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Enhancement of AC high voltage measurements' uncertainty using a high voltage divider calibration method

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Abstract. This paper discusses enhancing of the measurements' uncertainty for AC high voltage up to 100 kV. This is achieved by using a high voltage divider calibration method. Voltage measurements have been carried out at the Egyptian national institute for standards (NIS), using a high voltage measuring system (Phenix-KVM100), that consists of a high voltage divider and a voltage display. The voltage divider and display have been calibrated in low and high voltage ranges. Reference standard digital voltmeter and a multifunction calibrator have been used to calibrate the KVM100 for achieving accurate and traceable results. All calibrations have been performed automatically using Laboratory Virtual Instrument Engineering Workbench (LabVIEW) programs specially designed for this task. Uncertainty budget has been evaluated to get the measurements' expanded uncertainties.

Keywords: AC high voltage, voltage divider calibration method, automation, enhanced uncertainty

1 Introduction

In electric power systems, high voltages and currents accurate measurements are very important in power flow checking [1–3]. These measurements are done using different calibration methods such as series resistance microammeter method, generating voltmeter and sphere gaps method and resistance potential divider method. However, a high voltage divider calibration method remains the most common method to measure and calibrate the high voltage output of high voltage sources [4].

At the present time, programmable instruments are extensively used in metrological laboratories. Consequently, powerful automation is necessary to calibrate such instruments. The necessity of obtaining appropriate professional software is persisting due to the fact that commercial automation programs are not suitable for the highly accurate measurements [5,6].

In this paper, the traceability to the International System of Units (SI) for 100 kV AC high voltage measurements is achieved using a high voltage divider calibration method. This is provided by calibrating the FLUKE 8508A high precision digital voltmeter (DVM) via a reference standard FLUKE 5720A calibrator which is traceable to the SI units. To calibrate the Phenix High Voltage (KVM100) display with a full range of 100 kV AC, the DVM is placed in parallel with it. The Fluke 5720A calibrator is used to produce 1 kV at the high voltage side of the Phenix divider, while the voltage at the low voltage side is measured via the calibrated FLUKE 8508A DVM; this is to accurately determine the Phenix divider turn's ratio. A Haefely Trench 100 kV AC source of one/two stages (PZT100) [7] is used to supply the high voltage side of the KVM100 with a voltage up to 100 kV at 50 Hz, the Phenix display reading as well as the DVM readings are recorded. The measurements of the DVM are then multiplied by the determined turn's ratio to find out the corresponding high voltage AC readings. IEC 60060 international standard series [8] which regulate high voltage techniques and equipment greater than 1 kV are considered. LabVIEW programs have been particularly constructed to automatically perform all the calibrations in this work. LabVIEW software is a powerful and flexible instrumentation software system which contains two main components: the front panel and the block diagram. It also contains a comprehensive library for data collection, analysis, presentation and storage. The software has the facility to automatically calculate the estimated repeatability in the measurements, store the data, record, and report the calibration results [9,10]. The sources of uncertainty for all calibrations have been estimated and taken into account in the automatic programs.

2 KVM100 divider calibration

The nominal voltage turn's ratio of the Phenix-KVM100 is 10000:1. In order to acquire its actual value, several methods might be applied. The binary step up method [11] is one of the methods that bases on a sequence of steps to accurately determine the used resistors' values. One other

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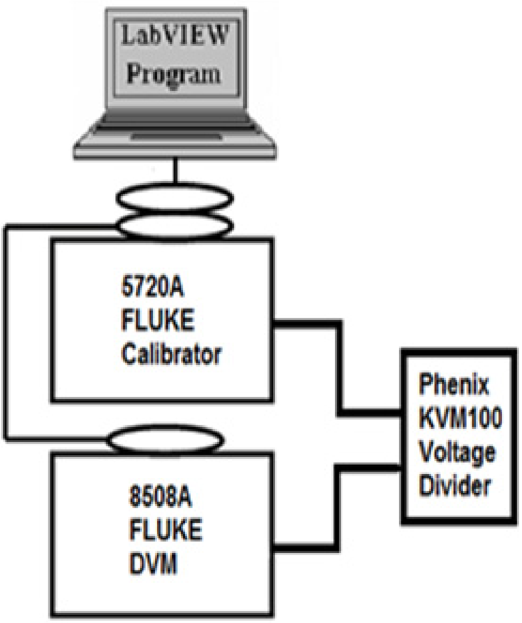

Fig. 1. Schematic diagram of Phenix-KVM100 divider automatic calibration.

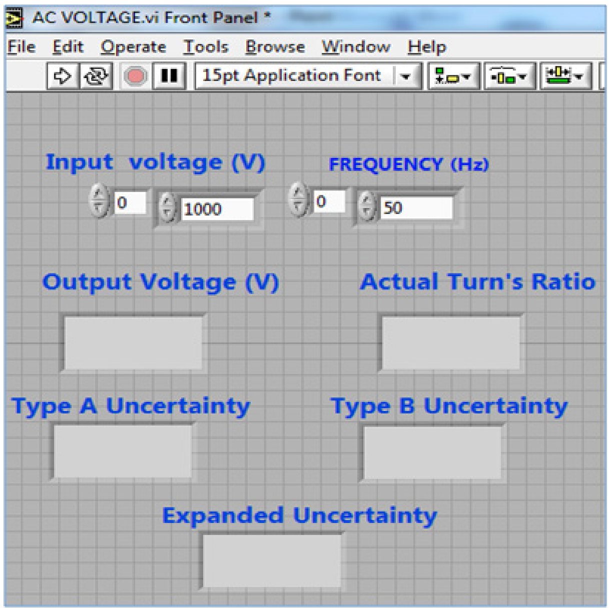

Fig. 2. Front panel of LabVIEW program for Phenix-KVM100 divider automatic calibration.

method is to use a turns' ratio meter that can obtain the turn's ratio of the voltage divider at different test voltages.

In this work the reference standard calibrator and digital voltmeter have been automatically controlled to find out the turn's ratio of the KVM100. The traceable FLUKE 5720A calibrator supplies the high voltage side of the KVM100 with 1 kV AC, 50 Hz voltage signals; while the DVM is measuring the output voltage from the low voltage side terminals. The turns' ratio is determined by dividing the calibrator's actual value by the DVM corresponding actual one. The actual reading of the calibrator input as well as the DVM reading is the average of fifty readings.

This calibration was automatically achieved using a LabVIEW program that has been designed for this task. Fifty readings have been automatically taken and transferred by the software to a prepared excel sheet. Figure 1 shows the schematic diagram of Phenix-KVM100 divider automatic calibration while Figure 2 illustrates the software front panel of this calibration. The turn's ratio has been automatically calculated and listed in the front panel by the software.

The temperature and relative humidity of the calibration laboratory have been adjusted and fairly controlled to (23 ± 1) °C and $(50\% \pm 10\%)$ RH, respectively.

3 Calibration of the KVM100 display

The Phenix KVM100 consists of a high voltage divider and $4\,\frac{1}{2}$digit LCD display (with both low and high voltage ranges). Its two main parts are connected via connecting cables. The HP 3458A DVM is used as a traceable reference standard to automatically calibrate the KVM100 display using another LabVIEW program that prepared for this calibration. In this calibration the DVM reading is the average of fifty readings recorded by the software and automatically stored in the prepared excel sheet.

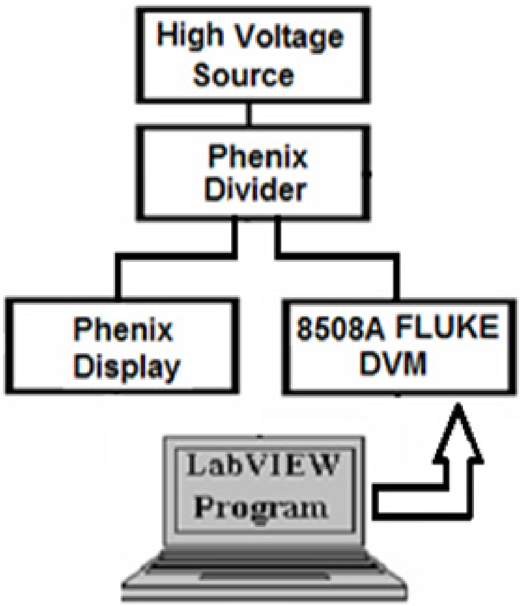

Fig. 3. Schematic diagram of Phenix display automatic calibration.

The Phenix KVM100 divider is connected to the Haefely Trench (PZT100) AC high voltage source. Figure 3 illustrates the KVM100 Phenix display automatic calibration schematic diagram. By applying the actual values of the estimated turn's ratio, the actual values of the input high voltages from 2 kV to 18 kV (at the low range) and from 20 kV up to 100 kV (at the high voltage range) have been acquired.

Table 1. Uncertainty budget of Phenix KVM100 divider calibration for 1 kV (50 Hz).

Uncertainty sources	Standard uncertainty	Probability distribution	Divider	C_i	Uncertainty contribution
Repeatability of the DVM readings	9.48 E-3 V	Normal	1	1	9.48 E-03 V
Calibration certificate of the calibrator	0.30 E-3 V	Normal	1	1	0.30 E-3 V
Calibration certificate of the DVM	2.50 E-2 V	Normal	1	1	2.50 E-2 V
Calibrator drift since last calibration	0.01 V	Rectangular	$\sqrt{3}$	1	5.8 E-3
DVM drift since last calibration	0.06 V	Rectangular	$\sqrt{3}$	1	0.03 V
Combined standard uncertainty					±4.06 E-2 V
Effective degrees of freedom					∞
Expanded Uncertainty at confidence level 95%, ($k = 2$)					±8.12 E-2 V

Table 2. Uncertainty budget of Phenix KVM100 display calibration for 100 kV (50 Hz).

Uncertainty sources	Standard uncertainty	Probability distribution	Divider	C_i	Uncertainty contribution
Repeatability of the Phenix readings	4.72 V	Normal	1	1	4.72 V
Resolution of the Phenix readings	5.00 V	Rectangular	$\sqrt{3}$	1	2.89 V
calibration certificate of the DVM	2.50 E-2 V	Normal	1	1	2.50 E-2 V
DVM drift since last calibration	0.06 V	Rectangular	$\sqrt{3}$	1	0.03 V
Combined standard uncertainty					±5.53 V
Effective degrees of freedom					∞
Expanded Uncertainty at confidence level 95%, ($k = 2$)					±11.06 V

4 Results and analysis

The calibration results' uncertainties of the Phenix-KVM100 divider and display have been investigated. The uncertainty is defined as the range of error of a measurement within which the true value of the measurand is estimated to lie within a stated level of confidence [12].

Type A and Type B evaluations are the two approaches to estimate the uncertainty sources. Type A evaluations of standard uncertainty components are founded on normal distributions, while type B evaluations are founded on a suitable chosen distributions. The combined standard uncertainty equals to the Root Sum Square (RSS), of all the uncertainty contributions [12,13].

The uncertainty budgets have been evaluated for all calibrations. All components of the combined standard uncertainty (Type A and Type B) have been taken into consideration in the designed LabVIEW automatic calibration programs. The evaluated uncertainty budget for the Phenix-KVM100 divider's calibration includes the repeatability of fifty DVM readings as a Type A uncertainty and Type B components as well.

In this calibration, the uncertainty values stated in the calibration certificate of the calibrator and the DVM adding to their drifts since last calibration are the Type B components.

For the Phenix-KVM100 display's calibration, the Phenix readings' repeatability is calculated as Type A uncertainty while its resolution, the uncertainty in the DVM calibration certificate and drift since last calibration are estimated as Type B components.

The expanded uncertainty has been evaluated by using the coverage factor $k = 2$, to give a level of confidence of approximately 95% according to the ISO GUM [13,14]. The uncertainty budget for calibrating the Phenix KVM100 divider at 1 kV–50 Hz is listed in Table 1. The divider calibration proves that the actual value of the turn's ratio is 99 696.988697 with $\pm 8.12 \times 10^{-2}$ V expanded uncertainty. Table 2 deals with the uncertainty budget for display calibration at AC 100 kV–50 Hz (as an example).

Table 3. Actual values of the low range voltages from 2 to 18 kV, 50 Hz and their expanded uncertainties.

Nominal values (kV)	Measured values (kV)	Actual values (kV)	± Expanded uncertainty (V)	± Expanded uncertainty (%)
2	2.028	2.047	1.024	0.05
4	3.960	3.984	1.594	0.04
6	6.014	6.054	2.422	0.04
8	8.005	8.057	2.417	0.03
10	10.006	10.014	3.004	0.03
12	12.008	12.290	3.687	0.03
14	14.022	13.981	4.194	0.03
16	16.041	15.985	4.796	0.03
18	18.033	17.985	5.396	0.03

Tables 3 and 4 illustrate the actual values of the Phenix readings for its low and high ranges respectively associated with their expanded uncertainties. Figure 4 shows the actual values of the Phenix readings versus their percentage uncertainties for the low range measurements, while Figure 5 shows it for the high range.

There is a degradation of the percentage uncertainties with respect to the voltage ranges to reach 0.01% from 80 kV to 100 kV. At lower voltage ranges the percentage expanded uncertainties are slightly higher but they do not exceed 0.05%. That is shown clearly in Figure 5, where very small uncertainty values have been achieved for higher AC voltage measurements, while higher uncertainty

Table 4. Actual values of the high range voltages from 20 to 100 kV, 50 Hz and their expanded uncertainties.

Nominal values (kV)	Measured values (kV)	Actual values (kV)	± Expanded uncertainty (V)	± Expanded uncertainty (%)
20	20.025	20.035	6.011	0.03
30	29.984	29.981	8.994	0.03
40	39.980	39.951	11.985	0.03
50	50.130	50.052	10.010	0.02
60	60.040	59.947	11.989	0.02
70	70.030	69.334	13.867	0.02
80	80.070	79.952	7.995	0.01
90	90.250	90.080	9.008	0.01
100	100.190	99.958	9.996	0.01

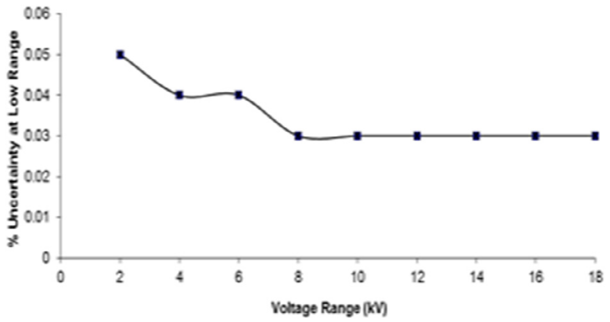

Fig. 4. Actual values of the Phenix-KVM100 Readings and corresponding expanded uncertainties for low range.

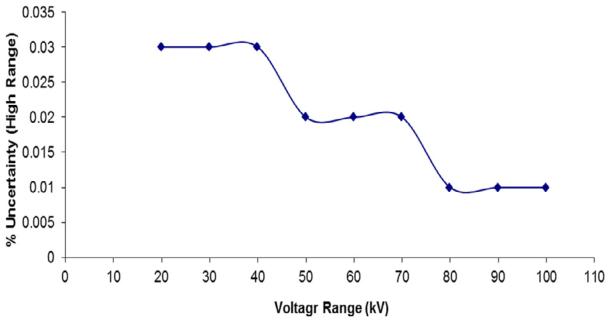

Fig. 5. Actual values of the Phenix-KVM100 Readings and corresponding expanded uncertainties for high range.

values appeared at the low ranges using this calibration technique.

Although some other factors might affect the uncertainty budget of Phenix KVM100 calibration including divider temperature rise, Corona discharge and power coefficient these factors still have neglected effect compared to the dominant one owed to the repeatability of the Phenix display readings consideration.

5 Conclusion

A high voltage divider calibration technique has been used to enhance the uncertainty of high voltage AC measurements up to 100 kV at NIS. Traceability of the AC high voltage measurements to SI units has been obtained as well. The KVM100 divider and display have been automatically calibrated using specially constructed LabVIEW programs. Applying the actual turn's ratio, the actual values of the Phenix-KVM100 readings as well as calibration uncertainties have been automatically calculated and stored in the prepared excel sheets. The percentage expanded uncertainties for the voltage ranges from 2 kV to 100 kV do not exceed 0.05% of their values. These percentage expanded uncertainties have been decreased to 0.01% at the higher ranges. Improved uncertainty results have been attained using this automatic calibration methodology.

References

1. G.J. Fitz Patrick, E.D. Simmon, High voltage and current metrology at NIST. Precision measurements of the past, present, and the future, in *Annual Report Conference on Electrical Insulation and Dielectric Phenomena, 2001*, pp. 277–280
2. C.K. Dwivedi, M.B. Daigavane, Multi-purpose low cost DC high voltage generator (60 kV output), using Cockcroft-Walton voltage multiplier circuit, Int. J. Sci. Technol. Educ. Res. **2**, 109–119 (2011)
3. Guizhen Wang, QiutingJia, Gang Cao, A measurement method of high DC voltage, in *Proc. of the Electrical Electronics Engineering Symposium (EEESYM), 2012*
4. E. Kuffel, W.S. Zaengl, J. Kuffel, Measurement of high voltages, in *High Voltage Engineering Fundamentals* (Butterworth-Heinemann, 2nd ed., 2000), pp. 77–195
5. U. Poliano, G.C. Bosco, M. Lanzillotti, Generalized automatic system for AC/DC transfer AC voltage and AC current measurements, IEEE Trans. Instrum. Meas. **55**, 1747–1751 (2006)
6. R. Flegar, T. Tasic, Software validation in measurement & testing, *Proc. of the INCOLAB Conference, Prague, 4 December 2003*
7. http://www.haefely.com/pdf/LL_KIT.pdf
8. https://webstore.iec.ch/preview/info_iec60060-3%7Bed1.0%7Den.pdf
9. H.M.A. Mageed, A.M. El-Rifaie, Electrical Metrology Applications of LabVIEW Software, J. Software Eng. Appl. **6**(3), 113–120 (2013)
10. H.M.A. Mageed, A.M. El-Rifaie, Electrical quantities in terms of the international system of units, in *Proc. World Congress on Engineering 2013 Conference, 3-5 July, London, UK*
11. Sang Hwa Lee, Kwang Min Yu Jeon Hong Kang, MunSeog Kim, Kyu Tae Kim, A Josephson voltage-traceable DC high-voltage divider evaluation using the binary step-up method, Measurement **45**, 488–492 (2012)
12. Fluke Corporation, *Calibration: philosophy in practice* (Legal Department, Everett, WA 98206-9090, 2nd ed., May 1994)
13. *The expression of uncertainty and confidence in measurement* (United Kingdom Accreditation Service, NA-MAS, M 3003, January 2007)
14. *Uncertainty guide to the expression of uncertainty in measurement* (JCGM 100, 2008)