

BIPM Capacity Building & Knowledge Transfer Programme

2019 BIPM - TÜBİTAK UME Project Placement

REPORT

Project name	Calibration of AC-DC Voltage Transfer Standards on Set-up Procedure
Description	Calibration of AC-DC voltage transfer standards and measurement software
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1. Motivation & Introduction

My project within the BIPM-TUBITAK UME Project Placements had the main aim of assisting the Mongolian Agency for Standards and Metrology (MASM) to increase and strengthen the capacity of its electrical measurements laboratory, which plays a vital role in the energy sector of Mongolia.

MASM's technical competence and capabilities in the area of AC-DC transfer standards, which is still not fully operational at our laboratory, need to be increased in the near future. Our laboratory has plans to establish a new AC-DC voltage measurement standard in response to increased demand from the industrial and energy sectors.

Participation in this programme presented a good opportunity to increase my knowledge about AC-DC transfer standard measurements and develop technical skills will contribute to establishing needed measurement standard services at MASM.

The practical part was based on observing the AC-DC transfer standard system, studying documents describing in detail the operation of the system in the Voltage Laboratory at TUBITAK UME.

2. Thermal Converters

High precision AC electrical metrology is organized around devices called AC-DC thermal converters. In the thermal method, DC and AC voltage are alternately applied to a heater resistor and the amounts of joule heating they produce are compared by measuring the temperature of the heater with a thermal sensor, for example a thermocouple. These structures are known as thermal converters and there are two main types that are widely used, vacuum thermocouple and electronic sensor based converters.

Figure 1: A thin filament heater and a thermocouple are inserted in a vacuum-shielded glass bulb. A thermocouple is attached to the heater at the midpoint of the heater using a bead made of glass or ceramics. A 2V thermal converter seen here was made during the project.



1.1 Thermal Converter Calibration

The first step of the measurement procedure is determining the input-output sensitivity characteristics “n” of both test and reference thermal current converters at working current.

Afterwards, at each particular frequency, AC and DC current sources are adjusted initially to produce as close outputs as possible on the test converter and then applied in sequence AC, DC+, AC, DC-, AC and the output of the converters are measured for each current. The output emf of the thermal converters should be measured at least 60 sec after changing the applied current.

The formula used to calculate the AC-DC difference of the test current converter is as follows:

$$\delta t = \frac{E_{as} - E_{ds}}{n_s \cdot E_{ds}} + \frac{E_{at} - E_{dt}}{n_t \cdot E_{dt}} + \delta s$$

Calibration Point	Frequency	AC-DC Difference	Standard Deviation
2 V	10 Hz	22.7 $\mu\text{V/V}$	0.8 $\mu\text{V/V}$

	20 Hz	-1 µV/V	0,4 µV/V
	30 Hz	-3.4 µV/V	0.5 µV/V
	40 Hz	-6.7 µV/V	0.6 µV/V
	500 Hz	-5.1 µV/V	1 µV/V
	1 kHz	-5.1 µV/V	0.3 µV/V
	10 kHz	-4 µV/V	0.5 µV/V
	20 kHz	-1.6 µV/V	1 µV/V
	50 kHz	0.9 µV/V	0.4 µV/V
	70 kHz	1.5 µV/V	0.4 µV/V
	100 kHz	4.8 µV/V	0.1 µV/V
	200 kHz	8.3 µV/V	0.5 µV/V
	500 kHz	16.3 µV/V	0.4 µV/V
	700 kHz	19.6 µV/V	0.1 µV/V
	1 MHz	24.1 µV/V	0.4 µV/V

1.4 MJTVC Uncertainty Budget

Range :			1 V - 3 V				Model Function : $\delta_x = \delta_{\text{diff}} + \delta_{\text{ref}} + \delta_{\text{con}} + \delta_{\text{sys}} + \delta_{\text{level}}$																							
Uncertainty Sources				Uncertainty Components												Sensitivity Coefficients			Uncertainty Contribution											
				(µV/V)															(µV/V) ²											
Description	Symbol	Estimated Value	Unit	Symbol	10 Hz	20 Hz, 30 Hz	40 Hz, 50 Hz, 55 Hz, 60 Hz	(100, 300, 400, 500) Hz, (1, 10, 20, 30, 50) kHz	70 kHz	100 kHz	200 kHz, 300 kHz	500 kHz	700 kHz, 800 kHz	1 MHz	Probability distribution	Factor	Symbol	Value	Unit	10 Hz	20 Hz, 30 Hz	40 Hz, 50 Hz, 55 Hz, 60 Hz	(100, 300, 400, 500) Hz, (1, 10, 20, 30, 50) kHz	70 kHz	100 kHz	200 kHz, 300 kHz	500 kHz	700 kHz, 800 kHz	1 MHz	
Measured Difference	δ _{diff}	δ _{1,2}	µV/V	u(δ _{diff})	0,8	0,5	0,6	1,0	0,5	0,5	0,5	0,5	0,5	0,5	Normal	1,00	C _{diff}	1,00	-	0,6	0,3	0,4	1,0	0,3	0,3	0,3	0,3	0,3	0,3	
Reference Std.	δ _{ref}	δ _{1,3}	µV/V	u(δ _{ref})	2,0	2,0	1,0	1,0	4,0	4,0	5,0	9,0	9,0	9,0	Normal	0,50	C _{ref}	1,00	-	1,0	1,0	0,3	0,3	4,0	4,0	6,3	20,3	20,3	20,3	
Connections	δ _{con}	0	µV/V	u(δ _{con})	0,2	0,2	0,2	0,2	0,5	0,5	0,6	1,0	1,5	2,0	Rect.	0,58	C _{con}	1,00	-	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,3	0,8	1,3	
Level Dependency	δ _{level}	0	µV/V	u(δ _{level})	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	Rect.	0,58	C _{level}	1,00	-	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	
System	δ _{sys}	0	µV/V	u(δ _{sys})	0,5	0,4	0,2	0,1	0,2	0,3	0,5	0,8	1,0	2,0	Rect.	0,58	C _{sys}	1,00	-	0,1	0,1	0,0	0,0	0,0	0,0	0,1	0,2	0,3	1,3	
																Total Variance		(µV/V) ²	u(δ _x) ²	2,1	1,7	1,0	1,6	4,7	4,7	7,0	21,4	21,9	23,5	
																Standard Uncertainty		µV/V	u(δ _x)	1,4	1,3	1,0	1,3	2,2	2,2	2,7	4,6	4,7	4,8	
																Expanded Uncertainty		µV/V	U(δ _x)	2,9	2,6	2,0	2,5	4,3	4,3	5,3	9,2	9,4	9,7	
																(k=2, 95 %)														
																Declared Uncertainty		µV/V	U(δ _x)	2,9	2,6	2,0	2,5	4,3	4,3	5,3	9,2	9,4	10	

1.5 Model Function

$$\delta_x = \delta_{diff} + \delta_{ref} + \delta_{con} + \delta_{sys} + \delta_{level}$$

δ_x	AC-DC transfer difference for the test transfer standard
δ_{diff}	AC-DC transfer difference between the test and the reference transfer standard
δ_{ref}	AC-DC transfer difference for the reference transfer standard
δ_{con}	AC-DC transfer difference due to the connections and connectors
δ_{sys}	AC-DC transfer difference due to the measurement system
δ_{level}	AC-DC transfer difference due to the voltage dependence of the thermal converter

2. Step-up procedure for AC-DC Current Transfer Standard

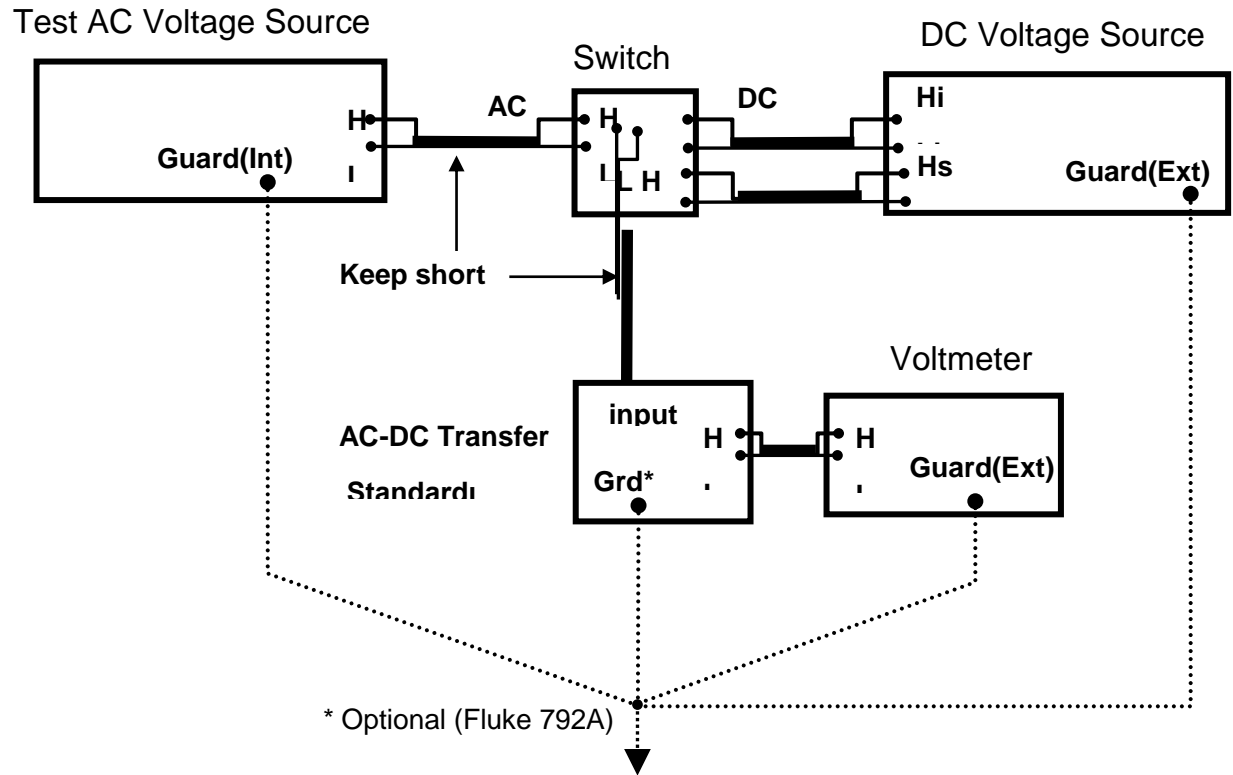
The step-up method includes the calibration of the thermal converter at half the nominal current (or at its lowest value applicable (%30-%100)) by using a traceable fundamental level TCC, and then the use of the calibrated converter in the calibration of the closest higher level TVC at half the nominal current (or in its lowest value applicable). In this way, all converters up to 100 A are in turn calibrated by using a fundamental 10 mA reference thermal current converter.

The thermal converters used at 10 mA current value are basic level and calibrated by PTB. These converters are crosschecked by comparing them to each other in 5 year periods.

Table 1. Calibration steps for AC-DC Current Shunts

Reference Standard	Test Standard	Test Current
10 mA MJTCC (Basic Level)	10 mA MJTCC	10 mA
10 mA MJTCC (Basic Level)	AC/DC Current Shunt 20 mA - MJTVC	10 mA
AC/DC Current Shunt 20 mA - MJTVC	AC/DC Current Shunt 50 mA - MJTVC	20 mA
AC/DC Current Shunt 50 mA - MJTVC	AC/DC Current Shunt 100 mA - MJTVC	50 mA
AC/DC Current Shunt 100 mA - MJTVC	AC/DC Current Shunt 200 mA - MJTVC	100 mA
AC/DC Current Shunt 200 mA - MJTVC	AC/DC Current Shunt 500 mA - MJTVC	200 mA
AC/DC Current Shunt 500 mA - MJTVC	AC/DC Current Shunt 1 A - MJTVC	500 mA
AC/DC Current Shunt 1 A - MJTVC	AC/DC Current Shunt 2 A - MJTVC	1 A
AC/DC Current Shunt 2 A - MJTVC	AC/DC Current Shunt 5 A - MJTVC	2 A
AC/DC Current Shunt 5 A - MJTVC	AC/DC Current Shunt 10 A - MJTVC	5 A
AC/DC Current Shunt 10 A - MJTVC	AC/DC Current Shunt 20 A - MJTVC	10 A
AC/DC Current Shunt 20 A - MJTVC	AC/DC Current Shunt 50 A - MJTVC	20 A
AC/DC Current Shunt 50 A - MJTVC	AC/DC Current Shunt 100 A - MJTVC	50 A

3. AC VOLTAGE SOURCE CALIBRATION



3.1 Measurement Procedure

AC test voltage is first applied to the thermal converter, and then the DC source is adjusted to produce as close as possible an output on the transfer standard to those produced by the test AC voltage. When the DC source is adjusted to produce an output on the thermal converter as at least as close as 50 ppm to those produced by AC voltage, the measurement cycle is initiated by applying AC and DC voltages to the transfer standard in sequence: AC, DC-, DC+, AC. The error of the AC source is calculated by the following equation:

$$\delta t = \frac{V_{dc} - V_{ac}}{V_{dc}} + \frac{E_{ac} - E_{dc}}{n * E_{dc}} + \delta s + C_d$$

where,

V_{dc} , V_{ac} DC source and test AC voltage sources settings respectively

E_{ac} , E_{dc} Output emf of the reference AC-DC transfer standard when applied AC and DC voltage respectively

n transfer value of transfer standard

δs AC-DC transfer difference of the reference ac-dc transfer standard

C_d Correction to the dc source, $C_d = (V_t - V_d)/V_d$, V_t – true value, V_d – display value of DC source

Positive error indicates that measured voltage produced by the AC source is higher than nominal at given voltage/frequency point.

3.2 Calibration by AC-DC Transfer Standard

$$\text{Model Function : } V_x = (V_{DC} + \delta V_{DC}) \times (1 + \delta_{AC-DC} + \delta_{set-up} + \delta_{conn})$$

V_x	The AC value applied by the AC voltage source to be calibrated
V_{DC}	The DC voltage value applied by the DC voltage source
δV_{DC}	The correction of the DC Voltage Source (voltage drift, environmental conditions, the load effect etc.)
δ_{AC-DC}	The AC-DC transfer difference of the reference AC-DC transfer standard
δ_{set-up}	The correction by the AC-DC transfer system (the short term stability of the voltmeter, resolution, the frequency dependency of the connection elements etc.)
δ_{conn}	The correction for the frequency dependency of the connection elements

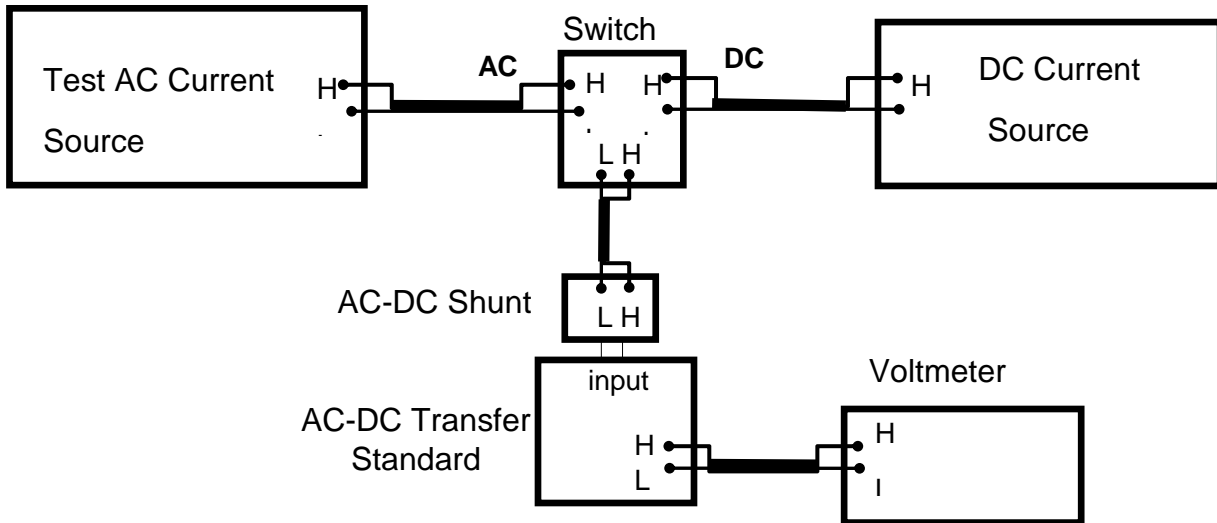
Table 2 : AC Voltage Source Calibration results

Nominal Value		Eac	Vdc+	Vdc-	Vdc	ac/dc diff.	Vac
1 V	40 Hz	0.8528917 V	1.0000072 V	-1.0000067 V	1.0000070 V	4.0 $\mu V/V$	1.000011 V
2 V	10 kHz	1.7058320 V	2.0000320 V	-2.0000260 V	2.0000290 V	-3.0 $\mu V/V$	2.000023 V
6 V	50 kHz	1.7732820 V	5.9999930 V	-5.9999560 V	5.9999745 V	10.0 $\mu V/V$	6.0000345 V
500 V	1 kHz	0.8942285 V	500.0100 V	-500.0063 V	500.00815 V	1.0 $\mu V/V$	500.0087 V

Table 3 : AC Voltage Source Uncertainty

$u(V_x)$ standard uncertainty	k	Sensitivity Coefficient	$u(V_{DC})$ DC Voltage applied from calibrator	k	Sensitivity Coefficient	$u(\delta V_{DC})$ DC Voltage correction	k	Sensitivity Coefficient	δ_{AC-DC} AC/DC Transfer Standard	k	Sensitivity Coefficient	δ_{set-up} Set-up uncertainty	k	Sensitivity Coefficient	δ_{conn} Connectors	k	Sensitivity Coefficient	Combined Uncertainty	Absolute Expanded Uncertainty	Relative Expanded Uncertainty
0,65 μV	1	1	1,2 $\mu V/V$	2	1	5,70 μV	2	1	5,0 $\mu V/V$	2	1 V	5,0 $\mu V/V$	1,73	1 V	1,0 $\mu V/V$	1,73	1 V	4,88 μV	9,76 μV	10 $\mu V/V$
0,96 μV	1	1	1,2 $\mu V/V$	2	1	10,70 μV	2	1	5,0 $\mu V/V$	2	2 V	5,0 $\mu V/V$	1,73	2 V	1,0 $\mu V/V$	1,73	2 V	9,46 μV	18,93 μV	10 $\mu V/V$
0,10 μV	1	1	1,2 $\mu V/V$	2	1	21,25 μV	2	1	5,0 $\mu V/V$	2	6 V	5,0 $\mu V/V$	1,73	6 V	1,0 $\mu V/V$	1,73	6 V	25,50 μV	51,00 μV	10 $\mu V/V$
11,84 μV	1	1	1,2 $\mu V/V$	2	1	3650,00 μV	2	1	15,0 $\mu V/V$	2	500 V	5,0 $\mu V/V$	1,73	500 V	1,0 $\mu V/V$	1,73	500 V	4422,7 μV	8845,3 μV	20 $\mu V/V$

4. AC CURRENT SOURCE CALIBRATION



4.1 Measurement Procedure

The AC test current is first applied to the thermal current converter, and then the DC source is adjusted to produce as close as possible output on the transfer standard to those produced by test AC current. When the DC source is adjusted to produce an output on transfer standard at least as close as 50 ppm to those produced by AC current, the measurement cycle is initiated by applying AC and DC currents to the transfer standard in sequence: AC, DC-, DC+, AC. The error of the AC source is calculated by the following equation:

$$\delta_t = \frac{I_{dc} - I_{ac}}{I_{dc}} + \frac{E_{ac} - E_{dc}}{n * E_{dc}} + \delta_s + C_d$$

where,

- | | |
|------------------|---|
| I_{dc}, I_{ac} | DC source and test AC current settings respectively |
| E_{ac}, E_{dc} | Output emf of the reference ac-dc transfer standard when applied ac and dc current respectively |
| n | transfer value of transfer standard |
| δ_s | Ac-dc transfer difference of the reference ac-dc transfer standard |
| C_d | Correction to the dc source |

A positive error indicates that measured current produced by ACsource is higher than nominal at given current/frequency point.

4.2 Calibration by AC-DC Transfer Standard

$$\text{Model Function : } I_x = (I_{DC} + \delta I_{DC}) \times (1 + \delta_{AC-DC} + \delta_{\text{set-up}})$$

I_x	The AC current supplied by the current source to be calibrated
I_{DC}	DC current supplied by the reference current source
δI_{DC}	The correction of DC current source (drift, environmental conditions, the loading effect etc.)
δ_{AC-DC}	AC-DC transfer difference of the AC-DC transfer Standard/AC-DC current shunt system
$\delta_{\text{set-up}}$	The correction due to the AC-DC transfer system (the short term stability and resolution of the voltmeter, the frequency dependency of the connection elements etc.)

Table 4 : AC Current Source Calibration Results

Nominal Value		Eac	Idc+	Idc-	Idc	ac/dc diff	Iac
100 mA	100 Hz	1.271768 A	100.0080 mA	-100.0054 mA	100.0067 mA	4.0 μ A/A	100.0071 mA
1 A	1 kHz	1.202042 A	0.999984 A	1.000024 A	1.000004	-1.0 μ A/A	1.000003 A
1 A	5 kHz	1.200646 A	0.999851 A	0.999888 A	0.9998695	-28.0 μ A/A	0.9998415 A
1 A	10 kHz	1.201627 A	0.999562 A	0.999603 A	0.9995825	-59.0 μ A/A	0.9995235 A

Table 5 : AC Current Source Uncertainty

$u(V_{ix})$ standard uncertainty	k	Sensitivity Coefficient	$u(I_{DC})$ DC Current applied from calibrator	k	Sensitivity Coefficient	$u(dI_{DC})$ DC Current correction			k	Sensitivity Coefficient	d_{AC-DC} AC/DC Transfer difference uncertainty	k	Sensitivity Coefficient	dset-up Set-up uncertainty	k	Sensitivity Coefficient	dcon Connectors	k	Sensitivity Coefficient	Combined Uncertainty	Absolute Expanded Uncertainty	Relative Expanded Uncertainty
0,08 μ A	1	1	11,0 μ A/A	2	1	4 5	0, 7	5,2 μ A	2	1	14,0 μ A/A	2	0,1 A	5,0 μ A/A	1,7 3	0,1 A	1,0 μ A/A	1,7 3	0,1 A	2,7 μ A/A	5,43 μ A	55 μ A/A
0,96 μ A	1	1	13,0 μ A/A	2	1	8 0	1 2	92,0 μ A	2	1	21,0 μ A/A	2	1,0 A	5,0 μ A/A	1,7 3	1 A	1,0 μ A/A	1,7 3	1 A	47,3 μ A/A	94,55 μ A	95 μ A/A
0,10 μ A	1	1	13,0 μ A/A	2	1	8 0	1 2	92,0 μ A	2	1	21,0 μ A/A	2	1,0 A	5,0 μ A/A	1,7 3	1 A	1,0 μ A/A	1,7 3	1 A	47,3 μ A/A	94,55 μ A	95 μ A/A
0,10 μ A	1	1	13,0 μ A/A	2	1	8 0	1 2	92,0 μ A	2	1	25,0 μ A/A	2	1,0 A	5,0 μ A/A	1,7 3	1 A	1,0 μ A/A	1,7 3	1 A	47,8 μ A/A	95,51 μ A	100 μ A/A

5. Conclusions and future work

All information gained including information gained on both practice and theory will be shared with laboratory personnel at MASM. Actions to be taken include:

- Research and development of a new AC-DC voltage and current standards and ensuring its traceability to the SI.
- Improvement of AC-DC traceability and technical organization.
- To disseminate traceability to the AC-DC transfer voltage and current standards.

6. Acknowledgements

I would like to thank the organizers from TUBITAKUME and BIPM for the opportunity to participate in this kind of training programme. It was a pleasure to work at UME together with people who were always willing to help. I would particularly like to thank Mr. Mehedin ARIFOVIC and Mrs. Naylan KANATOGLU from Voltage Laboratory for their unselfish transfer of knowledge and their great effort to make my project useful for me, as well as for MASM.