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Database management system of AC Voltage Standards

Abstract

The paper presents a database management system of AC voltage standards maintained in the Laboratory of AC-DC Standards of Institute of Measurement Science, Electronics and Control, Silesian University of Technology, Gliwice, Poland. The database stores the basic metrological parameters and other details of the standards, especially their AC-DC transfer differences at different voltages and frequencies. The database also stores previous (historical) values of the AC-DC transfer differences of the standards which enables the observation of time drift of these parameters.

Keywords: AC–DC transfer, AC voltage standard, primary standard, consistency of standards, traceability.

1. Introduction

The thermal AC–DC transfer is one of most accurate method of determining true root mean square (rms) value of the alternate voltage (AC). The accuracy of the thermal AC-DC transfer allows for usage of this method to reproduce standard AC voltage. A typical thermal AC voltage standard is composed of a thermal voltage converter (TVC) and an optional resistor, which - connected in series with the TVC - extends the input voltage of the standard [1]. The basic metrological parameter of a thermal AC voltage standard is the AC–DC transfer difference. In most cases, this parameter is measured by comparing the calibrated standard (Unit Under Test, UUT) with a reference standard with known AC–DC transfer difference. The set of AC voltage standards maintained in the Laboratory of AC-DC Standards at the Institute of Measurement Science, Electronics and Control in Electrical Engineering Faculty of Silesian University of Technology is composed of 26 TVCs and approximately 10 serial resistors. These standards have different nominal input voltages and construction and cover the voltage range from approximately 0.5 V up to 1000 V. Two primary standards from this set, of nominal input voltages $U_N = 3$ V and $U_N = 5$ V, are calculable standards, i.e., their AC-DC transfer differences were calculated in 10 kHz–1 MHz frequency range using a complex mathematical model [2]. The AC-DC transfer differences of these standards in 10 Hz – 10 kHz frequency range were determined by means of experimental methods. Some standards from the set were calibrated at National Measurement Institutes (PTB, NIST) or compared with primary AC voltage standards of Italy and Denmark [3]. The AC – DC transfer differences of the remaining standards from the set were determined by means of step-up and step-down method, i.e. by measuring their AC-DC transfer difference versus standards of lower or higher nominal input voltage, respectively [4].

Comparisons, evaluations and external calibrations of standards require lot of data to be analyzed and archived. Thus, an appropriate data management system is required. Such system was developed and introduced in the Laboratory of AC-DC Standards at Silesian University of Technology. A basic element of this system is the database, which stores values of AC – DC transfer differences of AC Standards. The database is used not only for storage or archiving purpose, but it is also very useful for investigation of long term stability of metrological properties of the AC standards.

2. Description of the database

The database stores all crucial information about standards, including basic metrological parameters and construction details. The database has form of spreadsheets embedded in Microsoft Excel. This solution simplifies the process of exchanging informations between the database and the program controlling the AC – DC transfer measurement procedure, which is written in Excel Visual Basic for Application (VBA). Database is stored in many Excel (*.xls) files. Basic parameters of AC standards are stored in the main xls file, whereas values of AC – DC transfer differences are stored in other Excel files. The structure of the database is shown on Fig. 1.

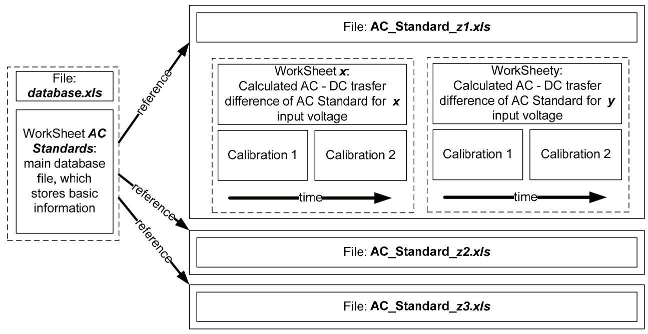

Fig. 1. Structure of the database

Each row in ”AC standards” worksheet in the „database.xls” file describes a single standard. It stores such information as nominal input voltage of the Standard, type of TVC used (for example a single junction thermal converter, a planar multijunction thermal converter [5] etc.) and resistance of the serial (range) resistor (if any). Each standard is labeled with an unique identifier, which is placed at first column of the ”AC standard” worksheet. Information about the type of TVC and the nominal input voltage are extremely important for AC–DC transfer, because they allow to estimate expected value of the output voltage E of the standard for a given input voltage U. If the output voltage of the standard is too low, the it will be impossible to perform the AC–DC transfer with required precision. Column “F” of the ”AC standards” worksheet contains filename of the Excel file where AC–DC transfer differences of a standard are stored. A screenshot of the main worksheet is presented in Fig. 2.

There are three buttons on the main worksheet, which start macros written in Excel VBA. They are used to:

- open a worksheet with calculated values of AC–DC transfer difference of the selected standard,
- store the results of measurements to the database,
- calculation of the AC–DC transfer difference of the standard taking part in a closed-loop comparison cycle.

Each standard can be used only in a specific input voltage range. For example standards based on planar multijunction thermal converters, can be used for input voltage in range from 20% to 100% of nominal input voltage. The AC–DC transfer difference depends on the input voltage of the standard, especially at low frequencies (< 40 Hz) [6]. Thus, the database contains look-up tables with AC – DC transfer differences of a specific standard determined at different input voltages. Each such look-up table is stored in a separate worksheet, which contain also the following informations:

- frequency,
- calculated AC–DC transfer difference,
- uncertainty of the AC–DC transfer difference,
- date of calibration/comparison,
- additional column with optional notes from the operator of the measurement system or a supervisor.

Open AC standard file | Generate report... | Add result of comparison to database

AC Standard Id	Type of AC Standard	Max. input voltage [V]	Thermal Voltage Converter	Range resistor	Comparsion results files	Comment
VS-1V-a	PMJTC	1	PTB PMJTC 90 Ω	-	VS-1V-a.xls	
VS-1V-b	PMJTC	1	PTB PMJTC 90 Ω	-	VS-1V-b.xls	
VS-1,5V-a	SJTC	1,5	Best SJTC 90 Ω/5 mA	ISAOHM 25µm/80mm, 222Ω (int)	VS-1,5V-a.xls	
VS-1,5V-b	PMJTC	1,5	PTB PMJTC 200 Ω	-	VS-1,5V-b.xls	
VS-1,5V-c	PMJTC	1,5	PTB PMJTC 200 Ω 2/09 #14	-	VS-1,5V-c.xls	Calibrated at PTB
VS-2V-a	PMJTC	2	PTB PMJTC 400 Ω	-	VS-2V-a.xls	
VS-3V-a	SJTC	3	Best SJTC 90 Ω/5 mA	ISAOHM 25µm/190mm, 510Ω (int)	VS-3V-a.xls	
VS-3V-b	PMJTC	3	PTB PMJTC 90 Ω	Alpha Metal Foil MP 200 Ω (internal)	VS-3V-b.xls	Calibrated at INRIM
VS-3V-c	SJTC	3	Best SJTC 90 Ω/5 mA	500 Ω µwave (internal)	VS-3V-c.xls	
VS-4,5V-a	PMJTC	4,5	Nikkohm TVC06AP 200 Ω	-	VS-4,5V-a.xls	
VS-5V-a	PMJTC	5	PTB PMJTC 90 Ω	Caddock MS315 390 Ω	VS-5V-a.xls	
VS-5V-b	SJTC	5	Best SJTC 90 Ω/5 mA	ISAOHM 15µm/132mm, 966Ω (int)	VS-5V-b.xls	
VS-7V-a	PMJTC	7	Nikkohm TVC04AP 500 Ω	-	VS-7V-a.xls	
VS-7V-b	PMJTC	7	Nikkohm TVC06AP 500 Ω	-	VS-7V-b.xls	
VS-10V-b	PMJTC	10	Nikkohm TVC06AP 1000 Ω	-	VS-10V-b.xls	
VS-10V-a	PMJTC	10	PTB PMJTC 90 Ω 1/09 #12	Caddock MS315 820 Ω	VS-10V-a.xls	
VS-20V-a	PMJTC	20	PTB PMJTC 90 Ω	Caddock MS315 1,8 kΩ	VS-20V-a.xls	
VS-30V-a	PMJTC	30	PTB PMJTC 90 Ω 1/09 #11	Caddock MS315 2,7 kΩ	VS-30V-a.xls	
VS-50V-a	PMJTC	50	PTB PMJTC 90 Ω 1/09 #10	Caddock MS315 4,7 kΩ	VS-50V-a.xls	
VS-70V-a	PMJTC	70	PTB PMJTC 90 Ω		VS-70V-a.xls	
VS-100V-a	PMJTC	100	PTB PMJTC 90 Ω	Caddock MS315 10 kΩ	VS-100V-a.xls	
VS-200V-a	PMJTC	200	PMJTC 90 Ω 1/09 #13x	Caddock MS315 18 kΩ	VS-200V-a.xls	
VS-300V-a	PMJTC	300	PMJTC 90 Ω 1/09 #14	Caddock MS315 27 kΩ	VS-300V-a.xls	
VS-500V-a	PMJTC	500	PTB PMJTC 90 Ω 1/09 #32	Caddock MS315 47 kΩ	VS-500V-a.xls	
VS-700V-a	PMJTC	700	PTB PMJTC 90 Ω		VS-700V-a.xls	
VS-1000V-a	PMJTC	1000	PTB PMJTC 400 Ω	FLUKE 792-7002 1000V	VS-1000V-a.xls	

Fig. 2. Main worksheet of the database

Results of each new (following) calibration are appended to the right of columns containing the previous results. It allows to observe time drift of the AC–DC transfer difference of a particular standard. Example worksheet was presented on Fig. 3.

Transfer differences of the UUT (elaborated)	
Type:	PMJTC5V
Symbol:	VS-5V-a
Act. date:	2014-05-03
Tamb (°C):	23.0±0.5
RH (%):	40±10
Amp/Buffer:	No
Dcsource:	F5440B
ACsource:	F5700A
Tee:	Shortest
Conditioner:	No
Switch:	HVSU-2
Rin (kohm):	
Exp n:	1,990
Voltage (V):	5

Freq Hz	TrDiff uV/V	StdUnc uV/V	Cal. date	Source	Comments
10	2,6	1,0	2014-04-19	2)	step down from VS-30V-a
20	1,0	1,0	2014-04-19	2)	step down from VS-30V-a
30	0,6	1,0	2014-04-19	2)	step down from VS-30V-a
40	0,2	0,6	2014-04-19	2)	step down from VS-30V-a
55	0,0	0,6	2014-04-19	1)	step up from VS-1.5V-c
60	0,0	0,6	2014-04-19	1)	step up from VS-1.5V-c
120	0,0	0,6	2014-04-19	1)	step up from VS-1.5V-c
300	0,0	0,6	2014-04-19	1)	step up from VS-1.5V-c
400	0,0	0,6	2014-04-19	1)	step up from VS-1.5V-c
500	0,0	0,6	2014-04-19	1)	step up from VS-1.5V-c
1000	0,0	0,6	2014-04-19	1)	step up from VS-1.5V-c
2000	0,0	0,6	2014-04-19	1)	step up from VS-1.5V-c
5000	0,4	0,6	2014-04-19	1)	step up from VS-1.5V-c
10000	0,8	0,6	2014-04-19	1)	step up from VS-1.5V-c
20000	1,2	0,6	2014-04-19	1)	step up from VS-1.5V-c
30000	1,4	0,6	2014-04-19	1)	step up from VS-1.5V-c
50000	2,5	0,6	2014-04-19	1)	step up from VS-1.5V-c
70000	3,6	2,1	2014-04-19	1)	step up from VS-1.5V-c
100000	5,3	2,1	2014-04-19	1)	step up from VS-1.5V-c
200000	8,6	2,6	2014-04-19	1)	step up from VS-1.5V-c
300000	10,8	2,6	2014-04-19	1)	step up from VS-1.5V-c
400000	14,6	5,1	2014-04-19	1)	step up from VS-1.5V-c
500000	17,9	4,6	2014-04-19	1)	step up from VS-1.5V-c
600000	21,8	5,1	2014-04-19	1)	step up from VS-1.5V-c
700000	26,0	4,6	2014-04-19	1)	step up from VS-1.5V-c
800000	28,7	4,6	2014-04-19	1)	step up from VS-1.5V-c
900000	34,5	5,1	2014-04-19	1)	step up from VS-1.5V-c
1000000	39,6	4,6	2014-04-19	1)	step up from VS-1.5V-c

Sources:
1) sPMJTC1,5VcalPTB_xPMJTC5V_1,5V_transfer28.1_60s_bez_bufora_najkrotszy_trojnik.xls
2) sPMJTC5V_xPMJTC30V_5V_transfer28.2_60s_bez_bufora_najkrotszy_trojnik.xls

1.5V | 5V

Fig. 3. AC–DC transfer difference worksheet

More detailed informations like date of comparison, ambient temperature and humidity, input voltage are placed at the top of each worksheet. Also the short description of the measurement system is placed there. The instruments used used in comparison/calibration, can have an impact on measured AC – DC transfer difference.

Another important parameter of the standard is the exponent of TVC transfer function, which depends on value of the input voltage. The values of this parameter, usually in the range 1.6…2.0, is usually measured for the both compared AC standards just before starting the AC – DC transfer measurement procedure and stored in the worksheet.

The frequency characteristic of AC–DC transfer difference of a UUT is in most cases measured using two reference standard, covering different frequency ranges. The final joint characteristic is elaborated manually by the operator of the measurement system. Creating an program, which would automatically calculate the full characteristic is rather problematic. In the described database values of AC–DC transfer differences of a UUT are calculated manually using measured differences of AC-DC transfer differences between the UUT and a reference standard and AC–DC transfer differences of the reference standard.

3. Comparison scheme of standards

Some of standards maintained in Laboratory of AC-DC Standards have similar nominal input voltage. It makes possible comparing them in pairs in different configurations. These comparisons can take a form of closed loops, which have structure of triangles, rectangles, etc. The example of a closed loop cycle is presented in Fig. 4.

It can be used to verify correctness of AC–DC transfer difference measurements of standards used in comparisons and to minimize random measurement errors. Results of comparisons of four standards shown in Fig. 4, can be written as set of linear equations [7]:

$$\begin{aligned}
\delta_{\mathrm{a,S3V}} - \delta_{\mathrm{a,S5V}} &= \delta_{r,\mathrm{S3V-S5V}} \\
\delta_{\mathrm{a,P1,5V}} - \delta_{\mathrm{a,S3V}} &= \delta_{r,P\mathrm{1,5V-S3V}} \\
\delta_{\mathrm{a,P1,5V}} - \delta_{\mathrm{a,S5V}} &= \delta_{r,\mathrm{P1,5V}-P\mathrm{5V}}\,, \\
\delta_{\mathrm{a,P5V}} - \delta_{\mathrm{a,S5V}} &= \delta_{r,\mathrm{P5V-S5V}} \\
\delta_{\mathrm{a,P5V}} - \delta_{\mathrm{a,S3V}} &= \delta_{r,\mathrm{P5V-S3V}}
\end{aligned} \tag{1}$$

where $\delta_{\mathrm{a},n}$ is the AC–DC transfer difference of the n-th standard and $\delta_{\mathrm{r},n\text{-}m}$ is result of comparison of the n-th standard with the m-th standard.

A planar multijunction thermal converter, which took part in comparison showed in Fig. 4, was marked with *P* index. Standards using single junction thermal converters, are marked with *S* index.

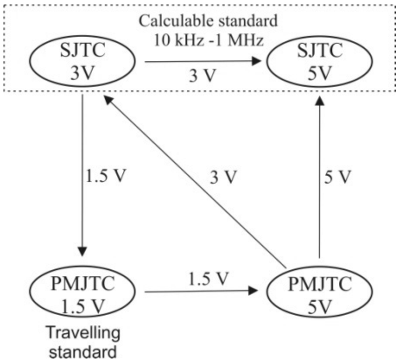

Fig. 4. Possible comparisons between 4 standards

The set of linear equations (1) can be rewritten using matrix notation:

$$\begin{bmatrix} 1 & -1 & 0 & 0 \\ -1 & 0 & 0 & 1 \\ 0 & 0 & -1 & 1 \\ 0 & -1 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \delta_{\mathrm{a,S3V}} \\ \delta_{\mathrm{a,S5V}} \\ \delta_{\mathrm{a,P5V}} \\ \delta_{\mathrm{a,P1,5V}} \end{bmatrix} = \begin{bmatrix} \delta_{r,\mathrm{S3SV-S5V}} \\ \delta_{r,P\mathrm{1,5V-S3V}} \\ \delta_{r,\mathrm{P1,5V-}P\mathrm{5V}} \\ \delta_{r,\mathrm{P5V-S5V}} \\ \delta_{\mathrm{mod,5V}} \end{bmatrix}, \tag{2}$$

where $\delta_{\mathrm{mod,5V}}$ is known value of AC–DC transfer difference of the calculable standard with $U_N = 5$ V.

Equation (2) can be rewritten as:

$$\mathbf{A} \cdot \boldsymbol{\delta}_a = \boldsymbol{\delta}_r , \tag{3}$$

where $\boldsymbol{\delta}_r$ is column matrix, which contains result of comparisons of two standards, $\boldsymbol{\delta}_r$ is column matrix, which contains sought values of AC–DC transfer differences of the standards.

Equation (3) should be solved for all frequencies independently. Because of possibility of random errors, it is extremely difficult to make the overdetermined system (3) consistent. A least squares method was used to find the solution. In this method, one looks for such a matrix $\boldsymbol{\delta}'_a$, for which sum of squares of differences between measured values of AC–DC transfer differences of compared standards and assumed values is the lowest:

$$\min \sum \left(\boldsymbol{\delta}'_{r,i} - \boldsymbol{\delta}_{r,i}\right)^2 , \tag{4}$$

where δ'_r is sought differences between AC–DC transfer differences of the two compared standards.

Equation (4) can be rewritten as [8]:

$$\min\left(\left(\mathbf{A} \cdot \boldsymbol{\delta}_a - \boldsymbol{\delta}_r\right)^t \left(\mathbf{A} \cdot \boldsymbol{\delta}_a - \boldsymbol{\delta}_r\right)\right). \tag{5}$$

A solution of (5) is column matrix:

$$\delta'_a = \left(\mathbf{A}^t \cdot \mathbf{A}\right)^{-1} \mathbf{A}^t \cdot \boldsymbol{\delta}_r = \mathbf{C} \cdot \boldsymbol{\delta}_r , \tag{6}$$

where δ'_a is estimated corrected value of AC–DC transfer differences of all standards, which took part in comparison.

The standard deviation is represented by difference $\boldsymbol{\delta}'_r$ - $\boldsymbol{\delta}_r$. It was used to estimate uncertainty $u_M(\delta)$ of calculated value of AC – DC transfer differences of UUTs:

$$u_M(\delta) = \sqrt{\frac{\left(\mathbf{A} \cdot \boldsymbol{\delta}_a - \boldsymbol{\delta}_r\right)^t \left(\mathbf{A} \cdot \boldsymbol{\delta}_a - \boldsymbol{\delta}_r\right)}{\nu}} \tag{7}$$

The parameter ν in (7) is the number of degrees of freedom:

$$\nu = n - k , \tag{8}$$

where n is number of rows in **A** matrix, representing the number of comparisons and k is number of columns of **A** matrix, representing the number of standards participating in comparisons.

Assuming that matrices $\boldsymbol{\delta}'_a$ and $\boldsymbol{\delta}_r$ are linearly dependent, it is possible to calculate covariance and estimate the total uncertainty of calculation of AC–DC transfer differences of standards participating in comparison cycle. The covariance matrix can be written as [7]:

$$\mathrm{cov}\left(\boldsymbol{\delta}'_a\right) = \mathbf{C} \cdot \mathrm{cov}\left(\boldsymbol{\delta}_r\right) \cdot \mathbf{C}^t , \tag{9}$$

Input uncertainties of measured AC – DC transfer difference are placed on the main diagonal of cov($\boldsymbol{\delta}_r$) matrix. The total uncertainty of AC–DC transfer difference of standards $\delta'_{a,i}$ can be expressed as:

$$u\left(\delta'_{a,i}\right) = \sqrt{\mathrm{cov}\left(\delta'_{a,i,i}\right)} , \tag{10}$$

where $\delta'_{a,i,i}$ are diagonal elements of matrix δ'_a.

The proposed algorithm was implemented in Microsoft Excel program using VBA macros. It allows calculation of AC–DC transfer differences of any number of standards participating in closed loop comparisons.

4. Summary

The developed management system and database stores the basic metrological parameters and other details of the AC voltage standards, especially their AC-DC transfer differences at different voltages and frequencies. The database also stores previous (historical) values of the AC-DC transfer differences of the standards which enables the observation of time drift of these parameters. The described management system and database is currently under testing.

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