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Implementation of BIPM Calibration Values to Calibration of A Solid State DC Voltage Standard in Laboratory of National Measurement Standard for Electricity and Time – BSN (SNSU – BSN)

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***Abstract* – A method for calibrating a solid state DC voltage standard in Laboratory of National Measurement Standards for Electricity and Time (NMS ET Lab) of National Standardization Agency of Indonesia is presented in this paper. The measurement and its evaluation are carried out based on differential measurement method to the test of solid state DC voltage standard by implementing calibration values from Bureau International des Poids et Mesures (BIPM) at the nominals of 1.018 V and 10 V. Corrections due to temperature, pressure, humidity coeficient and drift are also examined. Based on evaluation result, actual values for the 1.018 V and 10 V of the test were found to be 1.0179897 V and 9.999857 V with their respective measurement uncertainties of 1 µV and 17 µV.**

Keywords – Actual value, Calibration, Differential measurement method, Solid state DC voltage standard, Measurement uncertainty.

I. INTRODUCTION

In 2015, the traceability of DC voltage in Laboratory of National Measurement Standards for Electricity and Time (NMS ET Lab) as part of National Merology Institute of Indonesia under the name of National Standardization Agency of Indonesia (SNSU BSN) has been changed to primary standard of Bureau International des Poids et Mesures (BIPM) through a reference of solid state DC voltage standard (DVS), while before it was tracebled to the institution own primary standard PJVS (Programmable Josephson Voltage Standard) which cannot work properly since 2015. As national metrology institute of Indonesia, NMS ET Lab is responsible to maintain and disseminate the traceable value of DC voltage gotten from BIPM. The dissemination can be carried out by calibrating a test of DVS using a calibrated one as the reference. The measurement method which has been developed and widely used is differential measurement method. It performs a measurement with high accuracy since it measures the voltage difference between the reference and the test by cancelling an offset. However, the measurement is still influenced by some other factors such as temperature, humidity, pressure, drift, etc.

The reference of DVS owned by NMS ET Lab is a standard which have stability nearly 1.8 µV/V/year and have capability to generate voltage at nominal values of 1.018 V and 10 V [1]. The calibration performed by using differential measurement method is applied for both nominal values. Some of correction and uncertainty evaluation for influencing factors are carried out independently, i.e. correction and uncertainty related to environmental condition and the drift of the reference.

II. DESCRIPTION OF THE METHOD

The differential measurement method used to calibrate a DVS in this research adopts the differential measurement method for calibrating the DVS by H. M. A. Mageed [2]. This method has two steps of measurement called by forward measurement and reverse measurement. In forward measurement, the reference of DVS (S) is serially connected with the test of DVS (X) with position and polarity as shown by schematic diagram in Fig. 1. While in reverse measurement, as shown in Fig. 2., polarity of the reference of DVS (S) and the test of DVS (X) are each reversed but in the same position as the position of forward measurement. The voltage difference between the two DVS is measured using a digital voltmeter (DVM). For both forward and reverse measurements, data retrieval is performed ten times manually by using low thermal scanner as switching device.

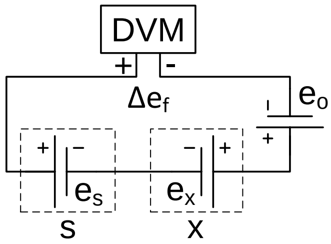


Fig 1. Schematic diagram of forward measurement

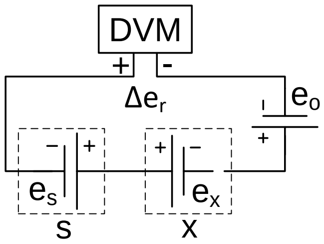


Fig 2. Schematic diagram of reverse measurement

At the forward measurement, based on null balance principle in closed loop circuit, schematic diagram which shown in Fig. 1. results the formulation in Eq. (1) where Δe_f is voltage difference read at DVM, e_s is voltage of the reference of DVS, e_x is voltage of the test of DVS, and e_o is the summation of the EMF's in the total circuit.

$$\Delta e_f = e_s - e_x + e_o \tag{1}$$

While at the reverse measurement, by using the same way, the schematic diagram shown in Fig. 2. derives the formulation shown in Eq. (2) where Δe_r is voltage difference read at DVM.

$$\Delta e_r = -e_s + e_x + e_o \tag{2}$$

Equation (1) and (2) are then subtracted, in order to eliminate the offset and EMF (e_o), resulting formulation in Eq. (3) or simply can be written as Eq. (4) where $e_m = \frac{\Delta e_f - \Delta e_r}{2}$.

$$e_x = e_s - \frac{\Delta e_f - \Delta e_r}{2} \tag{3}$$

$$e_x = e_s - e_m \tag{4}$$

This differential measurement method and formulation in Eq. (4) are implemented to calibrate a test of DVS owned by NMS ET Lab at the nominals of 1.018 V and 10 V.

The DVS (e_s) is affected by environmental condition during measurement, such as temperature, pressure, and humidity, and its value changes over time (drifting). Therefore, in Eq. (4), on the term of e_s need to be added correction factors related to temperature (c_T), pressure (c_P) and humidity (c_H) of environmental condition, as well as drift of the reference of DVS (c_d). While on the term of e_m, the correction factors relates to resolution (c_{res}) and accuracy (c_s) of the DVM. Besides, there is a correction term added to the evaluation, i.e. correction caused by EMF thermal (c_e). Therefore, Eq. (4) can be derived to Eq. (5) which is the final equation used to find actual voltage of the test of DVS (e_x).

$$e_x = (e_s + c_T + c_P + c_H + c_d) - (e_m + c_{res} + c_s) + c_e \tag{5}$$

In this evaluation method, e_s was taken from the reference of DVS calibration certificate issued by BIPM in 2019 which had actual value of 1.017 995 840 V with uncertainty (U_s) of 10 nV and 9.999 860 76 V with uncertainty (U_s) of 100 nV. These uncertainty is estimated to be normally distribution as stated in the BIPM certificate [3]. Therefore, their contribution can be calculate using Eq. (6).

$$u(e_s) = \frac{U_s}{2} \tag{6}$$

Some of correction factors notated by c_P, c_H, c_{res}, c_s and c_e were estimated to have zero value with some amount of uncertainty. As for c_T and c_d, the values were evaluated independently by observing data and calibration history.

Observation on the effect of temperature provided a linear response to DC voltage value of the DVS as shown by Fig. 3. for both nominals of 1.018 V and 10 V. Plotting using linear model approach was implemented on some measurement data of DC voltage (v) in Volt unit against temperature variation (T) in °C unit and resulted linear equations as shown in Eq. (7) and Eq. (8) for both nominals of 1.018 V and 10 V, respectively. c_T was obtained by finding the difference in DC voltage value of the DVS at the measuring temperature in NMS ET Lab with the one at the temperature stated in the calibration certificate by using Eq. (7) or Eq. (8). While temperature uncertainty ($u(c_T)$) was combined of uncertainty due to graph plotting using linear equations (u_{T1}), which the values were obtained from standard error based on Eq. (7) and Eq. (8), and uncertainty due to temperature instability during calibration (u_{T2}). The temperature uncertainty ($u(c_T)$) was mathematically calculated using Eq. (9).

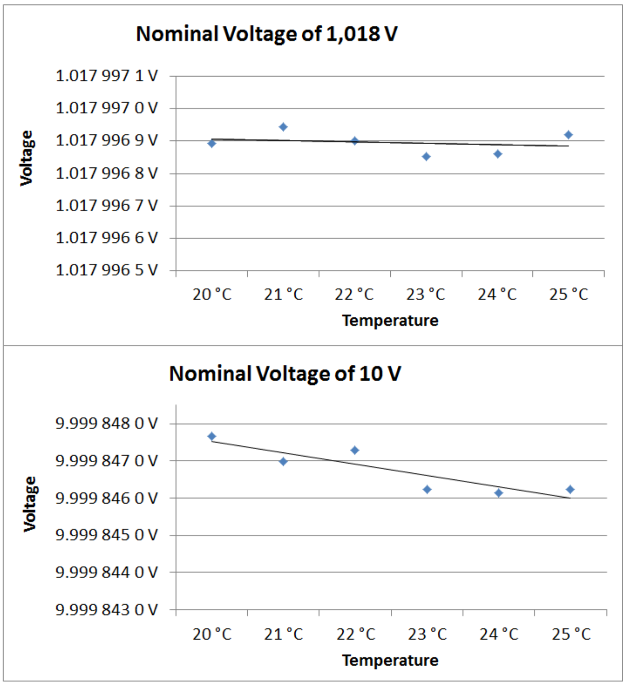


Fig 3. Response of DC voltage value of the DVS against temperature for both nominals of 1.018 V and 10 V

$$v = (-4.75E - 09)T + 1.018 \qquad (7)$$

$$v = (-3.05E - 07)T + 9.999 \qquad (8)$$

$$u(c_T) = \sqrt{u_{T1}^2 + u_{T2}^2} \qquad (9)$$

Different with the two environmental condition factors i.e temperature and humidity which will be explained later, effect of the pressure to DC voltage values of the DVS was calculated using a research results performed by others. A study conducted by Thomas J Witt concluded that the pressure difference gave an error equivalent to coefficient factor up to 0.020 µV/V/hPa [4]. Hence, ini this research, the pressure uncertainty ($u(c_p)$) contribution was found by multiply the coefficient factor with pressure difference measured in BIPM lab when the reference of DVS was calibrated and in NMS ET lab when the reference of DVS was operated as stated in Eq. (10).

$$u(c_p) = \frac{\frac{0.020}{10^6}\times(P_{BIPM}-P_{NMSLab})\times DVS}{\sqrt{3}} \qquad (10)$$

where :
$u(cp)$: pressure uncertainty
p_{BIPM} : pressure level in BIPM Lab
p_{NMSLab} : pressure level in NMS Lab
DVS : nominal value of DVS (either 1,018 V or 10 V)

The another environmental factor estimated having contribution to the measurement uncertainty is humidity. Same with the temperature factor, the humidity correction (c_H) and uncertainty ($u(c_H)$) was observed using data to find the values. The method was also same which is by plotting some humidity data using linear model approach resulting the Eq. (11) and Eq. (12) for nominals of 1.018 V and 10 V, respectively. c_H was estimated by calculating the difference of DC voltage value of DVS at the measuring humidity in NMS ET lab with the one at the humidity stated in the calibration certificate. While for humidity uncertainty ($u(c_H)$), the value was calculate by combining the standard error based on Eq. (11) or Eq. (12) (u_{H1}) and the uncertainty due to NMS ET lab temperature variation range when measurement was performed (u_{H2}) as shown in Eq. (13).

$$v = (1.29E - 08)H + 1.018 \qquad (11)$$

$$v = (-3.03E - 08)H + 10 \qquad (12)$$

$$u(c_H) = \sqrt{u_{H1}^2 + u_{H2}^2} \qquad (13)$$

The correction of the reference of DVS due to drift was estimated based on its calibration history to Programmable Joshepson Voltage Standard KIM (PJVS KIM). Observation of measurement history showed that the change in nominal values gave linear response to time. c_d was determined based on the slope of nominal values against the time change (m_d) and the difference date between the measurement (t) and the last time reference of DVS to be calibrated (t_0), which mathematically shown by Eq. (14). While drift uncertainty ($u(c_d)$) was estimated to be less than or equal to 0.4 µV/V and 0.8 µV/V respectively for the 1.018 V and the 10 V.

$$c_d = m_d \times (t - t_0) \qquad (14)$$

Other factors taken into account of the uncertainty measurement came form the DVM as it is used to read the dc voltage produce by DVS. The factors considered are Experimental Standard Deviation of the Mean (ESDM) ($u(e_m)$), DVM resolution ($u(c_{res})$), and DVM accuracy ($u(c_s)$). Moreover, the cabling system also has error contribution. Different material on two or more cable / terminal lead assembled on electrical system may results an electromotive force (EMF) thermal which affects the electrical performance ($u(c_e)$). All those factors were calculated either using data or the instrument manual specification based on rules of uncertainty evaluation by using type-A and type-B method [5].

The voltage evaluated in this research was DC voltage of a test of DVS at nominals of 1.018 V and 10 V. These DC voltage values were also the value of the reference of DVS own by NMS ET Lab which had been traceable to

SI through the primary standard of BIPM [3].

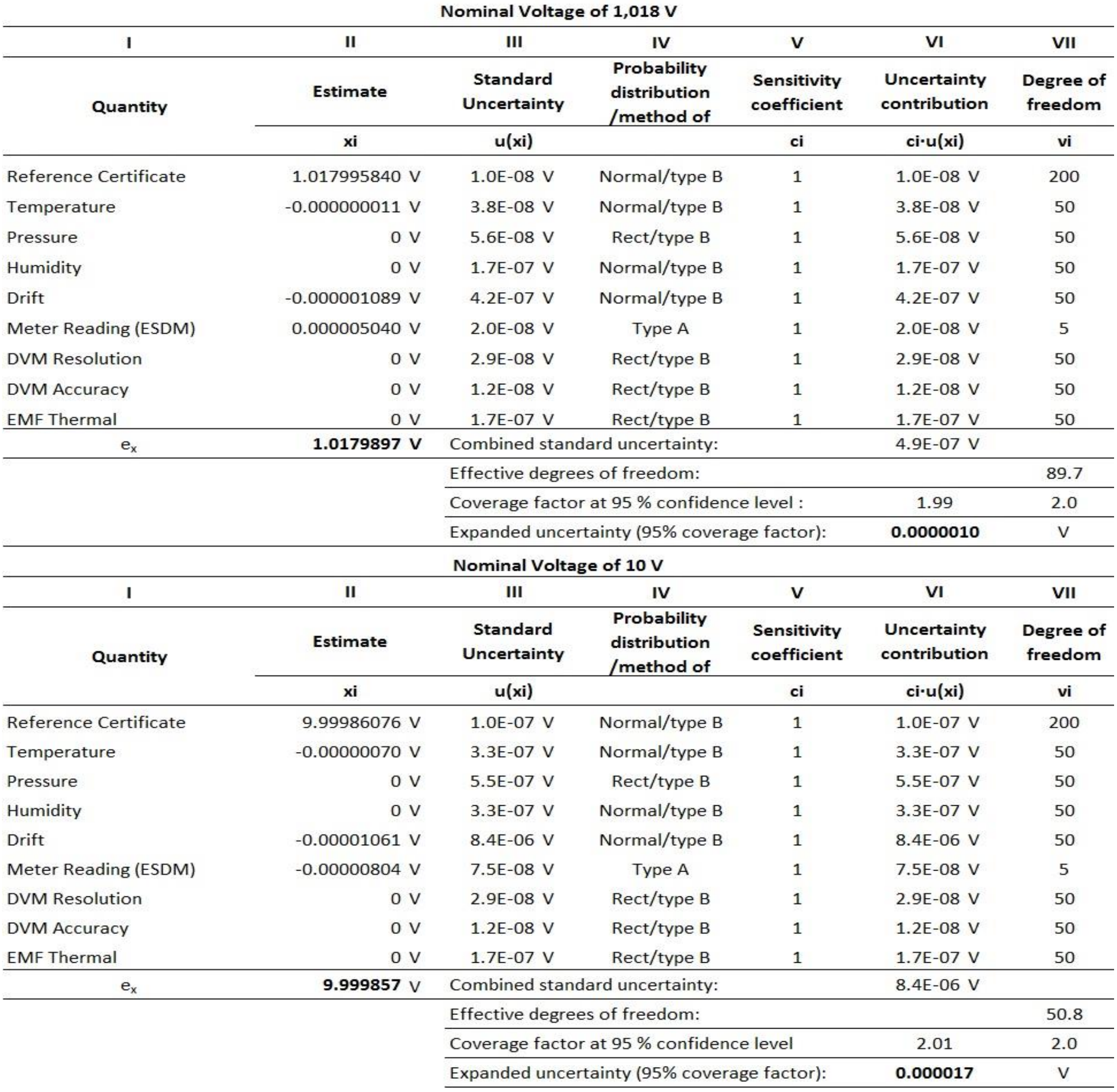
III. RESULTS AND DISCUSSIONS

Measurement was conducted in NMS ET Lab with the environmental conditioning shown in Table 1 Column II. Whereas the environmental conditioning when the reference of DVS calibrated in 2019 at BIPM lab is shown in Table 1 Column III. From temperature, pressure, and humidity conditioning mentioned in Table 1 and by using Eq. (7), (8), (9), (10), (11), (12), and (13), the correction and uncertainty values due to the environment condition (temperature, pressure, and humidity) are obtained as shown in Table 2 Column II and III respectively, both for the nominals of 1.018 V and 10 V. While correction and uncertainty caused by the reference of DVS's drift, also shown in Table 2 Column II and III, was estimated based on the difference of date between the last time reference of DVS was calibrated until the measurement was carried out in August 2020. The other uncertainty budgets such as DVM resolution, DVM accuracy, and EMF thermal were calculated using measurement data at the time of research conducted and data from the instruments specification manual.

Table 1. Environment conditioning during measurement of test of DVS in NMS ET Lab and measurement of reference of DVS in BIPM Lab

I	II	III
Environment Condition	**NMS ET Lab**	**BIPM Lab**
Temperature	(21 - 25) °C	21 °C
Pressure	1002 hPa	997.1 hPa
Humidity	(45 - 65) %RH	44.8 %RH

Table 2. Corrections and Uncertainties



Nominal Voltage of 1,018 V

I	II	III	IV	V	VI	VII
Quantity	**Estimate**	**Standard Uncertainty**	**Probability distribution /method of**	**Sensitivity coefficient**	**Uncertainty contribution**	**Degree of freedom**
	xi	**u(xi)**		**ci**	**ci·u(xi)**	**vi**
Reference Certificate	1.017995840 V	1.0E-08 V	Normal/type B	1	1.0E-08 V	200
Temperature	-0.000000011 V	3.8E-08 V	Normal/type B	1	3.8E-08 V	50
Pressure	0 V	5.6E-08 V	Rect/type B	1	5.6E-08 V	50
Humidity	0 V	1.7E-07 V	Normal/type B	1	1.7E-07 V	50
Drift	-0.000001089 V	4.2E-07 V	Normal/type B	1	4.2E-07 V	50
Meter Reading (ESDM)	0.000005040 V	2.0E-08 V	Type A	1	2.0E-08 V	5
DVM Resolution	0 V	2.9E-08 V	Rect/type B	1	2.9E-08 V	50
DVM Accuracy	0 V	1.2E-08 V	Rect/type B	1	1.2E-08 V	50
EMF Thermal	0 V	1.7E-07 V	Rect/type B	1	1.7E-07 V	50
e_x	**1.0179897 V**	Combined standard uncertainty:			4.9E-07 V	
		Effective degrees of freedom:				89.7
		Coverage factor at 95 % confidence level :			1.99	2.0
		Expanded uncertainty (95% coverage factor):			**0.0000010**	V

Nominal Voltage of 10 V

I	II	III	IV	V	VI	VII
Quantity	**Estimate**	**Standard Uncertainty**	**Probability distribution /method of**	**Sensitivity coefficient**	**Uncertainty contribution**	**Degree of freedom**
	xi	**u(xi)**		**ci**	**ci·u(xi)**	**vi**
Reference Certificate	9.99986076 V	1.0E-07 V	Normal/type B	1	1.0E-07 V	200
Temperature	-0.00000070 V	3.3E-07 V	Normal/type B	1	3.3E-07 V	50
Pressure	0 V	5.5E-07 V	Rect/type B	1	5.5E-07 V	50
Humidity	0 V	3.3E-07 V	Normal/type B	1	3.3E-07 V	50
Drift	-0.00001061 V	8.4E-06 V	Normal/type B	1	8.4E-06 V	50
Meter Reading (ESDM)	-0.00000804 V	7.5E-08 V	Type A	1	7.5E-08 V	5
DVM Resolution	0 V	2.9E-08 V	Rect/type B	1	2.9E-08 V	50
DVM Accuracy	0 V	1.2E-08 V	Rect/type B	1	1.2E-08 V	50
EMF Thermal	0 V	1.7E-07 V	Rect/type B	1	1.7E-07 V	50
e_x	**9.999857** V	Combined standard uncertainty:			8.4E-06 V	
		Effective degrees of freedom:				50.8
		Coverage factor at 95 % confidence level			2.01	2.0
		Expanded uncertainty (95% coverage factor):			**0.000017**	V

Overall, all correction and uncertainty values for each quantity calculated can be seen in Table 2 Column II and III. Column IV shows the the type of distribution for each uncertainty budget. This distribution type was then used to estimated the contribution of each budget uncertainty which is shown in column VI. Based on data of this column, the final uncertainty, which is the expanded uncertainty, was calculated. By using Eq. (5), implementing the e_s gotten from BIPM, and applying the evaluated values shown in Table 2, the actual voltage for the 1.018 V was found to be 1.0179897 V with uncertainty of 1 µV and the actual value for the 10 V was found to be 9.999857 V with uncertainty of 17 µV. The expanded uncertainty was evaluated in August 2020 with confidence level of 95% and coverage factor of 2.

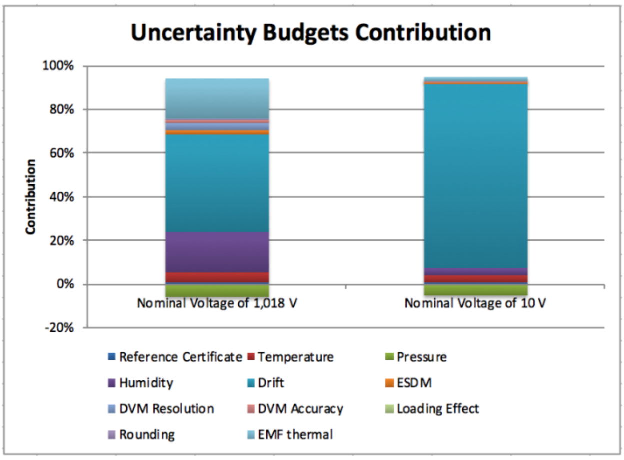


Fig 4. Uncertainty Budgets Contribution

The uncertainty budgets listed in Table 2 are then plotted graphically in order to get an illustration on how much the contribution of each budget. It can be seen in Fig. 4 that the major uncertainty contribution is uncertainty caused by the reference of DVS’s drift, for both nominals of 1.018 V and 10 V. The contribution proportion is almost hitting 50 % for the 1.018 V and 85 % for the 10 V.

IV. CONCLUSIONS AND OUTLOOK

The differential measurement method has been used to calibrate solid state DC voltage standard in Laboratory of National Measurement Standards for Elctricity and Time (NMS ET Lab) - National Standardization Agency of Indonesia (SNSU – BSN) by measuring the EMF in reverse and forward measurement. Based on the evaluation of the uncertainty budget, it is shown that drift of the DVS has a major contribution comparing with other source. The drift can be influenced by internal circuit of DVS and external condition. Therefore a further research can be performed to minimize the drift by characterization the drift of DVS and maintaining the environmental condition.

V. ACKNOWLEDGMENTS

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