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Voltage coefficient evaluation of high voltage arm in a resistive voltage divider using a modified Wheatstone bridge

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Abstract: In a resistive voltage divider we can evaluate the voltage dependence of high-voltage arm equivalent resistance, using a modified Wheatstone bridge. This is a flexible approach that allows the measurement of high-value resistors in different voltage levels. We can obtain the high-voltage arm equivalent resistance all over the operating range of the resistive voltage divider in order to evaluate the voltage coefficient.

Keywords: voltage divider, high-voltage arm, voltage coefficient, Wheatstone bridge

1. INTRODUCTION

A resistive voltage divider (RVD) consists of two basic modules: the high-voltage arm which has high ohmic resistance and is connected straight to the high-voltage direct current (HVDC) circuit; and the low-voltage arm which is connected to the low-voltage instrumentation.

In order to evaluate the voltage coefficient of Inmetro's standard RVD high-voltage arm we used a Modified Wheatstone Bridge (MWB) to perform the resistance measurements by a collaboration's project between High Voltage Metrology Laboratory (Lamat/Inmetro) and Calibration in Electrical Metrology Laboratory (Lacel/Inmetro).

2. MOTIVATION

The main objective of a RVD metrological characterization is the determination of its scale factor (SF). This factor defines a ratio between the high voltage input (V_{HV}) and its low voltage output (V_{LV}) compatible in magnitude to the instrumentation.

SF can be calculated by the ratio between V_{HV} and V_{LV}. Moreover, the SF can be obtained by the ratio between the high-voltage arm equivalent resistance (R_{HVeq}) and the low-voltage arm resistance (R_{LV}), according to equation (1).

$$SF = \frac{V_{HV}}{V_{LV}} = \left(\frac{R_{HVeq}}{R_{LV}} + 1 \right) \qquad (1)$$

The RVD high-voltage arm is usually constructed with a large number of resistors connected in series. The value of R_{HVeq} may change depending on the applied voltage level, due to factors such as heating and leakage current [1], so the voltage dependence curve of the high-voltage arm must be known. On the other hand R_{LV} suffers a much smaller influence of such effects, since the output voltage level has a small range of variation. The contribution of the high-voltage arm, therefore, is dominant when evaluating the linearity of the RVD scale factor [2].

3. METHODOLOGY

In order to evaluate the SF linearity throughout the entire RVD operation range the resistors set voltage coefficient (RVC) must be known [3]. RVC evaluation of the RVD high-voltage arm is an essential step in establishing its traceability.

To obtain RVC it is necessary to measure the resistance values in different voltage levels. We used the modified Wheatstone bridge since is an established method already implemented at Inmetro, and also used by other national metrology institutes (NMIs), such as VSL/Netherlands, NIST/Usa, PTB/Germany, among others.

3.1 High-voltage arm of the RVD

Lamat/Inmetro has a standard RVD with a rated voltage of 150 kV (positive and negative polarities), with direct traceability to the National Measurement Institute of Australia (NMIA), providing a total uncertainty not exceeding 50 µV/V to HVDC calibration services.

The high-voltage arm has an equivalent resistance R_{HVeq} = 225 MΩ consisting of a 150 shielded resistors series association. Each element has a nominal resistance of 1.5 MΩ, and is fixed in the central column in a helical arrangement. The resistive elements were selected and grouped in order to minimize the voltage and temperature coefficients [2]. The voltage drop at each resistor is around 1.0 kV for an input voltage of 150 kV. The terminals of each resistor are accessible between the outer shield housings. Figure 1(a) shows the schematic diagram of the RVD.

3.2 Modified Wheatstone Bridge

The Modified Wheatstone bridge allows the measurement of high-value resistors [4]. Lacel/Inmetro uses this methodology with quite satisfactory results.

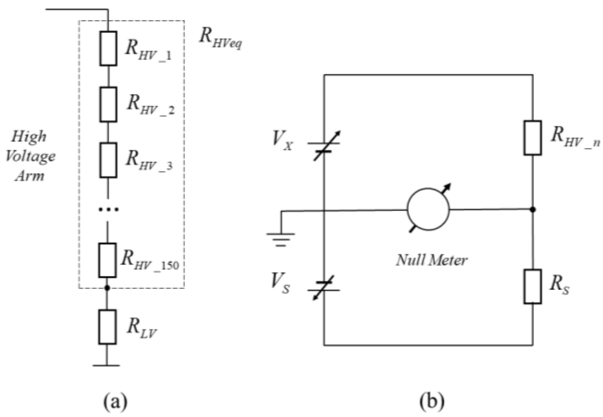

Figure 1. Schematic Diagrams (a) RVD (b) MWB

The measuring system consists of two DC sources (calibrators) connected in each of the two bridge arms, a reference resistor, the resistor under test, and a null detector. This approach provides wide range for both ratios and applied voltage. Null detection is also flexible and can be performed by a high-resolution electrometer or voltmeter [5]. Figure 1(b) presents the schematic diagram of the modified Wheatstone bridge. In balance condition, the resistor under test value can be calculated by equation (2).

$$R_{HV\_n} = R_S \frac{V_X}{V_S} \qquad (2)$$

4. MEASUREMENTS

At first, the high-voltage arm equivalent resistance R_{HVeq} was measured at a low-voltage, by connecting the 150 resistors set to the R_{HV_n} position, as shown in figure 1(b), and applying 990 V, i.e., 6.6 V in each of the 150 resistors. A total of 50 readings were taken in direct and reverse current direction during a period of 5 hours.

Then each one of the 150 resistors were measured at 990 V. They were individually connected to the R_{HV_n} position (see figure 1(b)). At least 10 readings were performed in each current direction during a minimum period of 1 hour.

This measurement process is time-consuming. Therefore, a sample of 18 resistors was selected to estimate the R_{HVeq} voltage dependence curve uncertainty in intermediate points. Measurements were taken at 330 and 660 V for each resistor in the sample.

All the measurements were performed inside a Faraday cage to minimize electromagnetic interference. The temperature was monitored, and the total temperature dispersion during the whole measurement process did not exceed 0.5 °C, in order to minimize temperature coefficient effects [3]. The full setup was automated, including voltage generation, change of polarities, reading of the null meter, as well as the thermo hygrometer reading.

5. RESULTS AND DISCUSSIONS

Table 1 presents the numerical results for the equivalent resistance in the high-voltage arm (R_{Hveq}) and its uncertainty (U_{Req}), determined at each voltage level. We assumed the resulting voltage dependence curve of R_{Hveq} has linear behavior, as shown in figure 2.

Table 1

Applied Voltage (V)	R_{HVeq} (MΩ)	U_{Req} (μΩ/Ω)
6.6	225.004508	6.0
330	225.001115	24.9
660	224.997652	9.9
990	224.994190	7.7

The R_{HVeq} value obtained by the measurements at 6.6 V (entire set) along with the equivalent resistance of the 150 resistors measured individually at 990 V were taken as reference points for the voltage dependence curve definition. The dispersion of 18 sample resistance values was used to calculate the intermediate results uncertainty.

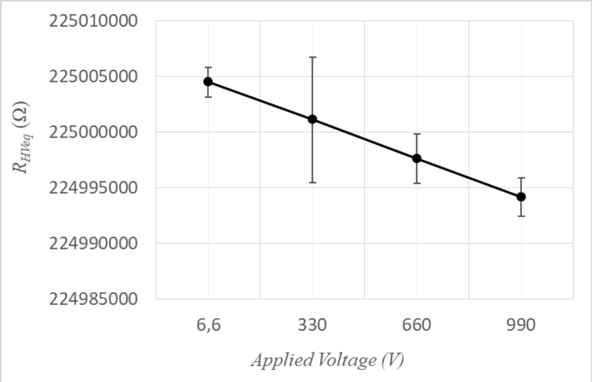

Figure 2. R_{HVeq} voltage dependence curve

From the R_{HVeq} values, we calculated the high-voltage arm RVC of the RVD as α = -10.5 Ω/V ± 4.5 Ω/V.

6. CONCLUSION

The high-voltage arm RVC of Inmetro's standard RVD was obtained using a MWB. R_{HVeq} for different voltage levels was obtained as well. An uncertainty component due to the temperature coefficient was added to the uncertainty budget. Further investigations are necessary to use the results for SF calculation. To make the Inmetro's standard RVD scale factor traceable by low voltage standards, investigations as temperature coefficient of RVD and leakage current in the high-voltage arm are needed. Moreover, measurement of low voltage arm resistance need to be carried out.

Nevertheless, the presented result is a relevant step in the Lamat/Inmetro HVDC traceability project, which aims to establish an uninterrupted traceability chain between low and high voltage within the institution.

7. REFERENCES

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