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Traceability of 100 kV *dc* high voltage measurements at NPL, India

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Recently, *dc* high voltage laboratory has been established at National Physical Laboratory, India (NPLI) for calibration of high voltage (HV) equipment. High Voltage resistive divider is the heart of *dc* high voltage measurements. The traceability of HV measurements is directly related to divider's traceability to Josphson voltage standard, which is the primary standard of *dc* voltage. In-house calibration of HV divider using traceable *dc* calibrator and 10 V reference standard has been discussed in the present paper. The overall uncertainty of measurement has also been calculated and is about 10 ppm.

Keywords: Calibration, High voltage measurement, Traceability
IPC Code:G12B13/00

1 Introduction

National Physical Laboratory, New Delhi, has recently established a new *dc* high voltage calibration facility up to 100 kV which is traceable to primary standard of *dc* voltage. Traceability is a very important characteristic of calibration. Traceability is an unbroken chain of comparisons from the measurement being made to a recognized national, legal standard. A traceable calibration is achieved when each instrument and standard, in a hierarchy stretching back to the national standard, is itself properly calibrated, and the results properly documented. The documentation provides the information needed to show that all the calibrations in the chain of calibrations were properly performed.

There is a considerable demand of *dc* high voltage equipment calibration from different power sectors, state electricity boards (SEBs), calibration laboratories and X-ray and TV industries etc. Earlier, we were using a high voltage resistive divider that was traceable to PTB, Germany, with an uncertainty of 0.02% at ratio 100000/10. We have made it now traceable to primary standard of *dc* voltage i.e. Josephson voltage standard that has been established at NPLI. After achieving traceability from Josephson Voltage Standard , the combined system uncertainty has improved considerably.

2 Methodology

Figs 1 and 2 show the methodology adopted to achieve traceability of *dc* high voltage measurements. The *dc* calibrator's 1000 V is first made traceable to calibrated 10 V *dc* reference standard (traceable to Josephson Standard) using a calibrated low voltage *dc* divider (Ref. 2) at 1000 V as shown in Fig. 1. The voltage of the calibrator is adjusted in order to produce a null in null-detector. Since the 1000 V divider's ratio as well as exact value of 10 V *dc* reference standard is known, exact value of calibrator's 1000 V can be ascertained.

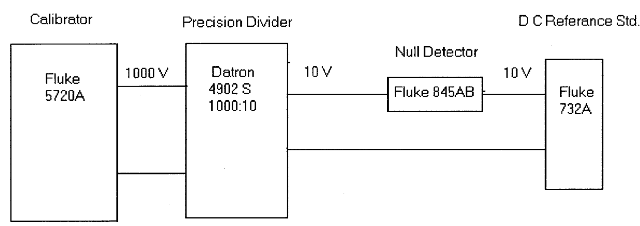

Fig. 1— Schematic diagram for calibration of calibrator

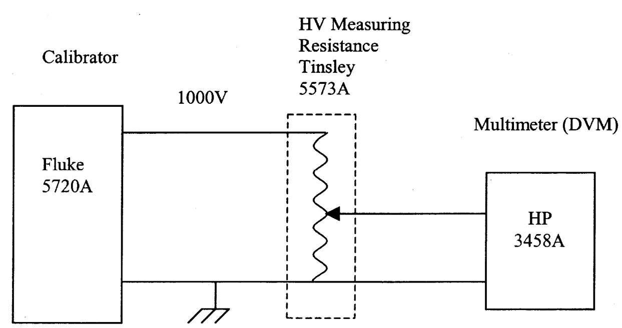

Fig. 2—Schematic diagram for calibration of HV measuring resistance

This known 1000 V from calibrator is applied to HV measuring resistance (UUC) as shown in Fig. 2. The value indicated at the divider's lower end (10 V and 1000 V tap) is measured on the calibrated DVM after HV simulation with input impedance of DVM kept at 10 MΩ for 1000 V tap (except at the marked value at 1 kV) and 100 GΩ for 10 V tap. The voltage between 10 and 100 kV was applied to HV measuring resistance in 5 kV steps with 15 min continuous warm-up time at set value. This time interval was obtained by stability studies of the divider in a separate experiment as discussed below.

Further, the high voltage characteristics of 100 kV divider with the 10,000:1 and 100:1 output, especially its linearity, was established between 10 and 100 kV by comparison with a stable 300 kV divider under well defined measurements conditions at Physikalish-Technishe Bundesanstalt (PTB) (Ref. 1) during its first calibration.

3 Stability Study of Resistive Divider

High voltage was applied to the HV divider and the output voltage measured at the lower end of the divider using a precision DVM. The changes in output voltage were observed with respect to time. The experiment was conducted over a period of one hour and a plot was made for output voltage versus time. This study was conducted at different levels of high voltage and a typical plot at 50 kV is shown in Fig. 3. This plot shows the warm up time of divider that is approximately 15 min in order to get a stable ratio. This technique is similar to the one used by PTB, Germany, to calibrate their HV dividers (private comm). The HV source (Fug, Germany) is traceable to National Standards maintained at NPL and is of known stability (≈ 50 ppm) and it is energized by well-stabilized and regulated power line having variations better than 1%.

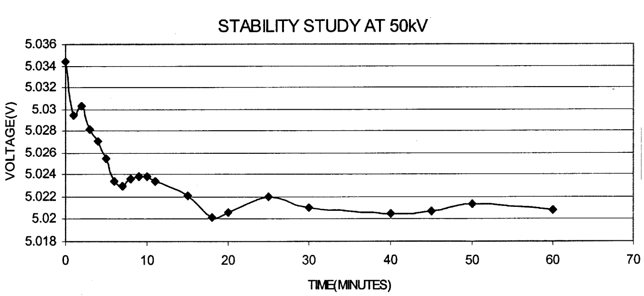

Fig. 3— Stability studies of ratio of HV divider

Table 1 —Experimental results of calibration at the various tapings

High voltage applied (kV)	Ratio	
	10V Tap	1000V Tap
1	9990.4	98.756*
		118.604
10	9990.5	118.606
20	9990.6	118.606
30	9990.6	118.606
40	9990.8	118.606
50	9990.9	118.607
60	9991.1	118.608
70	9991.1	118.607
80	9991.3	118.608
90	9991.4	118.608
100	9991.6	118.607

*… DVM impedance at 100 GΩ

4 Results

Table 1 shows the typical experimental results of calibration at the various tapings of the measuring resistance (HV divider) and Table 2 shows the uncertainty budget calculated as per GUM document (Ref. 4). Based on the above measurements, we can calibrate (Ref. 3) various HV equipment like dividers, probes, kV meters and power supplies etc., received from various industries.

Rapid advances in technology-communications, the Internet, tele-marketing, travel, etc. are accelerating the globalization of the world's market places. To facilitate this globalization, the Committee on International Weights and Measures (CIPM) has produced a Mutual Recognition Arrangement (MRA). This arrangement, signed into existence in Oct 1999, has the following objectives:

To establish the degree of equivalence of national measurement standards maintained by the National Metrology Institutes (NMIs). To provide for the mutual recognition of calibration and measurement certificates issued by the NMIs. To provide governments and other parties with a secure technical foundation for wider agreements regarding measurements that relate to international trade, commerce, and regulatory affairs.

In order to establish the degree of equivalence between national measurements standards, NPLI, the NMI of India, participates in various Key Comparisons (KCs) conducted by the Consultative Committee of CIPM and also arranges the International Peer-Review of it's various facilities by international technical experts. International peer-review of *dc* high voltage facility was conducted by PTB experts and consequently, we have three

Table 2— Uncertainty budget

Quantity	Estimated x_i (ppm)	Standard Uncertainty u (x_i) (ppm)	Probability Distribution /method of evalution(A,B)	Sensitivity coefficient c_i	Uncertainty Contribution u_i (R) (ppm)	Degree of Freedom ν_i
u_1 (DC calibrator)	3.5	1. 75	Normal, B	1	1. 75	∞
u_2 (Multimeter)	3	1.5	Normal, B	1	1.5	∞
u_3 (DC Ref. Standard)	1.5	0.75	Normal, B	1	0.75	∞
u_4 (DC Divider)	0.2	0.12	Rectangular, B	1	0.12	∞
u_5 (Detector)	0.03	0.02	Rectangular, B	1	0.02	∞
u6 (Repeatability)	U (x)	3.427	Normal, A	1	3.427	4
Expanded Uncertainty			k = 2.31		u (R)=9.70	ν_{eff} =9

Table 3—CMC Table
Calibration and Measurement Capabilities
Electricity and Magnetism, India, NPLI (National Physical Laboratory of India)

Calibration or measurement service			Measurand level or range			Measurement Conditions/Independent variable		Expanded Uncertainty				
Quantity	Instrument or artifact	Instrument type or method	Minimum value	Maximum value	Units	Parameters	Specifications	Value	Units	Coverage factors	Level of Confidence	Is the Expanded Uncertainty a relative one?
High *dc* voltage: sources	*dc* kilovolt source	Reference divider, digital voltmeter	1	100	kV	Current	> 0.5 mA	50	μV/V	2	95%	Yes
High *dc* voltage: meters	*dc* kilovolt meters	Reference divider, digital voltmeter	1	100	kV	Current	< 10 mA	100	μV/V	2	95%	Yes
High *dc* voltage ratios	High voltage resistive divider	Comparison	1000:1	10,0000:1	V/V	Voltage	1kV to 100kV	100	μV/V	2	95%	Yes

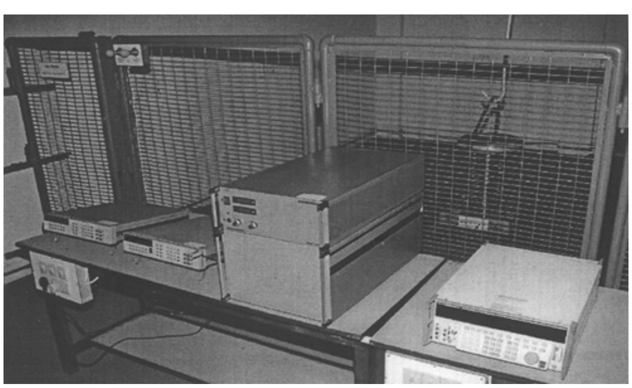

Fig. 4— DC High Voltage Calibration Laboratory

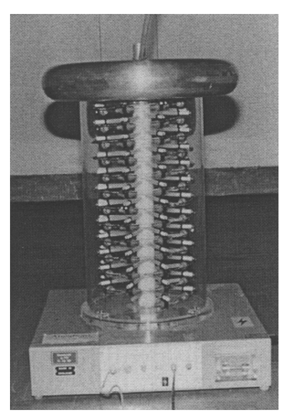

Fig. 5—High Voltage Standard Resistive Divider

calibration and measurement capabilities (CMCs) on the internet in Appendix C of BIPM website (www.bipm.org.) with uncertainties ranging from 50 to 100 ppm. The CMC table is reproduced below (Table 3) showing the uncertainties for various measurement capabilities. The photographs of this new *dc* High Voltage Calibration facility are shown in Figs 4 and 5.

5 Conclusion

We have successfully carried out the calibration of our HV measuring resistance in-house with traceability to Josephson voltage standards. The uncertainty of measurement has also improved from 0.02 to 0.001%.

Acknowledgement

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