Monitoring of AH-11A fused-silica drift in RCM-LIPI and its implementation

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Abstract. We have been monitoring our standard capacitors of AH-1100 fused-silica drift for 8 years to maintain and obtain the actual values of them. One of the advantages of the standard capacitors is to be used as a reference standard for ensuring the performance of an AC high voltage capacitive divider, that is commonly used to assess a voltage level on a power distribution from plants to end-users. This paper describes the monitoring of AH-1100 and its validation performed by comparing to the calibration results of KRISS, the national metrology institute of The Republic of Korea. The AH-1100 drifts is found to be less than 0.0052\,\mu F/F/year, and the comparison results show a good agreement, making the monitoring results have been validated. Moreover, the implementation has been performed with expanded uncertainties of 1.7 \,\textit{f}F for 10 \,pF and about 22 \,\textit{f}F for 100 \,pF.

1. Introduction
A voltage level on a power distribution shall be checked to know that an electrical quality from power stations (plants) to industrial or residential customers (end-users) is effective and also to ensure the continuity of distribution is running well. To assess it, having an AC high voltage value, engineers use an AC high voltage capacitive divider that had been calibrated. A work principle of the capacitive divider is that consider the two capacitors connected in series across an AC voltage. As the two capacitors are in series, the charge Q on them is the same, but voltage across them will be different and related to their capacitance values, as \( V = \frac{Q}{C} \). Therefore, to ensure the AC high voltage capacitive divider has good performance, it must be calibrated and has a metrological traceability to SI through standard capacitors as shown in figure 1.

In Research Center for Metrology LIPI (RCM-LIPI) as National Metrology Institute of Indonesia, has Fused-silica of Andeen-Hagerling 11A (AH-11A) mounted in AH-1100, consisting nominal values of a 10 \,pF and two 100 \,pF (namely 100-C and 100-D), as primary standard of capacitance value [2]. One of the big uncertainty contributions of the capacitance standard using AH-1100/AH-11A is drift, which is evaluated by using manufacturer specification and a year duration since the last calibration date.
Figure 1. Metrological traceability [1].

To improve the uncertainty of the drift, we have been performed monitoring of AH-11A for more than 8 years. The monitoring is performed by using Andeen-Hagerling 2700 (AH-2700) capacitance bridge based on the direct measurement method. The monitoring results are used as a drift correction to estimate each value of AH-11A as well as the each standard error of the estimation is also taken into account to uncertainty evaluation. To validate these monitoring results, we do a comparison with the 2017 calibration values of KRISS-South Korea. Then, we implement AH-11A based on the monitoring results to calibrate capacitance parameter of LCR meter. To validate this implementation, we also do a comparison with the calibration values of SCL-Hong Kong.

2. Monitoring of AH-11A and uncertainty

2.1. Method of monitoring
Monitoring measurements are performed at a test voltage of 15 Vrms and frequency of 1 kHz, which is commonly used for measurement of standard capacitors in the metrology field as well as international comparisons of capacitance are also carried out around this frequency, by direct measurement method using AH-2700. AH-2700 employs a three-terminal measurement configuration that permits high precision measurement and avoids stray capacitance which is very affected on low capacitance measurements [3, 4].
The environmental temperature of laboratory is kept at 23 ± 2°C. Also, the internal temperature of AH-11A fused-silica is controlled by using a temperature-controlled oven that is powered by via AH-1100 frame.
2.2. Monitoring results and its evaluation
The monitoring of drift is taken from November 2009 to January 2018. In figure 2, symbol ‘x’ represents reading values of 10 pF.

![Figure 2. Monitoring results of 10 pF AH-11A.](image)

In this monitoring, we need to evaluate the performance of AH-2700 to know its correction, even if on December 2008 the AH-2700 had been verified only in KRISS but no calibration so we did not have a correction for it. In the direct measurement for measuring a source, the known correction of a calibrated meter shall be necessary. Therefore, to get the correction of AH-2700, we do an extrapolation of reading value data for estimating a reading value in a time when AH-11A was calibrated, and then we obtain the estimated correction of AH-2700 by subtracting the calibration value of KRISS (with symbol ‘▲’ in figure 2) with the estimated reading value (with symbol ‘+’ in figure 2). After the correction of AH-2700 has been known, we implement this correction to all reading values of AH-11A as the corrected monitoring data, which can be used to obtain the estimated value of AH-11A, and it can be seen in figure 2 with symbol ‘+’. Also, from this evaluation, we can obtain the drift of 10 pF, that is 0.0052 μF/F/year within the fitting error of -0.086 μF/F as the error of estimate in uncertainty evaluation.

This monitoring is also performed for both 100-C and 100-D, and the obtained drifts are respectively -0.035 μF/F/year and -0.037 μF/F/year within each the fitting error of 0.018 μF/F and 0.025 μF/F.

2.3. Uncertainty of AH-11A
The uncertainty of AH-11A in each nominal has been updated since the last calibration issued by KRISS. The updated uncertainty contribution of AH-11A consists of its calibration uncertainty of KRISS, extrapolation to mean measurement date, instability of temperature, voltage measurement, and accuracy of AH-2700. The reported expanded uncertainties are stated at a confidence level of 95% with coverage factor k = 2, i.e. 6.1 μF/F for 10 pF, 5.9 μF/F for 100-C, and 5.9 μF/F for 100-D, which improves our uncertainty contribution of AH-11A to be around 1 μF/F.

2.4. Validation of monitoring result
Before these results are implemented, we need to check its validity. These are validated by calculating the normalized error $E_N$ value of the monitoring value to the 2017 calibration results issued by KRISS which are considered as the reference values. Also, $E_N$ use expanded uncertainty with a confidence level of 95%. The obtained $E_N$ are tabulated in table 1.
Table 1. The $E_N$ values based on monitoring results.

| Nominal Value | KRISS MV | RCM-LIPI EV | $E_N$ |
|---------------|----------|-------------|-------|
| 100           | 99,9999  | 100,0000    | 0,0005 |
| 100           | 99,9999  | 100,0000    | 0,0006 |

Although the updated uncertainty is less 1 $\mu$F/F than the current uncertainty contribution of AH-11A that uses 10 times manufacturer specification as a drift contribution, the updated uncertainties have good agreement with KRISS measurements. It means that its monitoring results have been validated.

3. Implementation to LCR meter measurement

3.1. Method of measurement

LCR meter is set at test voltage of 1V, frequency of 1 kHz, and zero DC BIAS voltage (OFF) by direct measurement using capacitors of AH-11A as reference. Each measurement was taken by 5 repeated measurements.

3.2. Measurement results and its evaluation

The measurements of LCR meter reading are taken from February 2017 to January 2018.

Figure 3. LCR reading measurement for 10 pF.

In figure 3, each symbol ‘x’ represents an average correction value of LCR meter for 10 pF AH-11A in each measurement every month. This correction value was obtained by subtracting the estimated value of AH-11A in each measurement date with the meter reading value of LCR meter. For the need of comparison, we need to estimate LCR meter correction to the same time when LCR meter was calibrated by SCL. It aims to minimize the different value of correction measurement between RCM-LIPI and SCL due to time-dependent change of LCR meter. Therefore, to get the estimated correction of LCR meter in the same time with SCL, we do an extrapolation using linear fitting of those correction values, with the estimated drifts of LCR obtained were 0.0002 $\mu$F/year for 10 pF, 0.005 $\mu$F/year for 100-C, and 0.005 $\mu$F/year for 100-D within each its fitting error to be included to uncertainty evaluation of LCR as error of its estimated correction. The difference of test voltage, for monitoring and calibrating LCR, on AH-11A is not included as correction of AH-11A values, since the actual voltage coefficients are not known. So we include an uncertainty based on the manufacturer specification.
Lead(fixture) effect is estimated by measuring the relative change of LCR reading with re-zeroing in every doing a measurement in different time but still same day.

3.3. Validation

Results of multiple measurements by RCM-LIPI or by SCL are compared by calculating the normalized error $E_N$ value where the calibration results of SCL are considered as the reference values in these comparisons. Also, $E_N$ use expanded uncertainty with a confidence level of 95%. The obtained $E_N$ are 0.08, 0.9, and 0.9. These results show that RCM-LIPI’s measurements have good agreement with SCL’s measurements.

4. Conclusions

The monitoring of AH-11A 10 pF and two 100 pF in RCM-LIPI have been doing for 8 years. The obtained drifts are less than -0.0052 μF/F/year within the fitting error of about 0.02 μF/F and the updated expanded uncertainties are less than 6.1 μF/F which it improves the uncertainty contribution of AH-11A to be about 1 μF/F. These have been validated by KRISS measurement. Also, implementation of monitoring results to calibrate LCR meter has been performed with expanded uncertainties of 1.7 fF for 10 pF and about 22 fF for 100 pF, and it has been validated by SCL measurement.

The LCR meter can be used for calibrate the standard capacitors that are to be used as a reference standard for ensuring the performance of an AC high voltage capacitive divider, that is commonly used to assess a voltage level on a power distribution from plants to end-users.

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