Strategy for traceability in electrical calibration laboratories using precision digital multimeters

Marcelo Melo da Costa, Thiago Brito Pereira de Souza
Centrais Elétricas do Norte do Brasil S/A, Rod. Arthur Bernardes, 2172 – 66115-000 – Belem / Brazil

marcelo.melo@eletronorte.gov.br, thiago.brito@eletronorte.gov.br

Abstract. This paper presents a strategy developed by Eletrobras Eletronorte Metrology Laboratory for traceability establishment of electrical calibrations, using a precision digital multimeter as reference standard. A method that uses the precision digital multimeter calibration report results at different points from those calibrated is shown and discussed, and some considerations to this method are done.

Keywords: precision digital multimeter; traceability; linearity; interpolation.

1. Introduction

Precision digital multimeters, like 8 ½ digits ones (for example Fluke 8508A and Agilent 3458A), are used as reference standards in many electrical calibration laboratories, due to their key characteristics. In principle, the architecture of a precision multimeter is no different to that of a low cost handheld. Figure 1 shows a block diagram. The key element is the analog to digital converter (ADC), defining the basic capability to take an electrical signal and provide a digital (numeric) representation. ADC accuracy, scale length, resolution, and speed vary tremendously from one instrument design to another. Precision metrology grade multimeters use an integrating ADC where the input signal is effectively compared to an internal reference through charge balance in an integrator circuit. Up to 8.5 digits resolution can be achieved with linearity better than 0.1 ppm of full scale over a scale length of 2x10^8 counts [1].

![Figure 1: Simplified digital multimeter block diagram](image-url)
Precision digital multimeters are calibrated at many discrete points, on their different measurement quantities and ranges, at different frequencies. It is very common that the user or laboratory may use the instrument at point different from those calibrated [3]. At Eletrobras Eletronorte Metrology Laboratory, after calibration and evaluation of calibration report, the precision digital multimeter used as reference standard calibrates the working standards, as Fluke 5522A and Fluke 5720A.

This paper presents the strategy developed by Eletrobras Eletronorte Metrology Laboratory to establish traceability for its working standards and calibration services using precision digital multimeters as its reference standard in voltage, current and resistance measurements, direct current (DC) and alternating current (AC). The strategy is based on the linear characteristics of the precision digital multimeter. First, the requirements for metrological evaluation of the multimeter are presented. After, the method for estimation of correction and uncertainties, based on the calibration report of the multimeter, is discussed. Finally, some conclusions are shown.

2. Precision digital multimeter calibration report and traceability

As the precision digital multimeter is the reference standard, it needs to be calibrated in a regular basis (generally on a 365 days interval). After calibration, it calibrates Laboratory working standards, as multifunction calibrator and precision resistance decades. The working standards are then used to calibrate the workload of the Laboratory.

In order to obtain a reliable set of calibration points, thus a good calibration report, that will be used as basis to trace the results of laboratory calibrations performed by its working standards, the ranges of the precision digital multimeter should be calibrated in a reasonable number of points. In the strategy discussed in this paper, at least five points should be calibrated in each range of the multimeter. For AC quantities, at least three different frequencies for the same voltage or current value should be calibrated.

3. Correction Estimation

In order to establish traceability to the metrological standards, and thus relate the measurement of the precision digital multimeter to SI, a correction, e.g., a compensation for an estimated systematic effect [4], should be assigned to each range of the precision digital multimeter.

Considering the constructive characteristics of the precision digital multimeter, this strategy defined that corrections for values (points) between calibration points should be calculated using linear interpolation between these calibration points. For example, considering Table 1, which shows 200 mV DC range calibration points and their corrections, if it is necessary to assign a correction for 90 mV DC, it would be 1.1 µV/V.

| Calibration point (mV) | Correction (µV/V) |
|------------------------|------------------|
| 20                     | 2.9              |
| 50                     | 2.2              |
| 100                    | 0.8              |
| 150                    | -0.7             |
| 190                    | -1.8             |

The same philosophy can be used when assigning corrections for AC calibration points with different frequencies (low frequency). For an intermediate frequency, the correction should be determined by linear interpolation between calibration points. Considering calibration data from Table 2, the correction for 1 V @ 300 Hz would be 50 µV/V.
Table 2: Corrections for 1 V AC calibration point at different frequencies.

| Calibration point (V) | Correction (µV/V) |
|-----------------------|------------------|
| 1 V @ 60 Hz           | 45               |
| 1 V @ 1 kHz           | 65               |
| 1 V @ 10 kHz          | 90               |

Other remarks should be considered when calculating corrections for values within a calibrated range: (1) When it is necessary to use a value higher than the highest calibration point within the range, its correction should be calculated using linear extrapolation; (2) The range cannot be used for values lower than lowest calibration point (no reliable correction). Figure 2 shows the graph for 200 mV DC range correction defined by this strategy.

![Correction for 200 mV DC range](image)

Figure 2: Correction for 200 mV DC range.

4. Uncertainty Estimate
The uncertainty to be assigned to the intermediate interpolated values can be done in at least two ways. A very conservative approach would be to assign an uncertainty to the interpolated value equal to the larger of the two uncertainties associated with the known values used in the calculation. A less conservative approach would be to interpolate linearly between the uncertainties, just as is done between the interpolated values of the ranges [3].

In this strategy, the uncertainty assigned to the interpolated value is the largest of the two relative uncertainties associated with the calibrations points. For example, considering data from Table 3, the largest uncertainty considering the calibration points 50 mV DC and 100 mV DC is 5.0 µV/V, so every voltage between 50 mV DC and <100 mV DC has an uncertainty, of 5.0 µV/V. This is a conservative estimate.

Table 3: Uncertainties for 200 mV DC range calibration points.

| Calibration point (mV DC) | Uncertainty (µV/V) |
|---------------------------|--------------------|
| 20                        | 7.4                |
| 50                        | 5.0                |
| 100                       | 3.5                |
| 150                       | 2.4                |
| 190                       | 2.2                |

The same philosophy can be used when estimating uncertainty for AC calibration points with different frequencies (low frequency) from those calibrated. For an intermediate frequency, the assigned uncertainty is the largest of the two uncertainties of the calibration points. For example, considering calibration data from Table 4, the uncertainty for 1 V @ 300 Hz should be 78 µV/V.
Table 4: Uncertainties for 1 V AC calibration point at different frequencies.

| Calibration point (V) | Uncertainty (µV/V) |
|-----------------------|--------------------|
| 1 V @ 60 Hz           | 78                 |
| 1 V @ 1 kHz           | 70                 |
| 1 V @ 10 kHz          | 85                 |

Some remarks should be considered when assigning uncertainties to values within a calibrated range of the precision digital multimeter: (1) When it is necessary to assign uncertainty for a value higher than the highest calibration point within the range, this uncertainty will be the same than last interval, e.g., the uncertainty between the highest calibration point and the 2nd highest; (2) The range cannot be used for values lower than lowest calibration point. Figure 3 shows the graph for 200 mV DC range uncertainty due to instruments calibration.

Figure 3: 200 mV DC range uncertainty.

5. Conclusions
This paper presented a strategy for traceability establishment in an electrical calibration laboratory that uses a precision digital multimeter as its reference standard. As the multimeter is a multi-quantity and multi-range instrument, it is calibrated at discrete points, but it is necessary on the regular working of the laboratory to use it at different points from those calibrated, so a method for estimation of correction and uncertainty of these points not calibrated was discussed. This strategy is validated periodically by means for interlaboratory comparisons.

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