.00	0.0000

Table 20. Participants corrected measurements ac voltage 100 V @ 1 000 Hz

Name of Participant	Parameter: AC Voltage	Reported Correction (V)	Applied Drift Correction (V)	Uncertainty of Measurement (±V)	Calculated E_N Value	Degrees of Equivalent (V)
CRV	100 V at 1000 Hz		0.05202	0.007		
NMISA		0.0479	0.05137	0.007	0.07	-0.0006
NIS		0.0403	0.04340	0.00070	1.23	-0.0086
LPEE-LNM		0.0460	0.04830	0.006	0.40	-0.0037
DEFNAT/ANM		0.0470	0.04879	0.012	0.23	-0.0032
NMISA		0.0491	0.04988	0.007	0.22	-0.0021
UNBS		-0.0053	-0.00532	0.0087	5.14	-0.0573
KEBS		0.0652	0.06500	0.0031	-1.69	0.0130
EMI		0.0133	0.01256	0.032	1.20	-0.0395
NMISA		0.0560	0.05482	0.007	-0.28	0.0028
SIRDC-NMI		0.0570	0.05447	0.065	-0.04	0.0025
NMISA		0.0551	0.05202	0.007	0.00	0.0000

Table 21. Participants corrected measurements ac voltage 1 000 V @ 40 Hz

Name of Participant	Parameter: AC Voltage	Reported Correction (V)	Applied Drift Correction (V)	Uncertainty of Measurement (±V)	Calculated E_N Value	Degrees of Equivalent (V)
CRV	1000 V at 40 Hz		0.65522	0.1		
NMISA		0.596	0.63863	0.1	0.12	-0.0166
NIS		0.523	0.56106	0.06280	0.80	-0.0942
LPEE-LNM		0.6	0.62823	0.09	0.20	-0.0270
DEFNAT/ANM		0.625	0.64701	0.082	0.06	-0.0082
NMISA		0.633	0.64255	0.1	0.09	-0.0127
UNBS		-0.573	-0.57328	0.101	8.64	-1.2285
KEBS		-0.004	-0.00649	0.0456	6.02	-0.6617
EMI		0.6726	0.66305	0.41	-0.02	0.0078
NMISA		0.699	0.68447	0.1	-0.21	0.0293
SIRDC-NMI		0.7	0.66900	1.8	-0.01	0.0138
NMISA		0.693	0.65522	0.1	0.00	0.0000

Table 22. Participants corrected measurements ac voltage 1 000 V @ 1 000 Hz

Name of Participant	Parameter: AC Voltage	Reported Correction (V)	Applied Drift Correction (V)	Uncertainty of Measurement (±V)	Calculated E_N Value	Degrees of Equivalent (V)
CRV	1000 V at 1000 Hz		0.58716	0.1		
NMISA		0.516	0.55863	0.1	0.20	-0.0285
NIS		0.457	0.49506	0.04620	0.84	-0.0921
LPEE-LNM		0.5	0.52823	0.09	0.44	-0.0589
DEFNAT/ANM		0.526	0.54801	0.086	0.30	-0.0392
NMISA		0.545	0.55455	0.1	0.23	-0.0326
UNBS		-0.516	-0.51628	0.0999	7.81	-1.1034
KEBS		0.81	0.80751	0.0402	-2.04	0.2203
EMI		0.606	0.59645	0.41	-0.02	0.0093
NMISA		0.624	0.60947	0.1	-0.16	0.0223
SIRDC-NMI		0.6	0.56900	1.9	0.01	-0.0182
NMISA		0.626	0.62600	0.1	-0.27	0.0388

Table 23. Participants corrected measurements ac current 10 mA @ 40 Hz

Name of Participant	Parameter: AC Current	Reported Correction (mA)	Applied Drift Correction (mA)	Uncertainty of Measurement (±mA)	Calculated E_N Value	Degrees of Equivalent (mA)
CRV	10 mA at 40 Hz		0.00211	0.002		
NMISA		0.0024	0.00186	0.002	0.09	-0.0002
NIS		0.0012	0.00069	0.00093	0.64	-0.0014
LPEE-LNM		0.0016	0.00124	0.0036	0.21	-0.0009
DEFNAT/ANM		0.0018	0.00152	0.0033	0.15	-0.0006
NMISA		0.0021	0.00194	0.0006	0.08	-0.0002
UNBS		-0.0017	-0.00169	0.00062	1.81	-0.0038
KEBS		0.0048	0.00534	0.046	-0.07	0.0032
EMI		0.0021	0.00217	0.24	0.00	0.0001
NMISA		0.0023	0.00253	0.002	-0.15	0.0004
NMISA		0.0016	0.00211	0.002	0.00	0.0000

Table 24. Participants corrected measurements ac current 10 mA @ 1 000 Hz

Name of Participant	Parameter: AC Current	Reported Correction (mA)	Applied Drift Correction (mA)	Uncertainty of Measurement (±mA)	Calculated E_N Value	Degrees of Equivalent (mA)
CRV	10 mA at 1000 Hz		0.00148	0.002		
NMISA		0.00179	0.00122	0.002	0.09	-0.0003
NIS		0.00126	0.00075	0.00190	0.26	-0.0007
LPEE-LNM		0.0009	0.00052	0.0035	0.24	-0.0010
DEFNAT/ANM		0.0011	0.00081	0.0029	0.19	-0.0007
NMISA		0.00149	0.00136	0.002	0.04	-0.0001
UNBS		-0.00117	-0.00117	0.00061	1.26	-0.0026
KEBS		0.0068	0.00740	0.07	-0.08	0.0059
EMI		0.01088	0.01101	0.24	-0.04	0.0095
NMISA		0.00165	0.00184	0.002	-0.13	0.0004
NMISA		0.00097	0.00148	0.002	0.00	0.0000

Table 25. Participants corrected measurements ac current 1 A @ 40 Hz

Name of Participant	Parameter: AC Current	Reported Correction (A)	Applied Drift Correction (A)	Uncertainty of Measurement (±A)	Calculated E_N Value	Degrees of Equivalent (A)
CRV	1 A at 40 Hz		0.00016	0.0003		
NMISA		0.000173	0.00019	0.0003	-0.07	0.0000
NIS		-0.000117	-0.00010	0.00015	0.78	-0.0003
LPEE-LNM		0.00017	0.00018	0.00043	-0.04	0.0000
DEFNAT/ANM		0.00015	0.00016	0.00042	0.00	0.0000
NMISA		0.000155	0.00016	0.0003	0.00	0.0000
UNBS		-0.000063	-0.00006	0.000599	0.33	-0.0002
KEBS		-0.000224	-0.00024	0.00463	0.09	-0.0004
EMI		0.000214	0.00021	0.04	0.00	0.0001
NMISA		0.000135	0.00013	0.0003	0.07	0.0000
NMISA		0.000172	0.00016	0.0003	0.00	0.0000

Table 26. Participants corrected measurements ac current 1 A @ 1 000 Hz

Name of Participant	Parameter: AC Current	Reported Correction (A)	Applied Drift Correction (A)	Uncertainty of Measurement (±A)	Calculated E_N Value	Degrees of Equivalent (A)
CRV	1 A at 1000 Hz		0.00007	0.0003		
NMISA		0.0001	0.00011	0.0003	-0.08	0.0000
NIS		-0.0003	-0.00028	0.00012	1.11	-0.0004
LPEE-LNM		0.0001	0.00011	0.00043	-0.08	0.0000
DEFNAT/ANM		0.0001	0.00011	0.00024	-0.10	0.0000
NMISA		0.0001	0.00007	0.0003	0.00	0.0000
UNBS		0.0000	-0.00004	0.000599	0.16	-0.0001
KEBS		-0.0002	-0.00023	0.0105	0.03	-0.0003
EMI		0.0001	0.00009	0.04	0.00	0.0000
NMISA		0.0000	0.00004	0.0003	0.07	0.0000
NMISA		0.0001	0.00007	0.0003	0.00	0.0000

Table 27. Participants corrected measurements ac current 10 A @ 40 Hz

Name of Participant	Parameter: AC Current	Reported Correction (A)	Applied Drift Correction (A)	Uncertainty of Measurement (±A)	Calculated E_N Value	Degrees of Equivalent (A)
CRV	10 A at 40 Hz		0.00177	0.005		
NMISA		0.00189	0.00232	0.005	-0.08	0.0005
NIS		0.00101	0.00139	0.00314	0.06	-0.0004
LPEE-LNM		0.0008	0.00108	0.015	0.04	-0.0007
DEFNAT/ANM		0.0022	0.00242	0.003	-0.11	0.0007
NMISA		0.00147	0.00157	0.005	0.03	-0.0002
UNBS		-0.00062	-0.00062	0.00602	0.31	-0.0024
KEBS		-0.00291	-0.00294	0.046	0.10	-0.0047
EMI		0.00629	0.00619	0.0043	-0.67	0.0044
NMISA		0.00157	0.00142	0.005	0.05	-0.0003
SIRDC-NMI		0.001	0.00069	0.043	0.02	-0.0011
NMISA		0.00215	0.00177	0.005	0.00	0.0000

Table 28. Participants corrected measurements ac current 10 A @ 1 000 Hz

Name of Participant	Parameter: AC Current	Reported Correction (A)	Applied Drift Correction (A)	Uncertainty of Measurement (±A)	Calculated E_N Value	Degrees of Equivalent (A)
CRV	10 A at 1000 Hz		0.00031	0.005		
NMISA		0.00047	0.00075	0.005	-0.06	0.0004
NIS		0.00044	0.00069	0.01580	-0.02	0.0004
LPEE-LNM		0.0018	0.00199	0.015	-0.11	0.0017
DEFNAT/ANM		0.0016	0.00174	0.0024	-0.26	0.0014
NMISA		0.00008	0.00014	0.005	0.02	-0.0002
UNBS		-0.000152	-0.00015	0.00601	0.06	-0.0005
KEBS		-0.00403	-0.00405	0.1046	0.04	-0.0044
EMI		0.00431	0.00425	0.0043	-0.60	0.0039
NMISA		0.00014	0.00004	0.005	0.04	-0.0003
SIRDC-NMI		0.001	0.00080	0.057	-0.01	0.0005
NMISA		0.00056	0.00031	0.005	0.00	0.0000

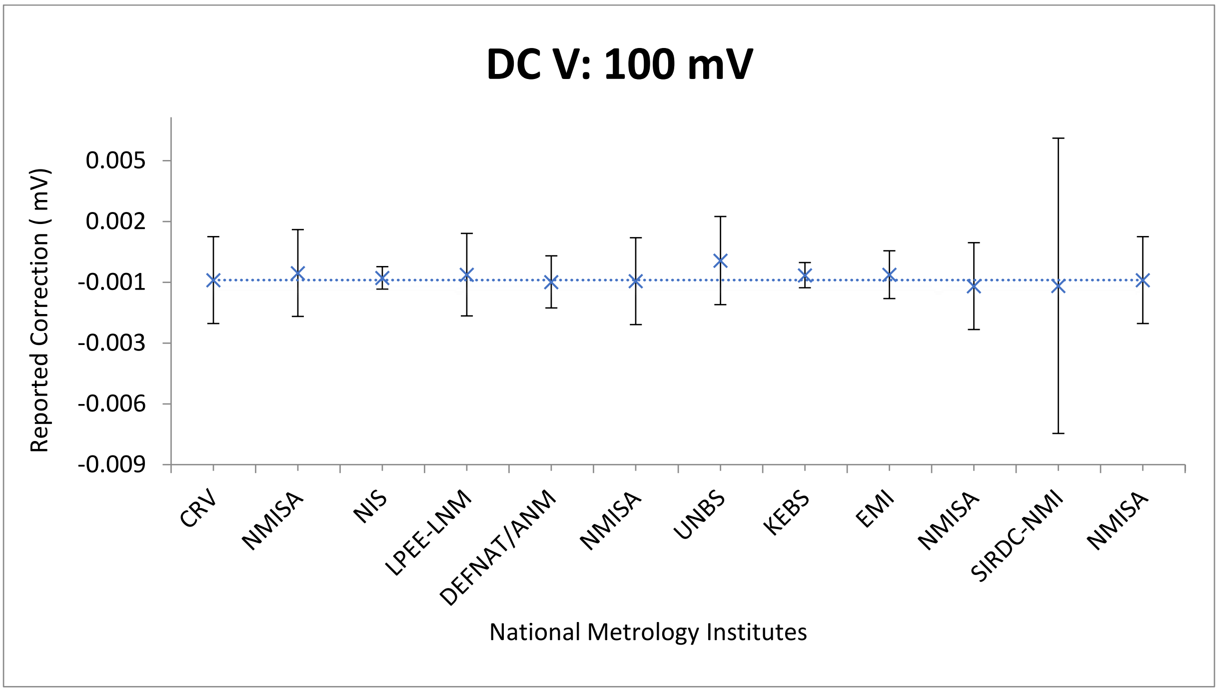

Figure 23. Reported results for dc voltage 100 mV

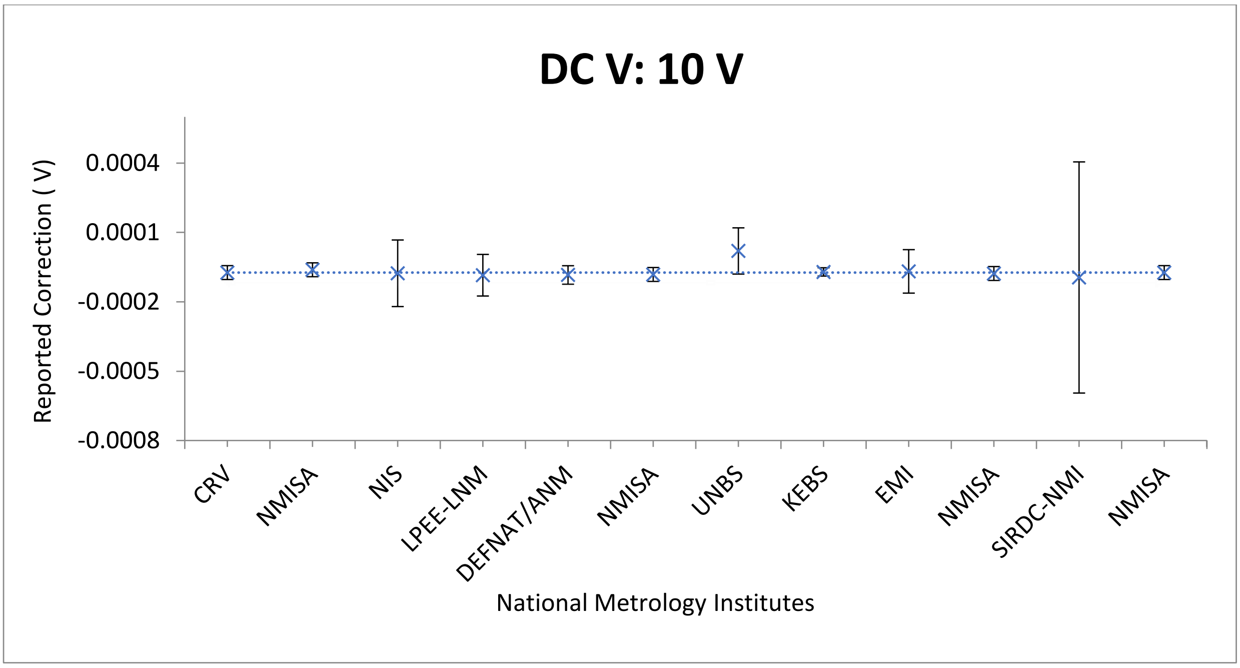

Figure 24. Reported results for dc voltage 10 V

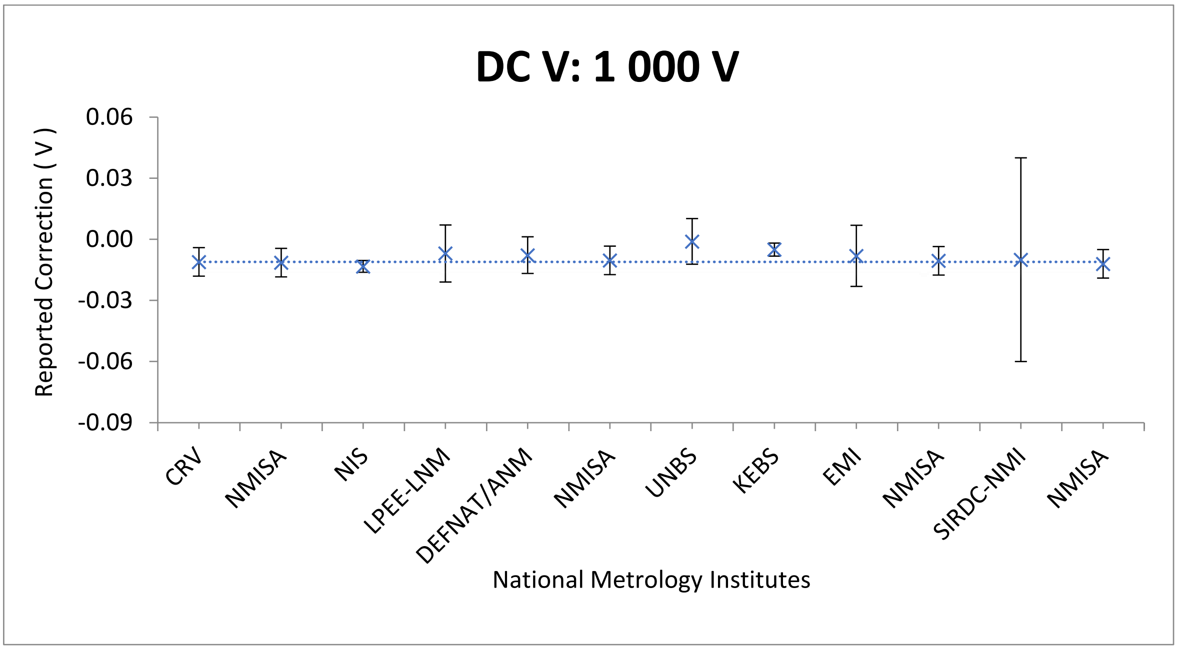

Figure 25. Reported results for dc voltage 1 000 V

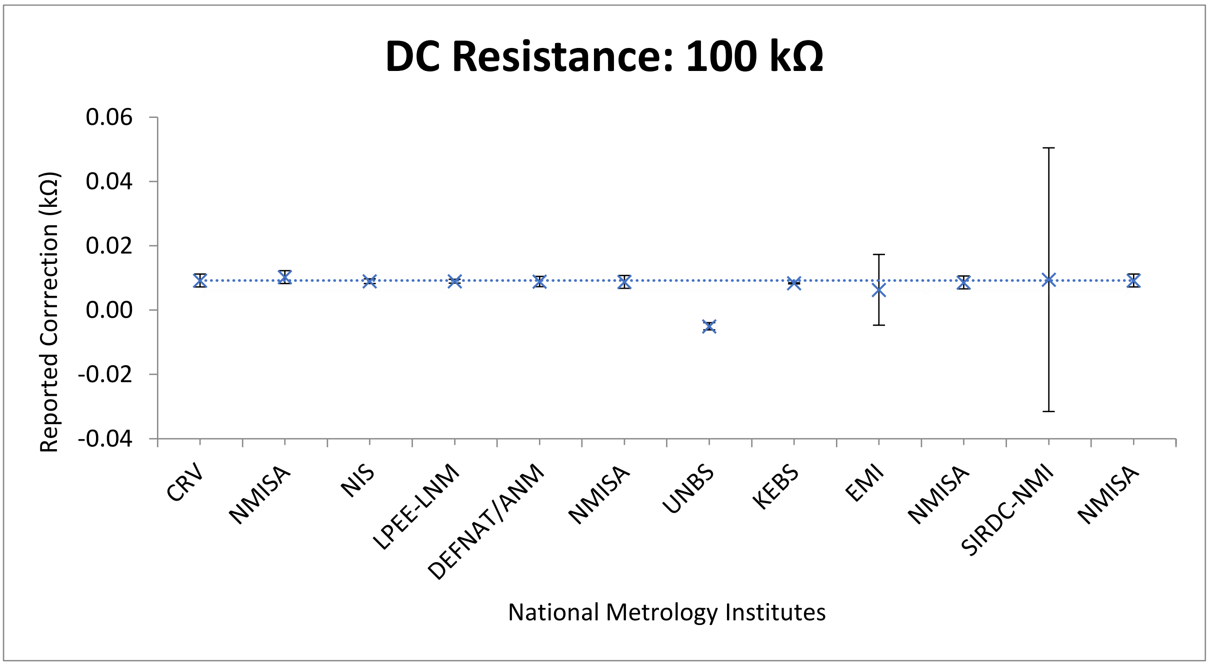

Figure 26. Reported results for dc resistance 100 kΩ

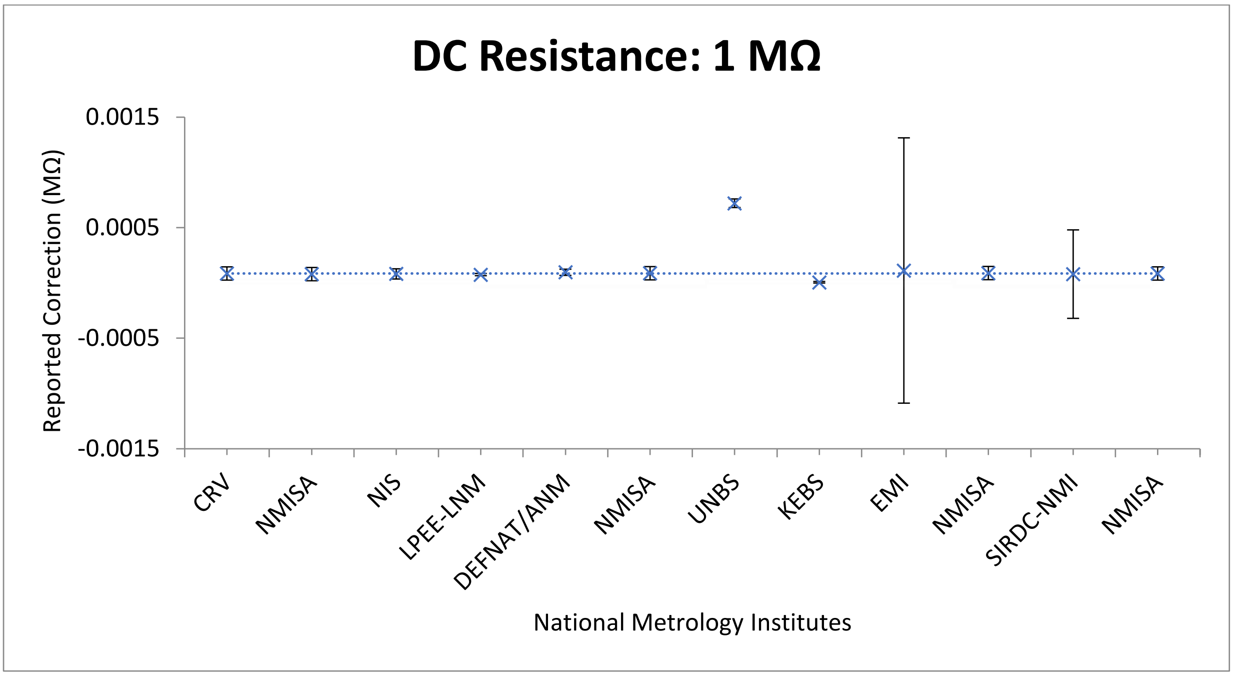

Figure 27. Reported results for dc resistance 1 MΩ

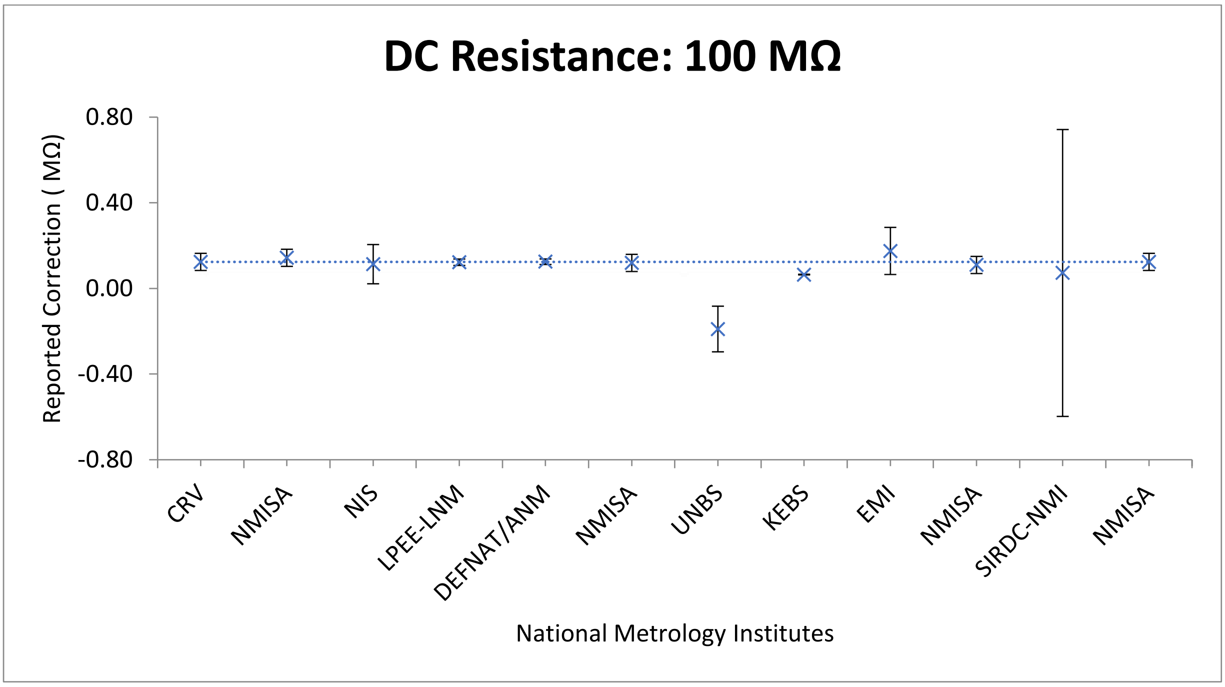

Figure 28. Reported results for dc resistance 100 MΩ

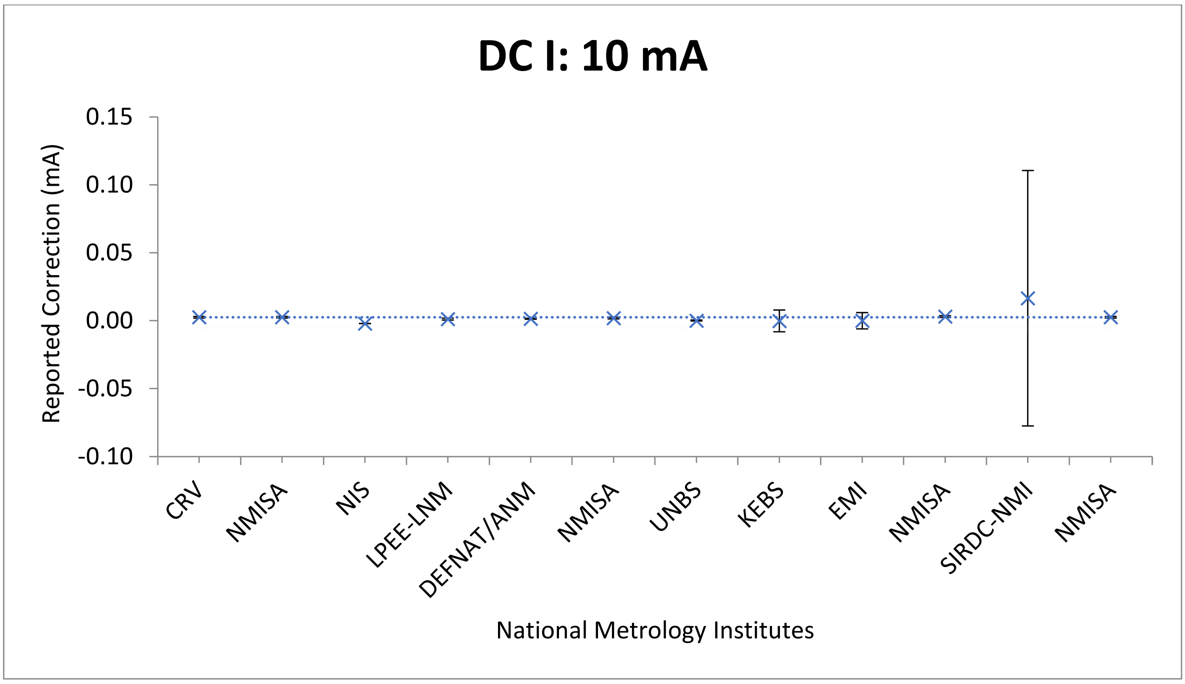

Figure 29. Reported results for dc current 10 mA

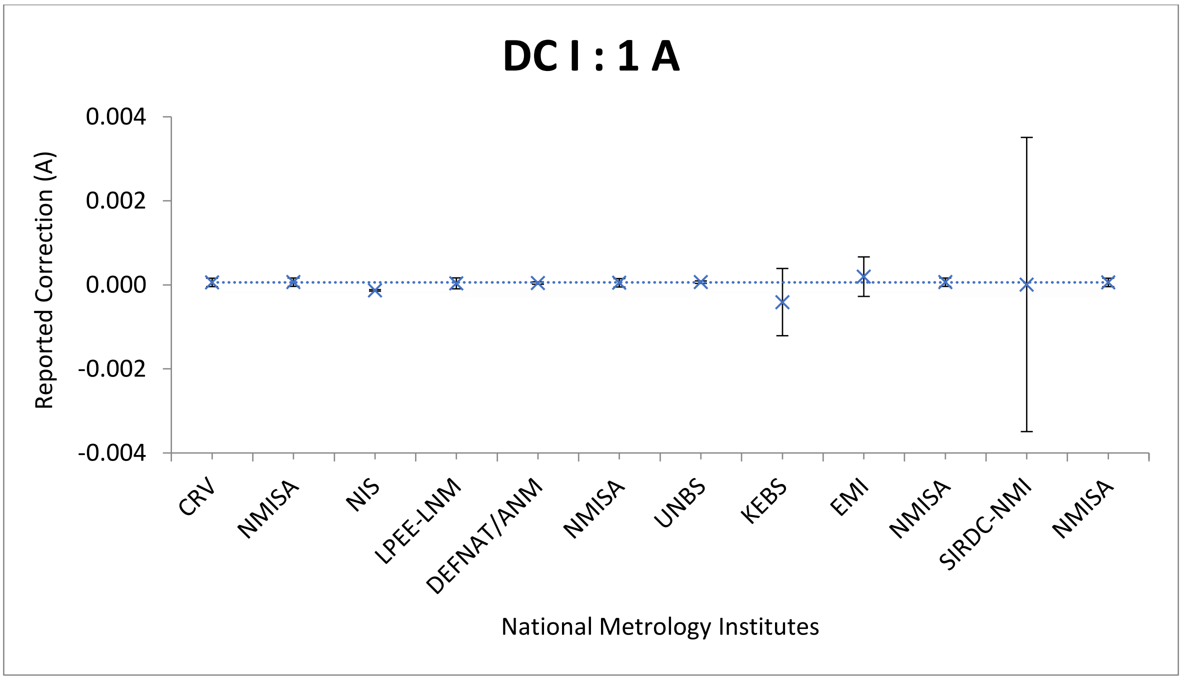

Figure 30. Reported results for dc current 1 A

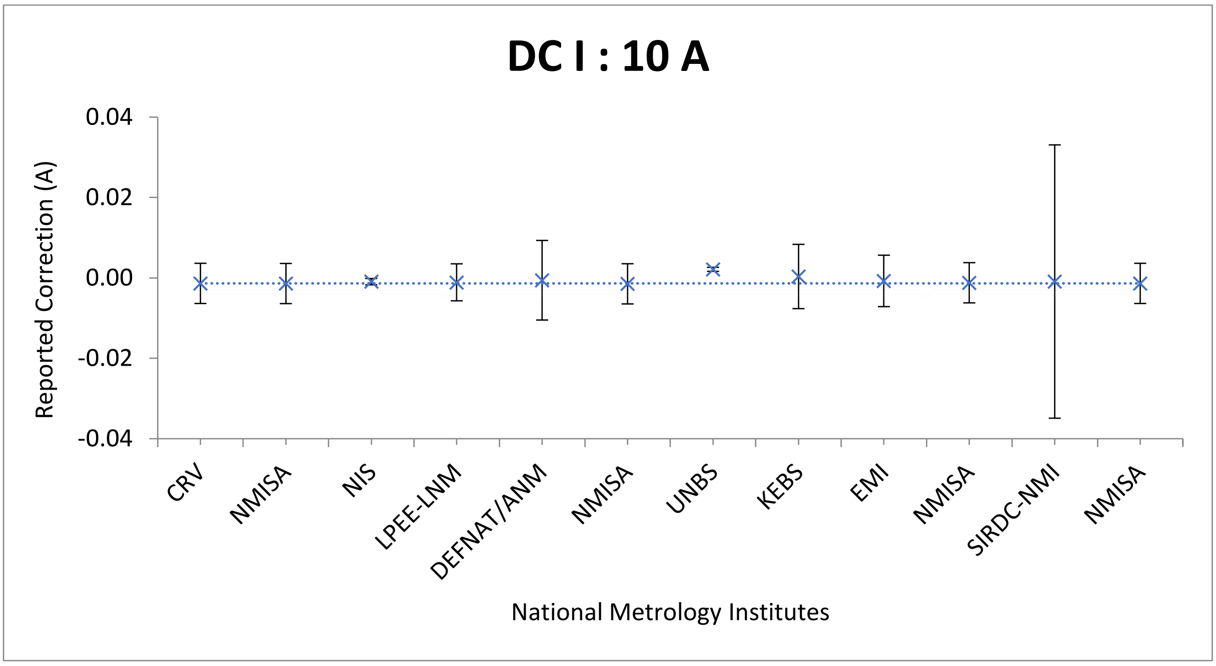

Figure 31. Reported results for dc current 10 A

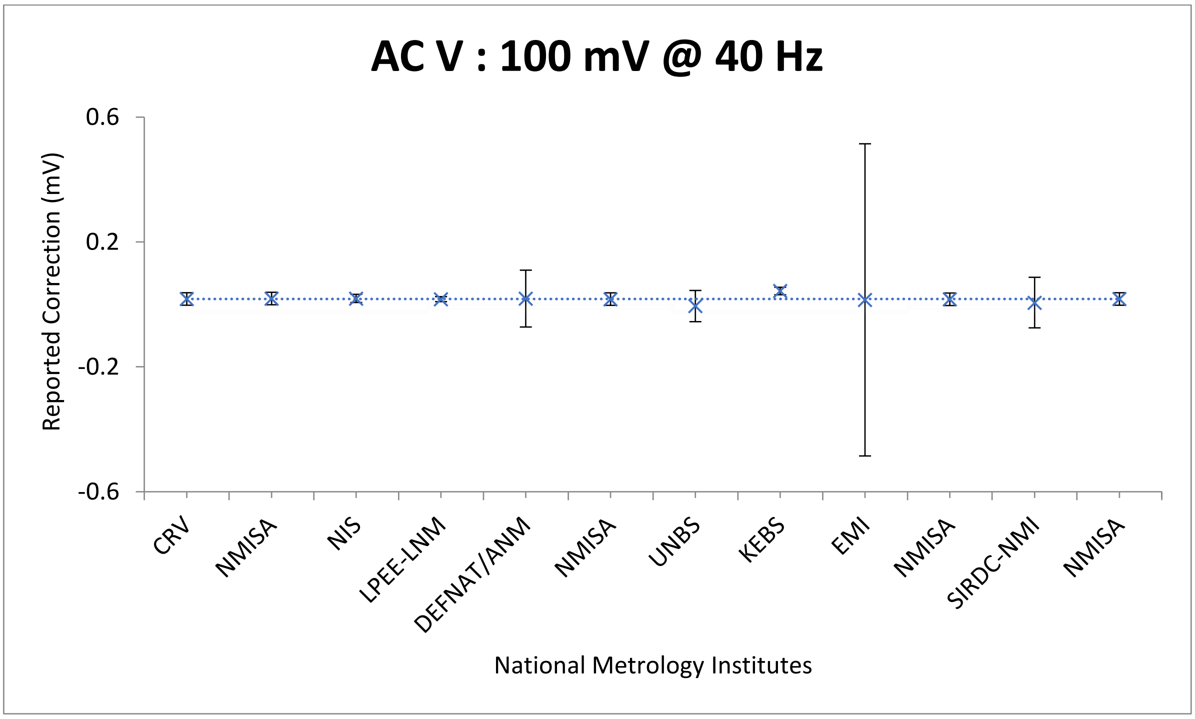

Figure 32. Reported results for ac voltage 100 mV @ 40 Hz

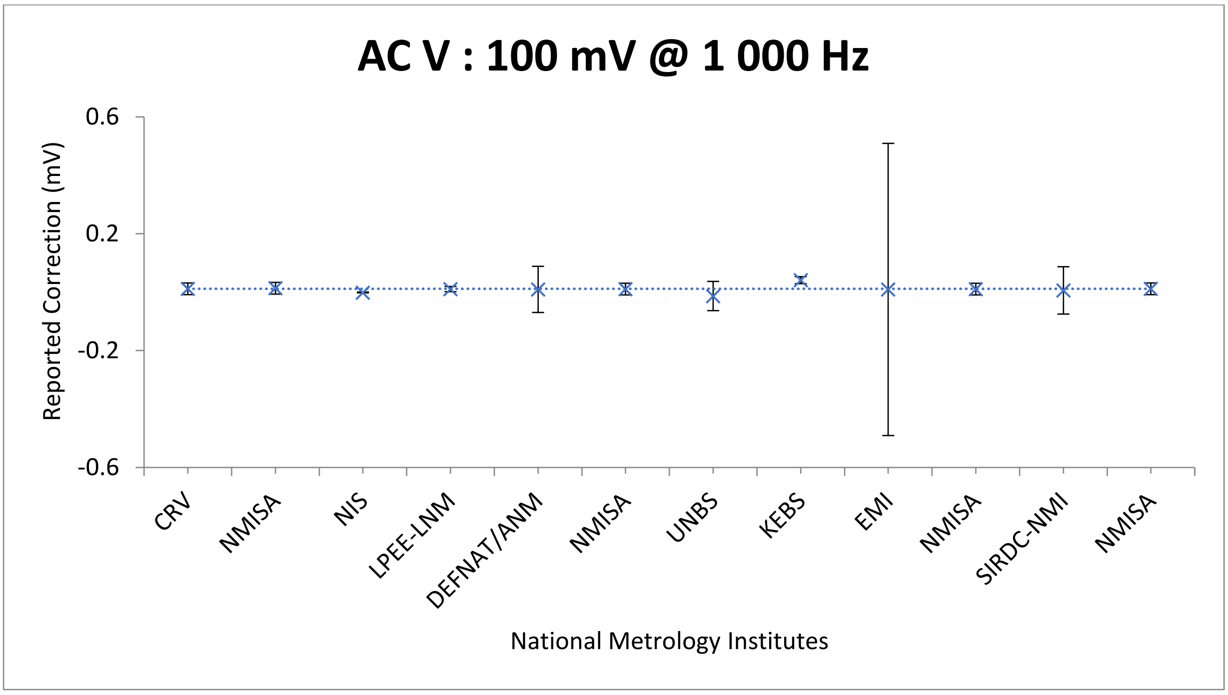

Figure 33. Reported results for ac voltage 100 mV @ 1 000 Hz

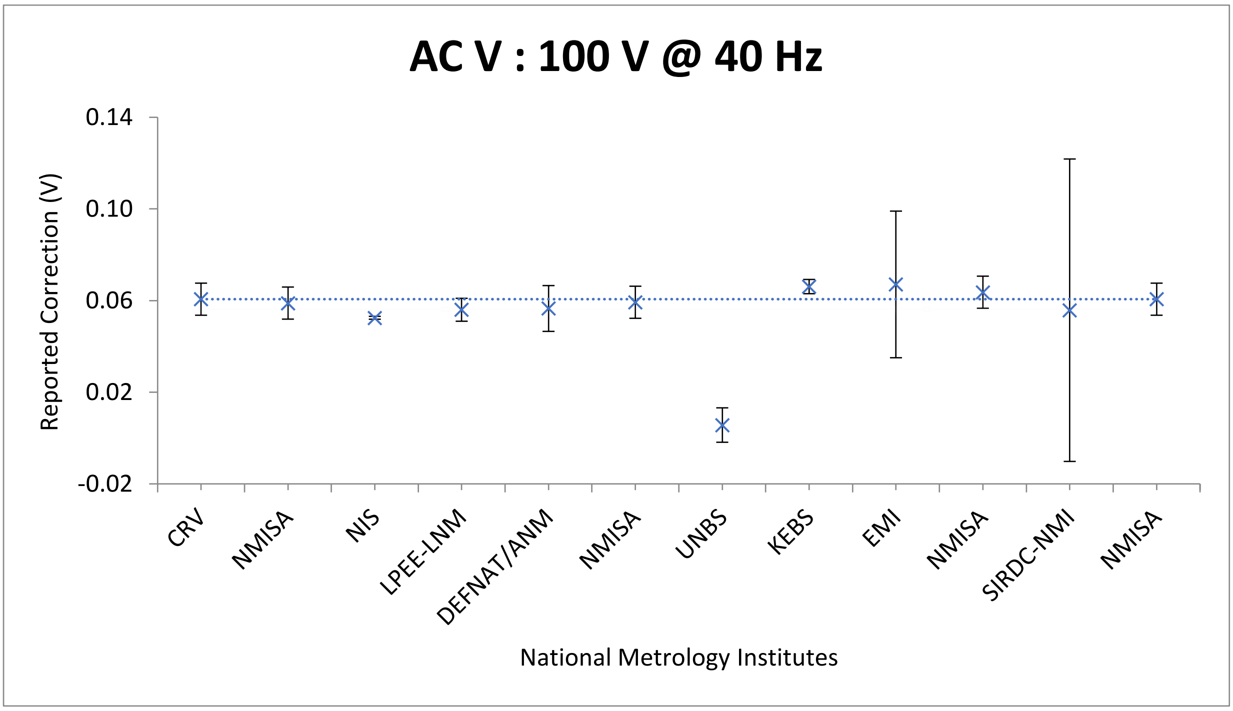

Figure 22. Reported results for ac voltage 100 V @ 40 Hz

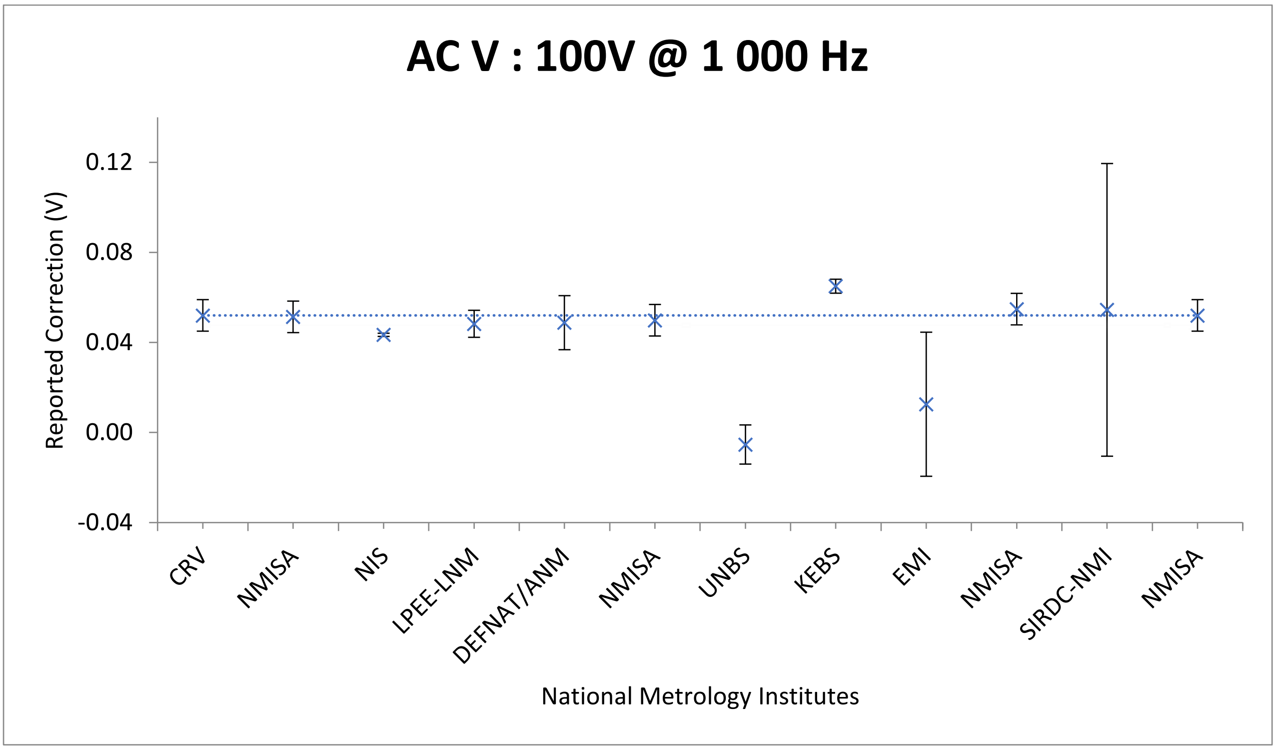

Figure 34. Reported results for ac voltage 100 V @ 1 000 Hz

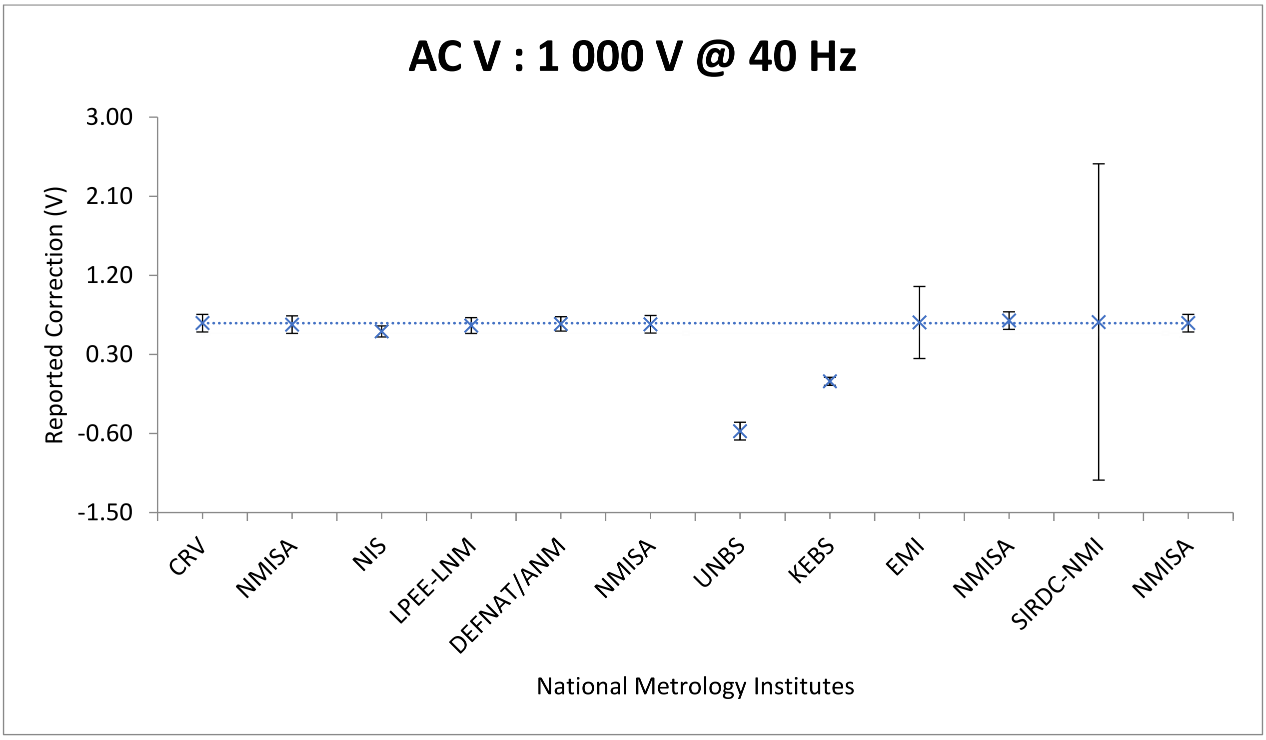

Figure 35. Reported results for ac voltage 1 000 V @ 40 Hz

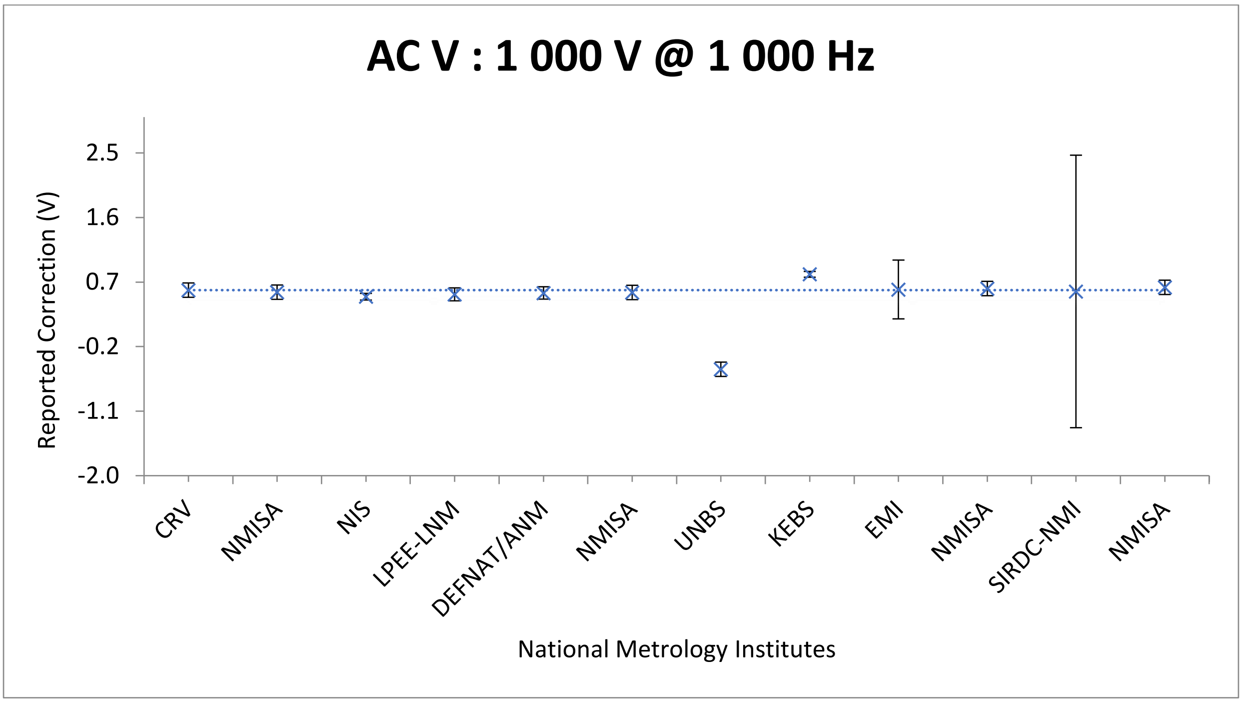

Figure 36. Reported results for ac voltage 1 000 V @ 1 000 Hz

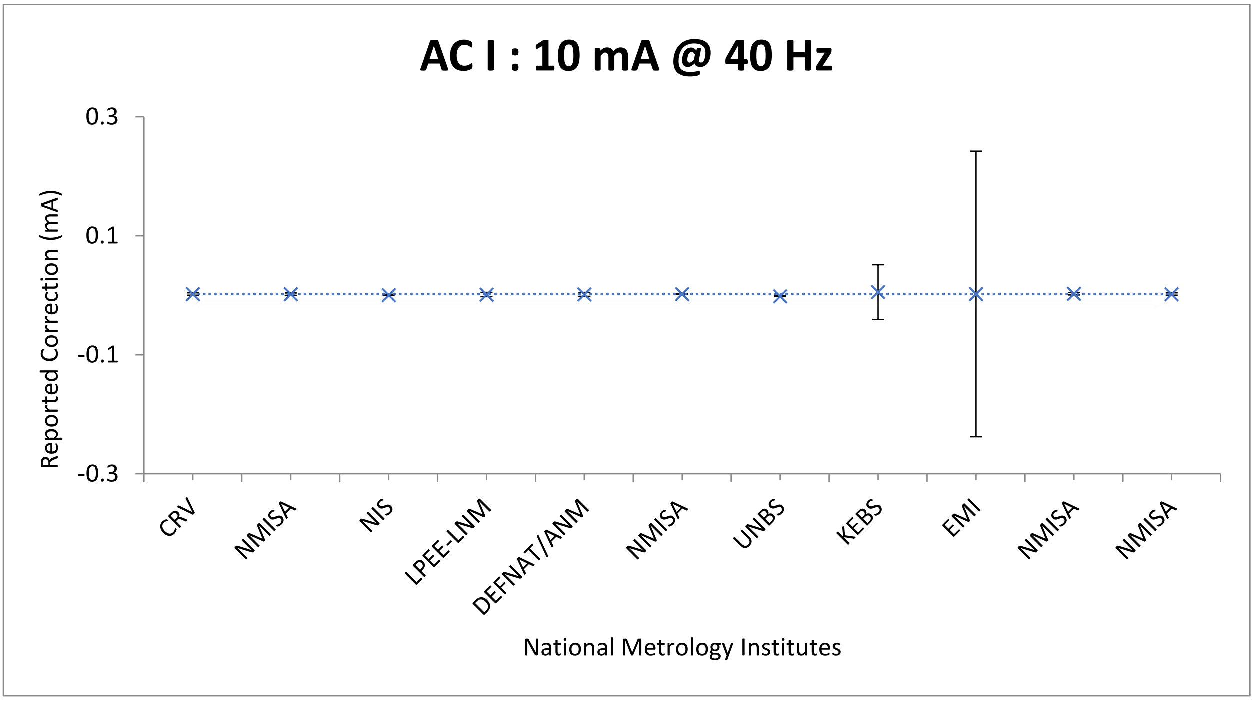

Figure 37. Reported results for ac current 10 mA @ 40 Hz

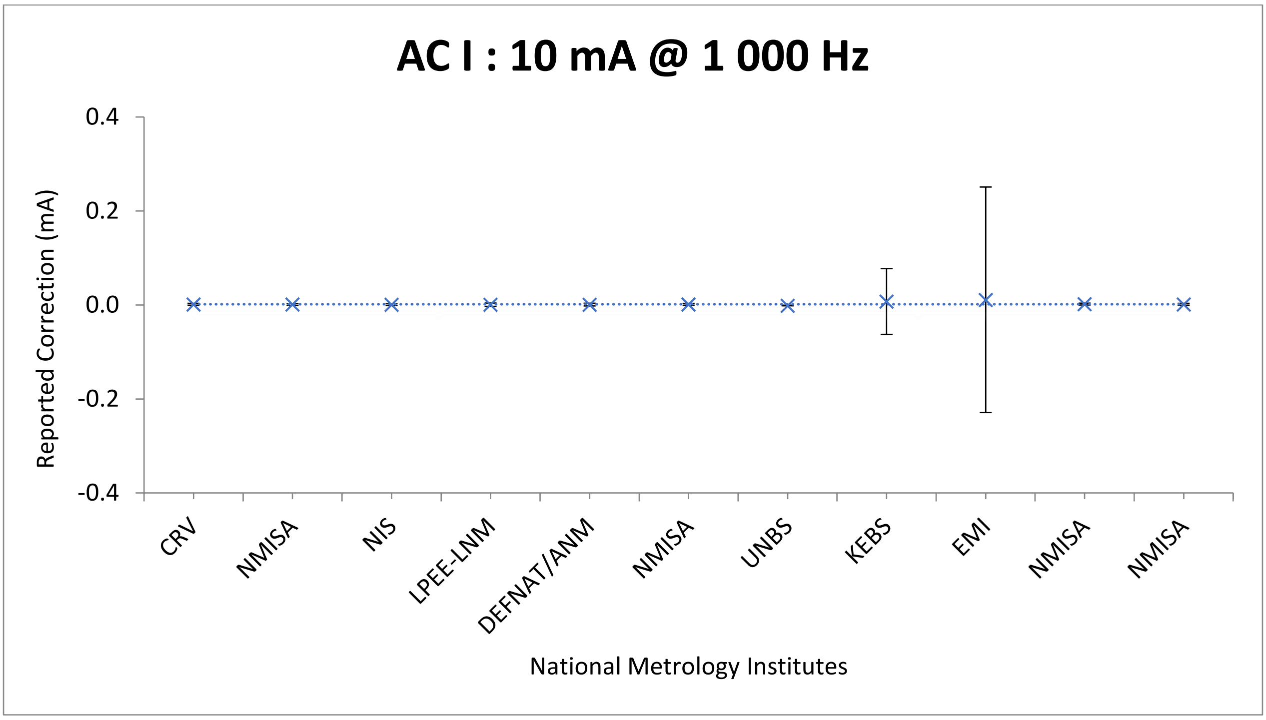

Figure 38. Reported results for ac current 10 mA @ 1 000 Hz

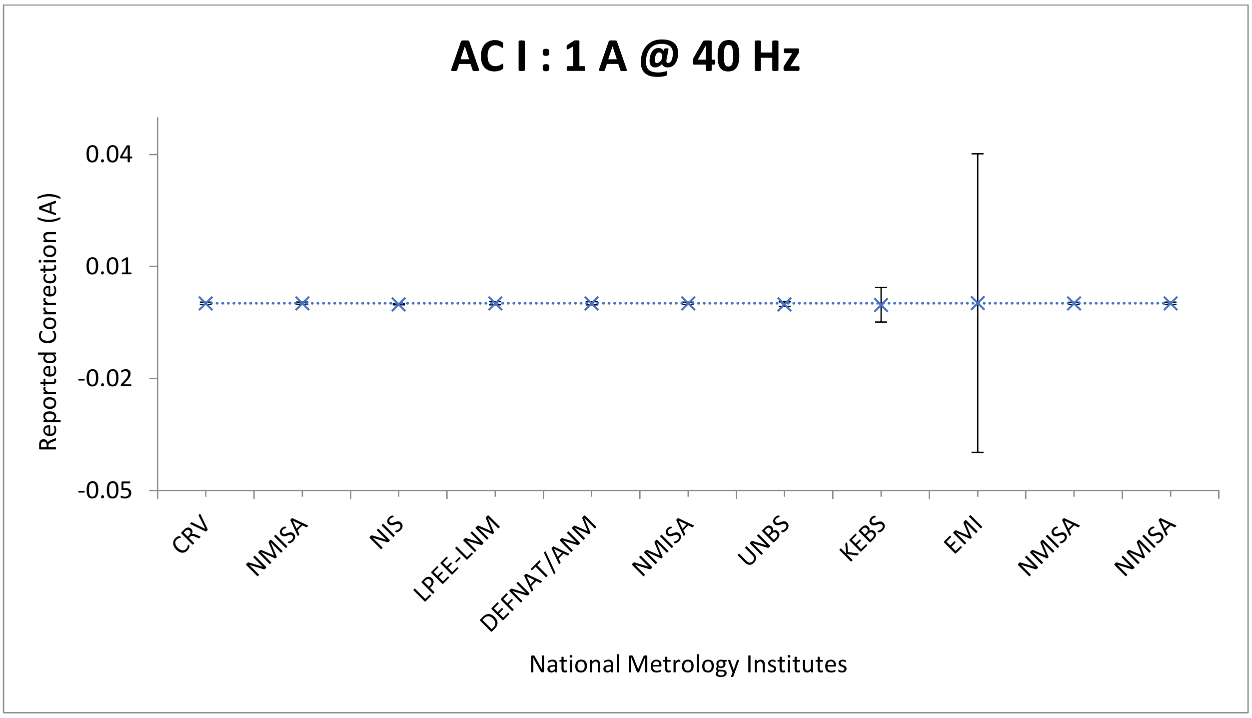

Figure 39. Reported results for ac current 1 A @ 40 Hz

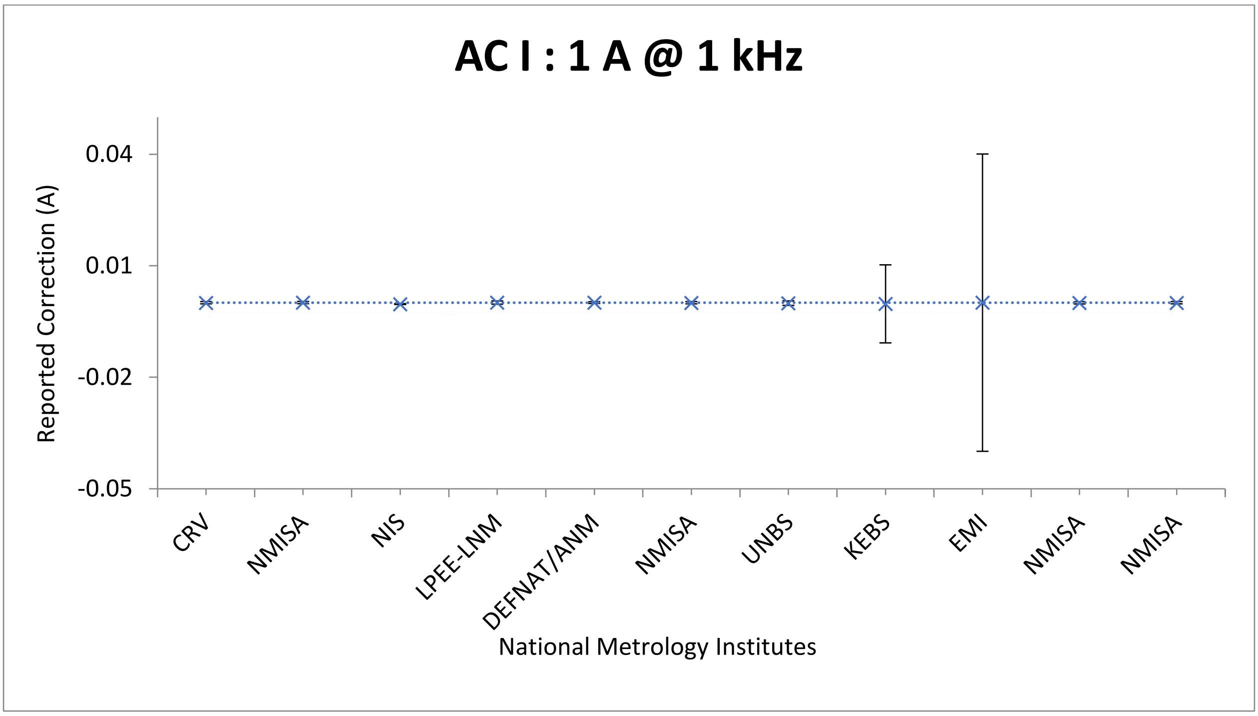

Figure 40. Reported results for ac current 1 A @ 1 000 Hz

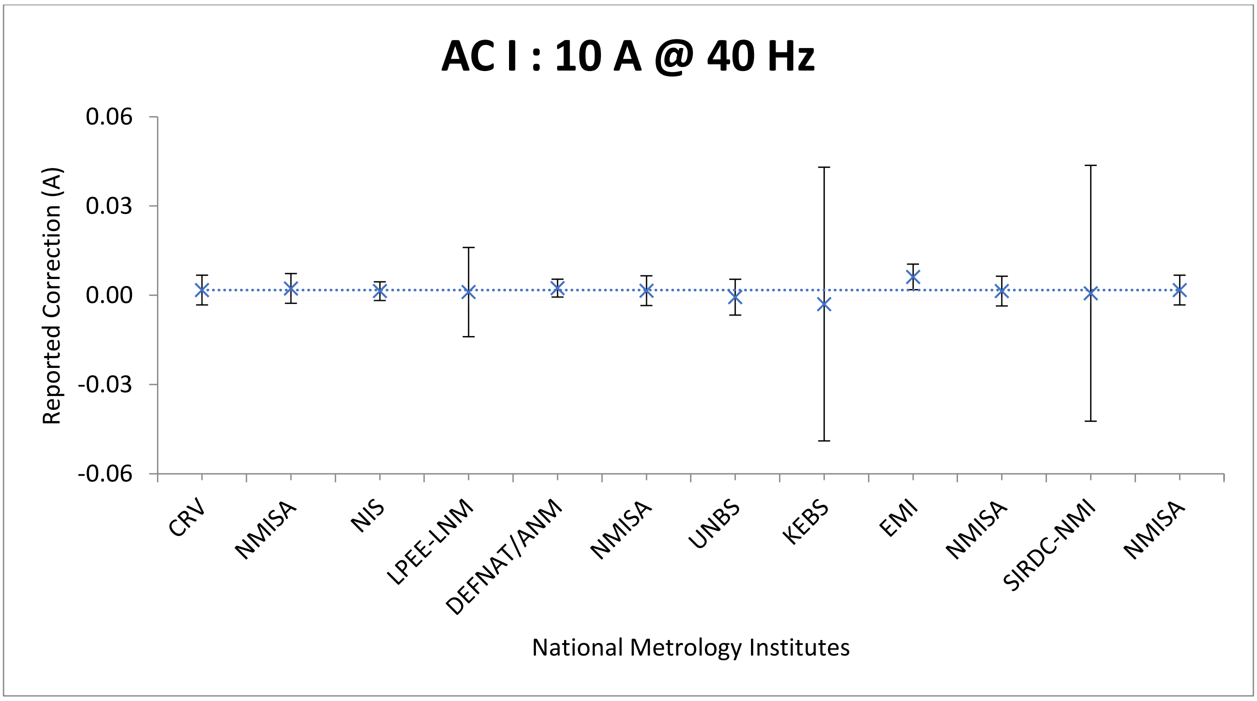

Figure 41. Reported results for ac current 10 A @ 40 Hz

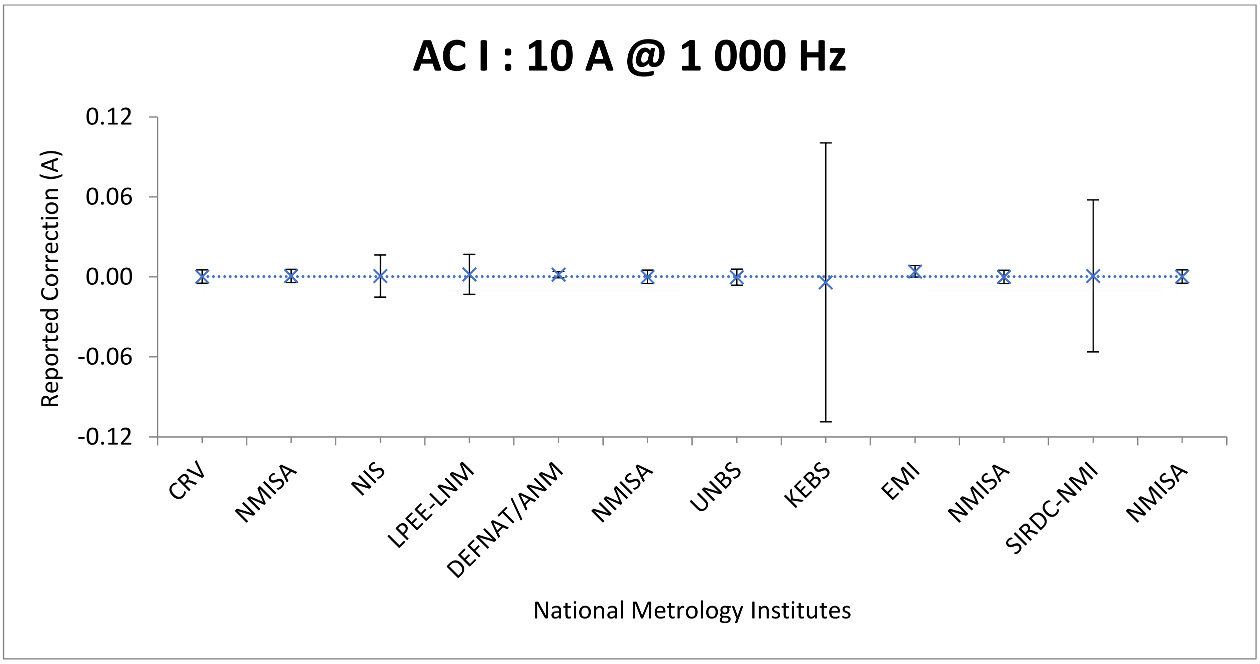

Figure 42. Reported results for ac current 10 A @ 1 000 Hz

6 Summary and conclusions

The AFRIMETS.EM-S2 comparison on 6½ digital multimeter piloted by National Institute of Standards, NIS was successfully carried out and completed. The National Metrology institute of South Africa, NMISA provided the comparison reference values. The comparison commenced January 2020 and completed August 2021. Different methods used by participants were tested and results proved good agreement and equivalent between participants within stated uncertainties. The National metrology institutes are encouraged to implement root cause analysis and corrective actions on values not in good agreement with other participants.

7 References

[1] CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons, March21,2007.
[2] Technical Protocol, comparison on digital multimeter (AFRIMETS.EM-S2), Version 1.0, 17 January 2019.
[3] Fluke 8845A/8846A Digital Multimeter User's Manual, July 2006, Rev. 2, 6/08
[4] Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement (GUM), JCGM 100, First edition, September 2008
[5] Cox M. G., "The evaluation of key comparison data", Metrologia, 2002, 39, 589-595.
[6] CCQM Guidance note: Estimation of a consensus KCRV and associated Degrees of Equivalence, version 10, 2013

8 Appendix A: Technical protocol

Technical Protocol

Version 1.1 (11/10/2019)

COMPARISON ON DIGITAL MULTIMETER (AFRIMETS.EM-S2)

Comparison Coordinator:

Prof. Dr. Mohammed Helmy Abd El-Raouf
National Institute of Standards, NIS, Egypt

CONTENTS

Technical Protocol

COMPARISON ON DIGITAL MULTIMETER (AFRIMETS.EM-S2)

1. Introduction

At the 2019 AFRIMETS TCEM committee meeting held on 8th and 9th July 2019 at Giza, Egypt, it was confirmed to initiate a comparison on digital multimeter calibration. The artifact, i.e. digital multimeter (DMM), will be supplied with the necessary cables by the Laboratoire de Metrologia de la Direction Generale des Transmissions et de l'Informatique, Tunisia (DEFNAT). This comparison was proposed to test the capabilities of the NMIs in measuring the following quantities:

DC voltage, DC current, DC resistance, AC voltage and AC current

The NIS agreed to coordinate this comparison and eight laboratories agreed to participate.

This protocol was prepared in accordance with the "Guidelines for CIPM key comparisons" as the comparison of the digital multimeter is so important for many NMIs [1-2].

2. Travelling Standard

2.1 Description of the standard

The travelling standard is a 6½ digit multimeter (Fluke model 8846A). This instrument can measure DC voltage up to 1000 V, DC current up to 10 A, resistance up to 1 G□, AC voltage up to 1000 V, and AC current up to 10 A. The details of the digital multimeter are listed in Table 1:

Table 1

General Information	
Power supply requirement	100 V / 120 V / 220 V / 240V □ 10 %
Power line frequency	50 Hz to 60 Hz
Power consumption	28 VA peak (12 W average)
Warm-up time	1 Hour to get full specification
Operating temperature range	0 °C to 50 °C
Operating humidity range	0 % to 80 % relative humidity
Temperature coefficient (18 °C - 28 °C)	See pages from 1-11 to 1-17, in the DMM user's manual
Transport Information	
Storage temperature range	–40 °C to 70 °C
Dimensions (H □ W □ D)	89 mm (H) □ 217 mm (W) □ 297 mm (D)
Shipping container (H □ W □ D)	167 mm (H) □ 470 mm (W) □ 360 mm (D)
Weight	3.6 kg
Shipping Weight	6.0 kg

2.2 Quantities to be measured

The quantities to be measured are DC voltage, DC current, DC resistance, AC voltage and AC current. The details of the measured parameters are listed in Table 2.

Table 2

Parameter	**Nominal value**
DC Voltage	100 mV, 10 V and 1000 V
DC Current	10 mA, 1 A and 10 A
DC Resistance	100 kΩ, 1 MΩ and 100 MΩ
AC Voltage	100 mV, 100 V and 1000 V at 40 Hz and 1 kHz
AC Current	10 mA, 1 A and 10 A at 40 Hz and 1 kHz

2.3 Method of computation of the Comparison Reference Value

The comparison reference value (CRV) will be computed by mean of the results obtained by the National Metrology Institute of South Africa, (NMISA). [3-5].

3. Organization of Comparison

3.1 Comparison communication

All communication should be directed to Prof. Dr. Mohammed Helmy Abd El-Raouf **mohammed_makka@yahoo.com** (refer to section 8).

3.2 Participants

The list of participating institutes with persons responsible for the comparison is given by Annex-1.

3.3 Time schedule

The circulation of the travelling standard has been organized in two loops in order to allow close monitoring of the behavior of the standard. Each laboratory will have two weeks for measurements and ten days for transportation. The circulation time schedule is given by Annex-2.

If unexpected circumstances prevent a laboratory from carrying out its measurements within the time allowed, it should send the travelling standard immediately to the laboratory next in line with information to pilot lab. If time allows, the laboratory may be able to carry out measurements towards the end.

3.4 Transportation, unpacking, handling and packing

The artifact will be transported using an **ATA Carnet** for custom clearance where possible.

An enclosure is provided for the digital multimeter so that it can be shipped as freight. This enclosure has dimensions and weight as shown in table 1. Extreme temperatures or pressure changes as well as violent impacts should be avoided.

With the travelling standard, one receipt form (Annex-3) and dispatch form (Annex-6) will be sent for each participant in the current loop. The pilot laboratory must be informed of receipt of the artifact and its dispatch to the next laboratory using the forms provided.

When shipping the standard, the shipping checklist form should be carefully followed in order to include all the material for the next laboratory.

3.5 Failure of travelling standard

In case of damage or malfunction of the travelling standard, this must be immediately reported to the pilot laboratory.

3.6 Financial aspects

Each participant laboratory is responsible for its own costs for the measurements, transportation to the next participant, and insurance of the shipment to the next participant and any customs charges as well as any damage that may occur within its country.

4. Measurement Instructions

4.1 Tests before measurements

After arrival of the travelling standard, it should be checked for any physical damage. Ensure that the mains voltage setting is applicable to the local supply, and check that the instrument is functioning correctly. It should be allowed to stabilize in a temperature and possibly, humidity controlled environment for at least 24 hours before starting measurements.

4.2 Measurement conditions

1. The digital multimeter should be used in the configurations given in Annex-4.
2. The instrument will be supplied without input leads. The input voltage, current and resistance are defined at the input terminals of the instrument.
3. A single earth connection must be used in the measurement setup to avoid ground loops.
4. The minimum settling time given in the table should be used after first application of the test signal.
5. The standard ambient conditions for measurement are

   Temperature: (23 ± 1) °C

   Relative humidity: 50% ± 10%

6. Before making DC measurements, for each point, a zero value should be applied and Auto Zero (check function) should be executed.
7. The measurement result is the correction for the Digital Multimeter calculated as: DMM correction = True (Applied) value – DMM reading.

Any standard method may be used for calibrating the digital multimeter. For example, the participant laboratories may use the following techniques:

- Direct comparison with a multifunction calibrator;
- Direct comparison with DC reference voltage standard and standard resistors; and
- Indirect comparison using voltage drop method for currents.

The calibration method must be presented in detail in the comparison report

5. Uncertainty of Measurement

5.1 Uncertainty components

All contributions to the measurement uncertainty should be listed in the report submitted by each participant.

Even though some contributions to the uncertainty are specific to each method of measurement, it may be useful to consider the following list to try to assure more comparable uncertainty evaluations (the list may be considered as the guidelines).

1. Reference voltage standard (for dc voltage parameter);
2. Standard resistor (for resistance parameter);
3. Reference divider (for high voltage);
4. Multifunction calibrator (for all or some of the parameters);
5. Thermal electromotive force (emf) (for low dc voltage);
6. Drift of the calibrator / reference standard since last calibration;
7. Effect of offset, non-linearity and differences in the gain of calibrator (when using a calibrator as the reference);
8. Repeatability; and
9. Finite resolution of the DMM to be calibrated.

5.2 Uncertainty budget

The uncertainty must be calculated according to the "Guide to the Expression of Uncertainty in Measurement" [6] for a 95% confidence level. In uncertainty evaluations, all uncertainty components taken into account should be included. The coverage factor and the effective degrees of freedom should be reported.

6. Measurement Results of the Laboratories

Results should be communicated to the Coordinator Laboratory National Institute of Standards (NIS) within 30 days of completing the measurements. An early report helps in evaluating the behavior of the travelling standard. A format-of-results form (Annex-5) is given in order to help summarize the essential information. The report should contain (for each measurement):

- A detailed description of the method used;
- The conditions of the measurement: values of temperature, humidity, with their limits of variation;
- Results of measurement;
- Standard uncertainties for each contributor;
- Combined standard uncertainty;
- Coverage factor;

- Effective degrees of freedom;
- Expanded uncertainty; and
- A detailed uncertainty budget.

7. Final Report of the Comparison

The process that will lead to the preparation of the final report of the comparison is explained in the “Guidelines for CIPM key comparisons” [1]. In short it is reported here.

After the conclusion of the circulation of the travelling standard the Coordinator Laboratory National Institute of Standards (NIS) will prepare a first draft (draft A) of the final report and will send it to the participants.

This draft will be confidential. The draft will be prepared within 4 months from the end of the measurements.

The participants will have one month to send their comments on draft A. If a laboratory’s result is abnormal, it can decide, at this stage, to withdraw its result or, if an explanation is found, can correct it.

On the basis of the comments received, the Coordinator Laboratory National Institute of Standards (NIS) will prepare the second draft (draft B), where the withdrawn results will not appear or, in case of correction, the original and the corrected results, with the given explanation, are reported. Draft B will be submitted to the TCEM-AFRIMETS and, after approval, will become the Final Report. The Final Report will form the basis for the publication of results, if any.

8. Comparison coordinator

The Coordinator of this comparison at NIS is Prof. Dr. Mohammed Helmy Abd El Raouf and his address is:

Mohammed Helmy Abd El Raouf
Head of Electrical Quantities Metrology Laboratory
National Institute of Standards, Egypt (NIS)
M. A. El-Sadat (Tersa) Street, El Haram, El Giza, Egypt.
P.O. Box: 136 Giza, Code No: 12211
Tel.: +2/ 01005875280
Fax: +202/ 33867451, +202/ 33862224
E-mail: Mohammed_makka@yahoo.com

References

1. Guidelines for CIPM key comparisons (available on the BIPM website): http://www.bipm.org/pdf/guidelines.pdf.
2. “Supplementary Comparison on Digital Multimeter”, (P1-APMP.EM-S8).
3. J. Randa, “Proposal for KCRV & Degree of Equivalence for GTRF Key Comparisons”, Document of Working Group on radio frequency quantities of the CCEM, GT-RF/2000-12, September 2000.
4. Cox M. G., “The evaluation of key comparison data: An introduction”, *Metrologia*, 2002, 39, 587-589.
5. Cox M. G., “The evaluation of key comparison data”, *Metrologia*, 2002, 39, 589-595.
6. Guide to the Expression of Uncertainty in Measurement, JCGM 100:2008, First edition September 2008 (available on the BIPM website: http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

Annex-1: PARTICIPANT DETAILS

No.	Name of laboratory	Contact person	Shipping address	ATA CARNET
1	Electrical Quantities Metrology Lab., National Institute of Standards, Egypt (NIS)	Dr. Eng. Heba Ahmed Mohamed Hamed Email: Heba_ahmed_mohamed@yahoo.com	Electrical Quantities Metrology Lab. National Institute of Standards, NIS, Egypt M. A. El-Sadat (Tersa) Street, El Haram, El Giza, Egypt. P.O. Box: 136 Giza, Code No: 12211	No
2	DCLF & RF section National Metrology Institute of South Africa, (NMISA)	Mr. M.M. Hlakola Email: mhlakola@nmisa.org	CSIR Campus, Building 5, Meiring Naude Road, Brummeria Pretoria 0182, South Africa	Yes
3	DEFNAT/ANM	Mr. Abdelkarim Mallat, Mdm. Nadia Fezai E-mail: metrologie@defense.tn, karim_mallat@yahoo.fr	1 Rue Lavoisier, 1000 Tunis, Tunisia	Yes
4.	Kenya Bureau of Standards (KEBS)	Mr. Gibson Aguko E-mail: agukog@kebs.org or gibsonaguko@yahoo.com	Kenya Bureau of Standards (KEBS) Popo Road, Off Mombasa Road, Past Bellevue Cinema, Nairobi - Kenya P.O. Box 54974-00200	No
5	Laboratoire National de Métrologie du Laboratoire Public d'Essais et d'Études, (LPEE-LNM)	Mr Abdellah ZITI E-mail: ziti@lpee.ma	Km 7, Route d'El Jadida, Oasis – Casablanca Moracco	Yes
6	Uganda National Bureau of Standards National Metrology Laboratory, (UNBS)	Mr. Patrick Kizito Musaazi E-mail: patrick.kizito@unbs.go.ug patrickmusazi@gmail.com	Uganda National Bureau of Standards (UNBS) P. O Box 6329 Kampala, Uganda Plot M217 Nakawa Industrial Area	No
7	Scientific and Industrial Research and Development Centre, National Metrology Institute, (SIRDC-NMI)	Mr. Raban Chikwanha E-mail: rchikwanha@sirdc.ac.zw rchikwanha@gmail.com	1574 Alpes Road. Hatcliffe. Harare. Zimbabwe	No
8	Electrical Laboratory National Metrology Institute of Ethiopia (NMIE)	Mr. Nesredin Nezir Hassen E-mail: nesredin03@gmail.com	B67, street 1405, Woreda 06, Bole Sub City, Addis Ababa, Ethiopia	No

Annex-2: CIRCULATION SCHEME
Circulation Scheme for Participants
Travelling standard: Fluke model 8846A S/N: 2797002

Laboratory	Receipt of Travelling Standard (DD/MM/YY)	Departure of Travelling standard (DD/MM/YY)	Report Dispatch (DD/MM/YY)
Loop 1			
South Africa	1-12-2019	14-12-2019	-----------
Egypt	25-1-2020	8-1-2020	8-2-2020
Morocco	19-1-2020	2-2-2020	2-3-2020
Tunisia	13-2-2020	27-2-2020	27-3-2020
South Africa	9-3-2020	-----------	-----------
Loop 2			
South Africa	-----------	23-3-2020	-----------
Uganda	3-4-2020	17-4-2020	17-5-2020
Kenya	28-4-2020	12-5-2020	12-6-2020
Ethiopia	23-5-2020	6-6-2020	6-7-2020
Zimbabwe	17-6-2020	1-7-2020	1-8-2020
South Africa	12-7-2020	26-7-2020	26-8-2020

Annex-3: RECEIPT FORM

Comparison on Digital Multimeter (AFRIMETS.EM-S2)

Receipt form

To: ________________________	**From:** ________________________
Attn: ________________________	**Fax No.:** ________________________
Fax No.: ________________________	**Tel No.:** ________________________
Date: ________________________	**Pages:** ________________________

The AFRIMETS.EM-S2 comparison pack was received on______/_____/_____*(date)*

The contents of the transport case, checked against the Packing List, were:

☐ Complete (INCLUDING CARNET)

☐ Incomplete (*please list missing items*)

____

After inspection,

The ‘travelling standard’ (digital multimeter) is in working condition? ------------- (Yes/No)

If no, is the damage serious? --------------- (Yes /No)

Remarks, if any:

____

____

____

Signature

Annex-4: OPERATIONAL SETTINGS

Digital Multimeter Fluke 8846A for AFRIMETS.EM-S2 Comparison

1. Manual range selection must be made for all measurements. Select the range before applying the test signal to the multimeter.
2. The front input terminals must be used for all measurements.
3. Reset the instrument to default settings before starting measurements (see page 3-26 in the User's Manual[1]).
4. Refer to table 3 for additional measurement setup requirements.

Table 3

Parameter	DC Voltage	DC Current	Resistance	AC Voltage	AC Current
Connection	As per figure 4.1 page 4-4 of the User's Manual [1]	As per figure 4.4 (10 mA) and 4.5 (1 A) on page 4-10 of the User's Manual [1]	As per figure 4.2 page 4-8 of the User's Manual [1]	As per figure 4.1 page 4-4 of the User's Manual [1]	As per figure 4.4 (10 mA) and 4.5 (1 A) on page 4-10 of the User's Manual [1]
Input impedance	High Input Z (See page 3-10 of the User's Manual [1])	Not applicable [2]	Not applicable [2]	Not applicable [2]	Not applicable [2]
Filter selection	D FLTR ON A FLTR ON[4]	D FLTR ON A FLTR ON[4]	D FLTR ON A FLTR off [4]	Select 3 HZ SLOW [4]	Select 3 HZ SLOW [4]
Display resolution	6 Digit, 100 PLC [3]	6 Digit, 100 PLC [3]	6 Digit, 100 PLC [3]	HIGH [3]	HIGH [3]
Math	ON	ON	ON	------------	------------
Zeroing	Required	Required	Required	Not applicable	Not applicable
Settling time	5 minutes (min)	5 min for 10 mA, 30 min for 1 A	5 min	5 min	5 min for 10 mA, 30 min for 1 A

[1] Fluke 8845A/8846A Digital Multimeter User's Manual, July 2006, Rev. 2, 6/08

[2] Although it is possible to turn on the "HIGH INPUT Z" function on the front panel for these parameters, doing so does not change the input impedance of the Digital Multimeter

[3] Page 3-7 in the User's Manual[1]

[4] Page 4-4 to 4-6 in the User's Manual[1]

Annex-5: FORMAT OF MEASUREMENT RESULTS

1. Participating Laboratory:

   a. Name of Laboratory: ______________________
   b. Address: ______________________
   c. Name of Contact Person: ______________________
   d. Tel No.: ______________________
   e. Fax No.: ______________________
   f. E-mail: ______________________

2. Standards and Instruments Used:

   a. Standard Used (Type or Model):
   b. Measuring Instruments (Model):

3. Measurement Method:

4. Measured Data:

   a. Environmental Conditions during measurements:

	Minimum	Average	Maximum
Temperature:	°C	°C	°C
Relative Humidity:	%	%	%

   b. Measurement Results:

Nominal Value	Mean Applied Value	Mean DMM reading	Mean DMM Correction	Uncertainty (95% C.L.)

Please Attach Detailed Uncertainty Budgets as per "GUM"

Document: Date ______________________

Signature ______________________

Annex-6: DISPATCH FORM

Comparison on Digital Multimeter (AFRIMETS.EM-S2)

Dispatch form

Participating laboratory ______________________________

Contact person ______________________________

Phone __________ Fax __________ E-mail ______________________________

The audit pack was dispatched on_____/_____/__________*(date)*

Courier (if applicable) ____________________ Tracking no ______________

Airline ______________ Flight no ____________ Dated ______________

The contents of the pack have been inspected after measurement in our laboratory and were found to be in good condition. ________ (Yes / No)

Please give details of any problems

Kindly send a copy to next Participant and the Pilot Laboratory