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Methodology for Obtaining Actual Dividing Ratios of High Voltage Capacitive Dividers

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***Abstract*— The AC high voltage is normally measured with high voltage divider which presents the standard dividing ratio between the unknown high voltage to the recognized standard low voltage. To achieve the traceability of the AC high voltage dividing ratios up to 200 kV at the Egyptian National Institute of Standards (NIS), a methodology using two series identical traceable 100 pF with 100 kV maximum AC voltage capacitors have been determined. In order to realize the actual dividing ratios up to 200 kV, the two capacitors have been connected in series to perform as a 200 kV capacitive voltage divider unit. Their actual dividing ratios have been achieved up to 100 kV AC root mean square (rms) voltage at 50 Hz by calibrating two series capacitors the via a traceable 100 kV high voltage reference standard measuring system. To extend the ranges of the actual dividing ratios at AC high voltages from 100 kV to 200 kV, an empirical formula has been concluded. Expanded uncertainties for all attained actual dividing ratios' measurements and calculations have been considered.**

***Index Terms*— AC high voltage measuring systems, high voltage dividers, dividing ratio, empirical formula, measurement uncertainty.**

I. INTRODUCTION

THE AC high voltage is commonly measured with high voltage dividers with high input capacitance. The dividing ratios of the high voltage dividers are obtained from the capacitance ratios between the outputs and inputs at working AC voltages [1]-[3]. Traceability of measurement results to the international system of units (SI) with specified uncertainties for the dividing ratios of high voltage dividers can be realized by the accurate determination of the actual dividing ratios as functions of voltages [4]-[10]. Capacitive high voltage divider contains a capacitor on the high voltage arm and another one on the low voltage arm. Minor parasitic resistances with insignificant influences are comprised in the capacitive dividers [11]. To establish the traceability of the high voltage measurements at NIS to the SI units, a methodology using two traceable similar 100 pF, 100 kV capacitors has been implemented. In this methodology, two capacitors perform as two identical AC high voltage capacitive dividers. To get the actual dividing ratios up to 100 kV for two series capacitors, they have been calibrated together via a traceable high voltage measuring reference standard (Phenix-kVM100).

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Traceability AC voltage measurements up to 100 kV for Phenix-kVM100 was previously achieved at NIS [12]. Traceability for each capacitor dividing ratio has been obtained by calibrating them individually via the Phenix-kVM100 reference standard with recent calibration certificates. To provide the actual dividing ratio for AC voltage measurements from 100 kV to 200 kV, an empirical formula has been demonstrated based on the concept that when the doubled voltage is applied to two similar pre-calibrated voltage dividers, this voltage is equally divided among the two dividers [13]. In this work, AC rms voltages at 50 Hz are applied. Environmental conditions of the calibration laboratory have been controlled to the temperature of (23 ± 1) °C and relative humidity of (50 ± 10%). The expanded uncertainties for all dividing ratios' measurements have been taken into consideration with 95% confidence level according to the ISO GUM [14]-[16].

II. ESTABLISHED SET-UP

The first step in this methodology is individually calibrating each capacitor via the traceable Phenix-kVM100 reference standard up to 100 kV rms AC at 50 Hz. Then, a set-up has been established by connecting the two identical capacitors in series to calibrate them via the traceable divider of the Phenix-kVM100. Haefely Trench high voltage AC source (PZT-100) is used to supply the high voltage side in this set-up. Two series capacitors act as a 200 kV capacitive voltage divider. They have been connected in parallel with the traceable divider of the Phenix-kVM100 reference standard. The display of the Phenix-kVM100 records the high voltages while the low voltages appear on a HP-3458A traceable digital voltmeter (DVM) at the same time. Figure 1 illustrates the block diagram for the established set-up.

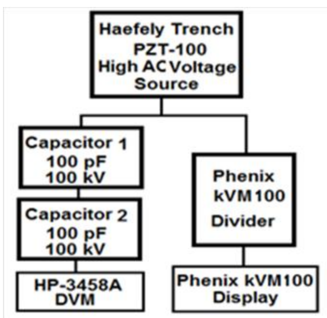

Fig. 1, Block diagram for the established set-up

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Each capacitive divider of the two identical capacitors used in this work consists of two capacitors one on the high voltage side (C) and the other one is on the low voltage side (c). As a consequence of calibrating each capacitor via the Phenix-KVM100, actual high voltages (V_{C1} ,V_{C2}) across C1 and C2 (from 10 kV to 100 kV with 10 kV step) have been acquired via the display of the Phenix-kVM100 reference standard while corresponding actual low voltages (V_{c1} ,V_{c2}) across c1 and c2 have been measured by the HP-3458A traceable DVM. Dividing ratios ɼ(C1) and ɼ(C2) have been obtained according to equations (1) and (2). Equation (3) presents the relation between the total voltage V_T (voltages across the two series capacitors) and each capacitor voltage. Dividing ratio of both capacitors together is $ɼ_s$(C1+C2) as existing in equation (4). An empirical formula for investigating the dividing ratios for voltages greater than 100 kV has been derived. Dividing ratios for voltages from 100 kV to 200 kV with 20kV step have been calculated by applying equation (6).

$$ɼ\,(C1) = \frac{V_{C1}}{V_{c1}} \tag{1}$$

$$ɼ\,(C2) = \frac{V_{C2}}{V_{c2}} \tag{2}$$

$$V_T = V_{C1} + V_{C2} - V_{c2} \tag{3}$$

$$ɼ_s(C1 + C2) = \frac{V_T}{V_{c1}} \tag{4}$$

$$V_{c1} \times ɼ_s(C1 + C2)_{atV_T} = V_{c1} \times ɼ(C1)_{atV_{C1}} + (V_{c2} \times ɼ(C2)_{atV_{C2}}) - V_{c2} \tag{5}$$

$$ɼ_s(C1 + C2)_{atV_T} = ɼ(C1)_{atV_{C1}} + (\frac{V_{c2}}{V_{c1}} \times ɼ(C2)_{atV_{C2}}) - \frac{V_{c2}}{V_{c1}} \tag{6}$$

The uncertainty budget in getting the actual dividing ratio of each capacitor and the ratio of the two series capacitors up to 100 kV includes the uncertainty from the HP-3458A DMM and the Phenix-kVM100 reference divider calibration certificates. To get the uncertainty of the two series capacitors $ɼ_s$(C1+C2) from 100 kV up to 200 kV according to GUM the following equations are obtained:

Let $\frac{V_{c2}}{V_{c1}} = Z$

$$Z = \frac{ɼ_s(C1 + C2)_{atV_T} - ɼ(C1)_{atV_{C1}}}{ɼ(C2)_{atV_{C2}} - 1} \tag{7}$$

$$U_{ɼ(C1+C2)}{}^2 = (\frac{dɼ(C1 + C2)}{dɼ(C1)})^2 \times U_{ɼ(C1)}{}^2 + (\frac{dɼ(C1 + C2)}{dɼ(C2)})^2 \times U_{ɼ(C2)}{}^2 + (\frac{dɼ(C1 + C2)}{dZ})^2 \times U_{(Z)}{}^2 \tag{8}$$

$$\frac{dɼ(C1 + C2)}{dɼ(C1)} = 1 \tag{9}$$

$$\frac{dɼ(C1 + C2)}{dɼ(C2)} = Z \tag{10}$$

$$\frac{dɼ(C1 + C2)}{dZ} = ɼ(C2)_{atV_{C2}} - 1 \tag{11}$$

$$U_{ɼ_s(C1+C2)}{}^2 = Uɼ(C1)_{atV_{C1}}{}^2 + Z^2 \times Uɼ(C2)_{atV_{C2}}{}^2 + (ɼ(C2)_{atV_{C2}} - 1)^2 \times U_{(Z)}{}^2 \tag{12}$$

III. Results and Discussions

The actual dividing ratios of capacitor1 and capacitor2 associated with their expanded uncertainties are listed in Table I and Table II respectively while actual dividing ratios and uncertainties of two series capacitors from 10 kV up to 100 kV (rms@50Hz) are listed in Table III. The ratios from 100 kV to 200 kV have been calculated from the empirical formula and their expanded uncertainties have been evaluated from equation 12. Table IV lists the dividing ratios at the double AC rms voltages (120 kV, 140 kV, 160 kV, 180 kV, and 200 kV) at 50 Hz and their expanded uncertainties as well.

TABLE I
ACTUAL DIVIDING RATIO OF CAPACITOR1

Actual Value		Ratio V/V	Expanded Uncertainty, ±(V)
High voltage (kV)	Low Voltage (V)		
9.964	14.3684	693 : 1	3.19
19.961	29.2940	681 : 1	6.67
30.224	44.0885	686 : 1	9.87
39.986	58.5509	683 : 1	11.06
50.038	73.3719	682 : 1	11.06
60.432	88.6153	682 : 1	11.06
69.444	102.7554	676 : 1	11.06
79.964	116.4621	687 : 1	11.06
89.917	131.0947	686 : 1	11.06
99.960	145.9740	685 : 1	11.06

TABLE II
ACTUAL DIVIDING RATIO OF CAPACITOR2

Actual Value		Ratio V/V	Expanded Uncertainty, ±(V)
High voltage (kV)	Low Voltage (V)		
10.487	15.2857	686 : 1	3.19
20.003	29.1307	687 : 1	6.67
30.019	43.7413	686 : 1	9.87
40.032	58.3016	687 : 1	11.06
49.986	72.8885	686 : 1	11.06
59.964	87.4988	685 : 1	11.06
69.383	102.1815	679 : 1	11.06
79.872	116.5622	685 : 1	11.06
89.996	129.8861	693 : 1	11.06
100.294	144.3178	695 : 1	11.06

TABLE III
ACTUAL DIVIDING RATIOS OF THE TWO SERIES CAPACITORS UP TO 100 KV (RMS@50HZ)

Actual Value		Ratio V/V	Expanded Uncertainty,	
High voltage (kV)	Low Voltage (V)		±(V)	%
10.210	7.2280	1413 : 1	3.19	0.03
20.154	14.2309	1416 : 1	6.67	0.03
30.038	21.2089	1416 : 1	9.87	0.03
40.010	28.3266	1412 : 1	11.06	0.03
49.953	35.3721	1412 : 1	11.06	0.02
60.042	42.4671	1414 : 1	11.06	0.02
69.349	49.4441	1403 : 1	11.06	0.02
80.014	56.6239	1413 : 1	11.06	0.01
90.018	63.7765	1411 : 1	11.06	0.01
99.477	70.0164	1421 : 1	11.06	0.01

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TABLE IV
ACTUAL DIVIDING RATIOS OF THE TWO SERIES CAPACITORS FROM 100 KV TO 200 KV (RMS@50HZ)

Nominal Value (kV)	Ratio V/V	Expanded Uncertainty,	
		±(V)	%
120	1415:1	14.02	0.01
140	1424:1	14.02	0.01
160	1420:1	14.02	0.01
180	1401:1	14.02	0.01
200	1396:1	14.02	0.01

The average dividing ratio of the two capacitors equals to 1413:1 at AC voltages up to 100 kV whole it equals to 1412.5:1 after applying the empirical formula at the AC voltages up to 200 kV. This means that the empirical formula results are in good agreement with the experimental results with approximately the same average dividing ratio for the AC voltages. Moreover, the percentage expanded uncertainties associated with the dividing ratio results are very small with respect to their corresponding high AC voltage ranges up to 200 kV. Ranges of uncertainties are from 0.01% to 0.03% of the voltages.

IV. CONCLUSIONS

In this work two similar 100 pF, 100 kV capacitors act as two identical AC high voltage capacitive dividers. Traceable Phenix-kVM100 has been used as a reference standard to calibrate the two capacitors. Series connection for both capacitors has been performed to get their actual dividing ratio up to 200 kV AC. In this set-up, the actual dividing ratio up to 100 kV has been experimentally acquired. To get the dividing ratio from 100 kV to 200 kV, an empirical formula has been mathematically derived. The derivation of the empirical formula is based on the criterion that when the doubled voltage is applied to the two pre-calibrated series similar divider; the input voltage is approximately equally divided across the two dividers. It is concluded that the empirical formula results are compatible with the experimental results with more or less equal average dividing ratio for the AC voltages up to 200 kV. Uncertainty components associated with the actual dividing ratios results have been taken into account. Small expanded uncertainties associated with the dividing ratio results are obtained. The results show that this methodology for obtaining actual dividing ratios of capacitive dividers is reliable.

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