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CALIBRATION OF DISSIPATION FACTOR STANDARDS

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Abstract

Dissipation factor (DF) standards obtained by connecting a shielded three-terminal capacitor in series with a shielded resistor have been developed for calibration purposes. An analysis of these DF standards, including precautions in their construction and use, is presented and calibration procedures using the NIST high voltage capacitance bridge is discussed.

Summary

Introduction

The Electricity Division of NIST provides a calibration service for standard capacitors including devices used in standards laboratories and also specialized capacitors used in power industry applications [1]. The dissipation factor (designated as DF) or tangent of the loss angle (tan δ) is expressed as a dimensionless ratio of the loss component to the reactive component of the effective admittance or impedance of the device. During the past few years calibrations have been provided for dissipation factor standards obtained by connecting in series a shielded three-terminal capacitor and a shielded resistor. To support a calibration service, NIST has constructed similar standards. While some of the advantages of three-terminal admittance standards are compromised in such a configuration, moderately high accuracies can be maintained, typically within 50×10^{-6} of the total admittance and within 1×10^{-3} of the dissipation factor value.

This report presents an analysis of such dissipation factor standards, including precautions in their construction and use, and outlines the calibration procedure using the NIST high voltage capacitance bridge. In the analysis, the capacitors and resistors have been assumed to have negligible phase angles. Methods are available to determine true phase angle of capacitors. A three-terminal capacitor with its phase angle measured on a fundamental basis was used as a reference standard for definitive calibration of the dissipation factor standards.

Circuit Analysis of Dissipation Factor Standards

The dissipation factor standard consists of the series-connected three-terminal capacitor and three-terminal conductance shown schematically in Fig. 1. The two devices are directly connected with a coaxial connector and adaptor, without the use of any flexible leads, to ensure repeatable connector capacitance. The following terminal

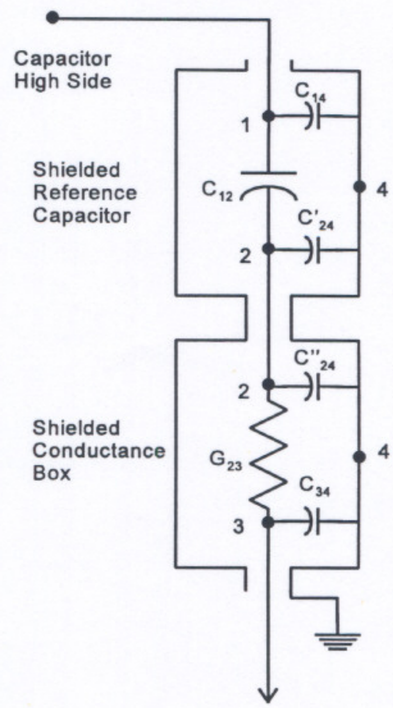

Figure 1.
Dissipation Factor Standard.

labeling applies: (1) input, (2) junction, (3) output, and (4) shield. Besides the two components normally measured in three-terminal networks, C_{12} and G_{23}, there are three ground capacitances, C_{14}, C_{34}, and C_{24}, the latter directly affecting the value of the DF standard. Note that C_{24} comprises the sum of the parallel ground capacitances C'_{24} and C''_{24} of the component boxes and coupling connector.

It is illustrative to obtain the equivalent π-network shown in Fig. 2 through the T-π transformation, which transforms the T-network formed by C_{12}, G_{23}, and C_{24} into Y_{31}, Y_{14}, and having the following component values:

$$Y_{14} = j\omega C_{14} - \omega^2(C_{12}C_{24})/(G_{23} + j\omega(C_{12}+C_{24})) \quad (1)$$

$$Y_{34} = j\omega C_{34} + j\omega C_{34}G_{23}/(G_{23} + j\omega(C_{12}+C_{24})) \quad (2)$$

$$Y_{13} = j\omega C_{12}G_{23}/(G_{23} + j\omega(C_{12}+C_{24})) = j\omega C_{12}(1 - jD)/(1+D^2) \quad (3)$$

where

$$D = \omega(C_{12}+C_{24})/G_{23} \quad (4)$$

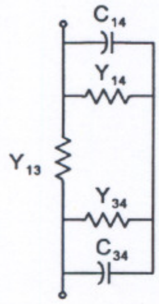

Figure 2.
T-π Transformation of DF Circuit.

is the dissipation factor of the network. Also the effective parallel capacitance C_{13} and G_{13} comprising Y_{13} are

$$C_{13} \equiv C_{12}/(1+D^2) \qquad (5)$$

$$G_{13} = \omega C_{12}D/(1+D^2)\,. \qquad (6)$$

The effective capacitance C_{13} is the original three-terminal capacitance C_{12} reduced by a factor of $(1+D^2)^{-1}$. Fortunately the effect is negligible for small D ($<10^{-3}$) because of the quadratic contribution of D in Eq. (5). As seen from Eq. (4), D is directly influenced by the presence of C_{24} and therefore it has to have a stable value after reassembling the standard. Since ground capacitances in normal three-terminal operation do not affect the measured capacitance, they normally do not have the same stability. It is therefore desirable to keep C_{24} as small as possible relative to C_{12}.

Precautions in Construction and Use of DF Standards

The construction and use of the DF standard should yield accurate and stable values of capacitance and DF as defined by Eqs. (5) and (4), respectively. A highly stable capacitance C_{12} consistent with that of laboratory standards should be used. The capacitor should be gas dielectric, hermetically sealed, with a shielding enclosure that is separate from the protective outside box. A nominal value of 1000 pF for C_{12} will yield a range of DFs between 1×10^{-4} and 1×10^{-2} with resistors that are readily available. The ground capacitances should be small, preferably <50pF. The resistors should be stable (temperature dependence $\leq$10ppm/°C), have negligible phase angle at 50 - 60Hz (time constant $\leq 10^{-7}$ sec), and have such value as to produce DF value within ± 0.01 of the desired nominal value. The resistors should be specially made to match the measured capacitance values C_{12} and C_{24} and produce the desired value according to

$$R_{23} = 1/G_{23} = D/\omega(C_{12}+C_{24}). \qquad (8)$$

The measurement of C_{12} can be accomplished with NIST high voltage capacitance bridge or any other suitable instrument. The measurement of C_{24}, having total value of 35 pF can be determined within ±2 pF with the NIST bridge. Since C_{12} is 1000 pF, the value of the required resistor can be calculated to within $\pm 2\times10^{-3}$.

In summary, the measurement of all component values enables the adjustment of the actual DF value of the standard to be close to the nominal value; such a measurement of component values also provides a crosscheck of the measured value of the entire standard.

Calibration of Dissipation Factor Standards

Typically two instruments are required: a standard whose dissipation value has been established on some fundamental basis and a comparison instrument -- usually an impedance ratio bridge -- for calibrating other DF standards such as those described here. For capacitors it is easiest to use other capacitance devices as fundamental references. One such standard described by Astin[2] consists of a parallel plate capacitor operated in vacuum and having a provision for adjusting plate spacing. In such a capacitor the only significant dissipative mechanics could be associated with surface coatings and contaminants contributing an effective resistance in series with the capacitance. As the plate spacing is increased the relative contribution of the surface effects decreases and the dissipation factor vanishes in the limiting case.

Devices Constructed and Test Results

Having achieved absolute determination of DF in a suitable standard, it is useful to transfer this value to a working-type standard capacitor, typically having a value of 100 pF to 1000 pF with the latter being the preferable value for sensitivity considerations. A set of nine resistor factor boxes were built and tested with a 1000 pF standard gas-filled capacitor to produce nominal dissipation factors of 1×10^{-5}, 2×10^{-5}, 5×10^{-5}, and their decade multiples up to .01. An actual comparison of the DF values obtained from the component values and that from system measurements agreed to well within 1×10^{-3}. The DF values showed similar stabilities over a period of weeks and for temperatures between 17.5°C and 23.0°C.

References

[1] NIST Calibration Services Users Guide 1991, NIST SP-250, October, 1991

[2] A.V. Astin, "Measurement of Relative and True Power Factors of Air Capacitors", J. Res. Nat. Bur. Stand., vol. 21, p. 425, Oct. 1938, RP1138