IMPROVEMENT AND CONFIRMATION OF A NEW AUTOMATIC SYSTEM FOR AC-DC CALIBRATION AT NIS, EGYPT

Mamdouh M. Halawa, Ahmed Hussein
National Institute for Standards (NIS)
Tersa St., Giza, El-Ahram, Box: 136, Code: 12211, Egypt
Tel. 0020105402742, Fax. 002023867451, E-mail: Mamdouh_halawa@yahoo.com

Abstract*:* The recent Improvements in AC–DC transfer capabilities at National Institute for Standards (NIS), Egypt, include an automated AC–DC transfer comparator system with international confirmation of the results through bilateral intercomparison with NPL, England. The system can be used to measure additional characteristics of thermoelements and operates over a frequency range from 20 Hz to 100 kHz for a voltage level from 0.5 V to 1 kV. The results of bilateral intercomparison including the proficiency test of the new system are reported. The expanded uncertainty assigned to the NIS working standard is given and its components are briefly discussed. The results show that the agreement between the two laboratories is better than the expected uncertainties

1. INTRODUCTION

AC voltage and current are most accurately measured by using thermal converters that compare the heating effects of the unknown alternating signals to those produced by a known DC signal. The devices used to make this comparison are thermal voltage converters (TVCs) and thermal current converters (TCCs) [1]. They usually consist of a heater structure, which carries alternately the AC and DC signals and one or more thermocouples spaced along the heater to monitor its temperature. By applying AC and both polarities of DC in a timed sequence, and measuring the thermocouple output, one can use the conventional definition of AC-DC difference, δ, as:

$$\delta = \frac{V_{ac} - V_{dc}}{V_{dc}} \qquad (1)$$

where V_{dc} is that value of DC which, when applied with positive and negative polarities, produces the same mean response as the rms AC quantity V_{ac}.

AC–DC transfer standards are maintained by National Institute for Standards (NIS), Egypt to provide a primary link between AC and DC quantities. Those standards are traceable to the National Institute for Standards and Technology (NIST), US. The needs for lower uncertainty in calibrations of TVCs and TCCs motivated the NIS to upgrade its standards and facilities. The automated system described here overcomes the deficiencies of the manual test methods at NIS. Using the control software, the operator makes the range and frequency selection and receives an automated test report at the end of each measurement. The system covers a frequency range from 20 Hz to 100 kHz for the voltage range from 0.5 V to 1000 V. For all voltages, the goal was to reassessment of the total measurement uncertainties in this area. In addition to performing AC-DC difference tests, the system can be used to calibrate AC voltage sources or high sensitivity digital AC voltmeters. The system produces statistical information about the AC-DC transfer difference measurements as well as some novel measurements such as linearity constants, time constants, and response time. This uncertainty level obtained by the new system is sufficient to satisfy the present requirements at NIS.

2. SYSTEM HARDWARE

The block diagram of the automatic calibration system is shown in Fig. 1. The system consists of a programmable source, Wavetek 9100, for both AC and DC volts, two TVCs (one standard, the other the unknown), two digital multimeters (DMMs), HP 3458A, with resolution of 10 nV to monitor the output of each TVC, a PC with a GP-IB controller and a printer for printing the test report. The measuring sequence adopted in this system is AC, DC+, DC-, AC [2]. The readings from DMMs are used to compute some characteristics (linearity, time constant …etc.) and the AC-DC difference of the test devices. The complete comparison procedure, including all data and statistical analysis, is performed without any interruption.

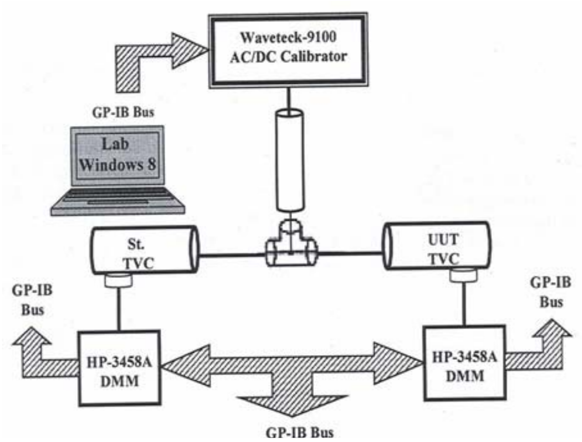
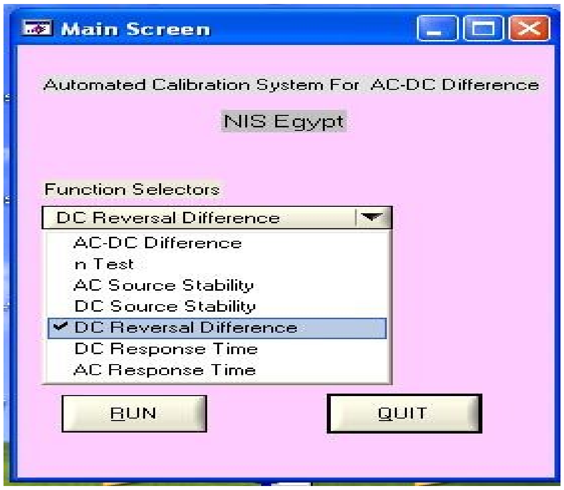


Fig. 1: Block Diagram of the Automatic System

3. SYSTEM SOFTWARE

The software, written in C++ and using the Lab Windows program, provides flexibility for the system. The selected function is entered into the program via the screen shown in Fig. 2. The operator chooses either the AC-DC difference measurements or the tests of determining the TVC characteristics. The test frequencies and the nominal test voltages are entered in the main screen.

The remaining entries of the measurement process set the device warming-up time, the number of measurements per cycle, the test sequences used in the determination of the AC-DC difference and the averaging time of the DMM. The test results are printed and/or saved on disk.



Function Selectors: DC Reversal Difference

Fig. 2: Test Parameters Selection Screen

4. AC-DC DIFFERENCE TEST PROCEDURE

The response of the TVCs is defined by [3]:

$$E = KV^{n} \tag{2}$$

where *E* is the output EMF of the Thermal Element (TE) of the TVC, *V* is the voltage applied, *K* is a constant and varies somewhat with large changes in heater current and *n* is usually 1.6 to 1.9 at rated heater current but it is nearly constant over a narrow range where nearly equal AC and DC values are compared. The factors *K* and *n* are parameters characteristic of the particular TVC. The relationship between a small change in TE heater voltage (Δ*V*) and the corresponding change in output (Δ*E*) is expressed as:

$$\frac{\Delta V}{V} = \frac{\Delta E}{n.E} \tag{3}$$

The AC-DC difference, basically, is defined as [3]:

$$\delta = \frac{V_a - V_d}{V_d}, \tag{4}$$

where V_d is the DC voltage which when reversed produces the same mean output voltage as V_a, i.e.

$$V_d = \frac{V_+ + V_-}{2} \tag{5}$$

After completing the sequence of four steps by applying successively AC, DC+, DC- and AC voltages to minimize the effects of drift in the TVCs outputs, the AC-DC difference of the test TVC, δ_t, is evaluated as:

$$\delta_t - \delta_s = \frac{(E_{as} - E_{ds})}{n_s \cdot E_{ds}} - \frac{(E_{at} - E_{dt})}{n_t \cdot E_{dt}} \tag{6}$$

where δ_s is the AC-DC transfer difference of the standard TVC, E_{as} and E_{at} are output electro motive forces (EMFs) of the standard and the unknown TVCs for AC test voltage, respectively. The mean EMF values for forward and reverse DC test voltages are taken as E_{ds} and E_{dt}, respectively. As the preceding equations show, the value of the exponent *n* for the TVC must be known. The exponent varies with applied voltage, and its variation can be determined by performing "n-test". This test will be discussed in the next section.

A test run consists of 20 determinations of AC-DC difference for the same voltage and frequency then the average of the 20 determinations is calculated and printed on the system's printer. An important additional option is involved in the AC-DC difference program to avoid application of voltages great enough to damage the TEs. The applied value must be less than 110 percent of the rated voltage of the TVC. If the applied value is outside this condition, the program should to be aborted immediately.

5. OTHER SYSTEM CAPABILITIES

5.1 The "*n* Test"

One important test that is readily performed automatically is that of determining a Thermal Element's "*n*" characteristic. Typical results for a 5 mA, Ballantine type TVC which was tested with a nominal 10 V range resistor are plotted in Fig. 3.

The characteristic *n* is given by [3]:

$$n = \frac{\Delta E \ / \ E}{\Delta V \ / V} \qquad (7)$$

Where ΔE is the measured change in output EMF for small changes in the applied voltage ΔV, V is the nominal test voltage for the TVC and E is the measured EMF at the nominal test voltage.

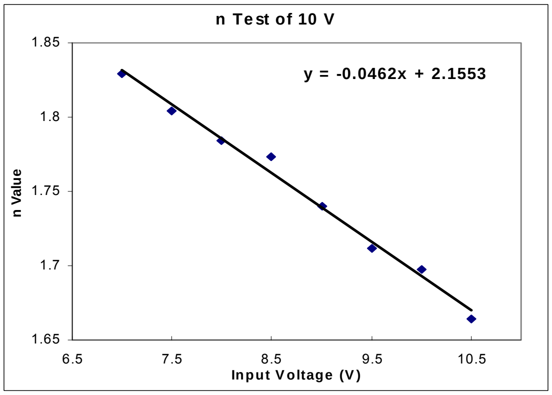


Fig. 3: n Test for a 10V TVC

The value of ΔV was programmed to be ± 0.5 percent of nominal test voltage V. Sufficient time was allowed after each voltage change (≈ 40 seconds) for TE to reach its final EMF value. According to the results shown in Fig 4, the TVC was tested from 70 to 110 percent of the rated voltage. The total elapsed time to obtain the eight data points was about 1 hour. Each value of *n* is computed as the average of 2 determinations (+0.5 % and -0.5 %) at any given voltage. The computed equation for *n* as a function of applied voltage was plotted. The *n* value at the rated voltage of the 5 mA Ballantine type 10 V TVC, for example, was 1.698. The value of *n* at the rated voltage is either stored in the computer's data file or is typed by the operator into the computer program for the TE at the starting of an AC-DC difference measurements.

5.2 DC Reversal Difference (*DCRD*)

The DC reversal difference (*DCRD*) of the TE could readily measured and is defined as the difference in applied values of both polarities of DC voltage required to produce an equal output EMF of the test TE [4]. The value of *DCRD* was actually measured as:

$$DCRD = \frac{2 \ (E_+ - E_-)}{n \ (E_+ + E_-)} \qquad (8)$$

where E_+ and E_- are the TE output EMFs with equal DC+ and DC- voltages applied, and *n* was given as in (7). The program was designed to determine the *DCRD* as a function of the applied voltage. Typical results for a 5 mA, Ballantine type TVC which was tested with a nominal 100 V range resistor are plotted in Fig. 4 where the voltage was changed from 70 % to 105 % of its rated value in 5 % increments.

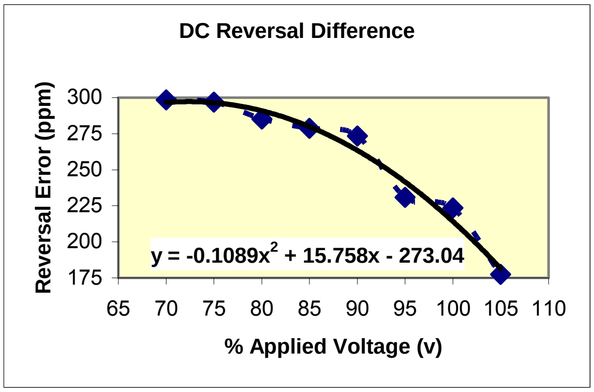


Fig. 4: 100 V DC Reversal Difference

5.3 Steady State Time of Thermal Element

The steady state time of the TE was measured by applying the full rated DC and AC voltage suddenly and monitoring the variation of the output EMF during two minutes. It was found that, when DC and AC voltage (50 Hz) are applied, the output EMF of the TVC requires about 32 s and 36 s respectively to reach its rated value and to stop the drift approximately.

6. UNCERTAINTY STATEMENT

Manual calibration system has been in operation for many years at NIS, and its uncertainty has been documented [5]. For example, the best-expanded uncertainty of the manual operation was about 30 ppm. However, this value was reduced by ratio of about 1:3 after using the new automated system. In addition to the calibration of the reference unit, common sources of error in this type of measurement are: the stability of calibrators and multimeters, self-heating, ambient temperature effects and drift effects [2, 4, 5, 6]. The contribution of noise to system uncertainty can be reduced by proper grounding and shielding of the system. The uncertainties were calculated in accordance with National Institute of Standards and Technology (NIST) requirements [6], which divide the uncertainty assigned to the measurements into Type A uncertainties (those evaluated by statistical means) and Type B uncertainties (those evaluated by other means) and then combine these uncertainties in a form of root-sum of squares (RSS). For AC-DC measurements, the Type B uncertainties are generally dominating [7]. The mathematical model to evaluate the uncertainty can be written as:

$$\delta_t = f(\delta) = \frac{(E_{as} - E_{ds})}{N_s \cdot E_{ds}} - \frac{(E_{at} - E_{dt})}{N_t \cdot E_{dt}} + \delta_s \quad (9)$$

or $$\delta_t = \Delta\delta + \delta_s \quad (10)$$

The equation for the propagation uncertainty can be expressed as follows.

$$[\frac{u(\delta_t)}{\delta_t}]^2 = [\frac{u(\Delta\delta)}{\delta_t}]^2 + [\frac{u(\delta_s)}{\delta_t}]^2 \quad (11)$$

The sources of relative uncertainty are the type A uncertainty of $\Delta\delta$. For 20 times of each measuring point, the standard uncertainty (U_A) is calculated by Equation (8).

$$u_A = \frac{\sigma}{\sqrt{20}} \quad (12)$$

where σ is the standard deviation of the 20 readings. For example, the computed type A of AC-DC calibration by using this new automatic system was 3.5 ppm for 10 V at 50 Hz. Type B has many contributions such as the contributions due to the T-connector, the standard (calibrated) TVC and the used DMMs. The uncertainty determination for the standard TVC is not treated in this paper. Using uncertainty statements from commercially calibrated TVCs, the expanded uncertainty of 10 V at 50 Hz (k = 2, for 95 % confidence level) is tabulated in Table 1.

Table 1: Uncertainty budget of 10V at 50 Hz

Source of Uncertainty	**Probability Distribution**	**Uncertainty Contribution ± ppm**
Calibration Certificate	Normal (Type B)	5
Tee Connector	Rectangular (Type B)	0.63
Room Temp. Change	Rectangular (Type B)	0.12
Repeatability (for 20 times)	Normal (Type A)	3.5
Combined Standard	Normal	6.1
Expanded Uncertainty	Normal (k = 2)	**12**

7. CONFIRMATION OF THE SYSTEM RESULTS

To confirm the results of the new automated system, a set of 0.5 V, 3 V and 10 V TVCs were sent to NPL, UK, for calibration. Two of these ranges were re-calibrated at NIS, Egypt, by using the new automated system. The results of the comparison are tabulated in Table 2. For example, the visual representative of the relative error and its associated expanded uncertainties for the range of 3 V at 50 Hz is plotted against the result of NPL as shown in Fig. 5.

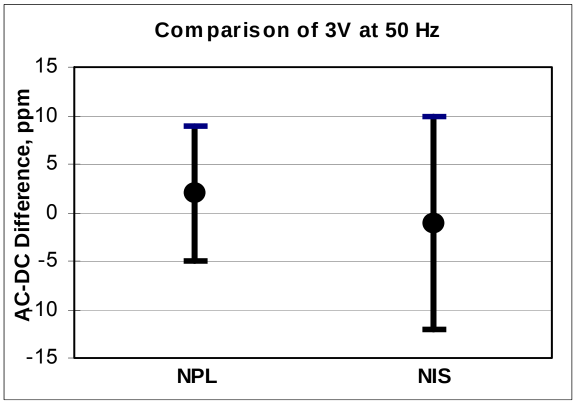


Fig. 5: Comparison of 3 V at 50 Hz.

Table 2: Results of comparison between NIS and NPL

Range	NPL Results			NIS Results	
	AC-DC Difference, ppm	Expanded Uncertainty, ± ppm		AC-DC Difference, ppm	Expanded Uncertainty, ± ppm
3 V (50 Hz)	1	6		-3	10
3 V (1 kHz)	-1	6		-2	13
3 V (20 kHz)	3	6		6	15
10 V (50 Hz)	2	7		-1	12
10 V (20 kHz)	-1	7		-4	13
10 V (100 kHz)	-4	8		-5	16

Proficiency test (Efficiency test) is defined as the determination of the laboratory's performance by means of comparing and evaluating calibrations or tests on the same or similar items or materials by two or more laboratories in accordance with predetermined conditions. The error normalized was used for the treatment of the data according to the following proficiency equation [9].

$$E_n = \frac{\lfloor L_\upsilon - R_\upsilon \rfloor}{\sqrt{U_{L_\upsilon}^2 + U_{R_\upsilon}^2}} \qquad (13)$$

where:

E_n = normalized error of the applicant laboratory.

L_v = the value as measured by the applicant lab.

R_v = the value as measured by the reference lab.

U_{Lv} = the uncertainty of the applicant lab.

U_{Rv} = the uncertainty of the reference lab.

To pass the proficiency test, the value of E_n should to be less than one (i.e. En < 1) [9]. Table 3 lists the results of this test using NPL as a reference lab. The results pass the efficiency test at all the measuring points.

Table 3: Summary of the efficiency test results

Range	Frequency	E_n value
3 V	50 Hz	0.57
"	1 kHz	0.2
"	20 kHz	0.04
10 V	50 Hz	0.23
“	20 kHz	0.04
"	100 kH	0.17

8. CONCLUSION

This paper describes NIS's efforts on improving its AC-DC transfer comparator system and gives a related uncertainty budget. It is suitable to support AC-DC difference determinations at 10 – 16 ppm uncertainty level. To confirm the efficiency of this system, bilateral intercomparison between NIS, Egypt and NPL, England has been performed using the results of AC-DC difference of HOLT 3 V and 10 V at different frequencies. The calculated results show a good agreement for the majority of these functions.

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