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New internal multi-range resistors for ac voltage calibration by using TVC

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Abstract

Accurate calibration of ac voltages up to 1000 V by using thermal converters requires range resistors connected in series with the converter. The combination of a thermal converter and range resistor is known as the thermal voltage converter. In this paper, multi-range internal range resistors are designed and implemented in the National Institute for Standards (NIS), Egypt to cover the ac voltage ranges from 10 V to 750 V. The range resistor values are 2 kΩ, 10 kΩ, 20 kΩ, 40 kΩ, 100 kΩ, and 150 kΩ to cover the voltage ranges 10 V, 50 V, 100 V, 200 V, 500 V, and 750 V, respectively. The six range resistors are mounted in series with a single-junction thermo-element in the same box to provide a new thermal voltage converter. The required range resistor is selected by using a six-pin selector switch. Each resistor is connected to a selector pin. The new thermal voltage converter ranges are automatically calibrated against other standard thermal voltage converters at different frequencies by using a LabVIEW program to determine their ac–dc transfer difference at each range. The expanded uncertainties are estimated according to the GUM for all ranges at different frequencies. The performance of the new thermal voltage converter is also evaluated by comparing its ac–dc differences and its accuracy in measuring the ac voltage at different frequencies with a traditional thermal voltage converter.

Keywords: ac voltage calibration, thermal voltage converter, ac–dc transfer difference, range resistors, uncertainty

(Some figures may appear in colour only in the online journal)

1. Introduction

Measurement of ac voltage is of great importance because it is used in many fields such as industry, generation, transmission, and the distribution of electrical power, communication, and electronics [1]. The maintenance and improvement of ac voltage metrology is therefore an important area for National Metrology Institutes. The most accurate standard for measuring ac voltage is the ac–dc transfer standard, which is maintained by means of ac–dc thermal converters (TCs) that operate on a thermal principle [2]. Ac–dc transfer is required to link the ac measurements to the determination and maintenance of the SI units which are performed exclusively at dc [3]. The main component of the TCs is the thermo-element (TE).

Most TCs have a rated voltage equal to 1 V, but many applications require ac voltages up to 1000 V. To accurately calibrate ac voltages higher than 1 V and up to 1000 V by using TCs requires a range resistor connected in series by a coaxial connector with the TC. This construction is generally called the thermal voltage converter (TVC). To cover voltages from 2 to 1000 V, a set of range resistors is provided, each of which covers a different voltage range. These range resistors are selected manually or automatically by using an automated multi-range system which consists of a hardware circuit derived by a software LabVIEW program. The range resistors are automatically selected by means of electronic relays that connect the suitable range resistor to measure the required value of the measurand ac voltage [4].

In this paper, a new TVC is designed and implemented in NIS, Egypt to cover the ac voltage ranges from 10 to 750 V. The new TVC is constructed from internal multi-range resistors and a single-junction TE, which are mounted in the same

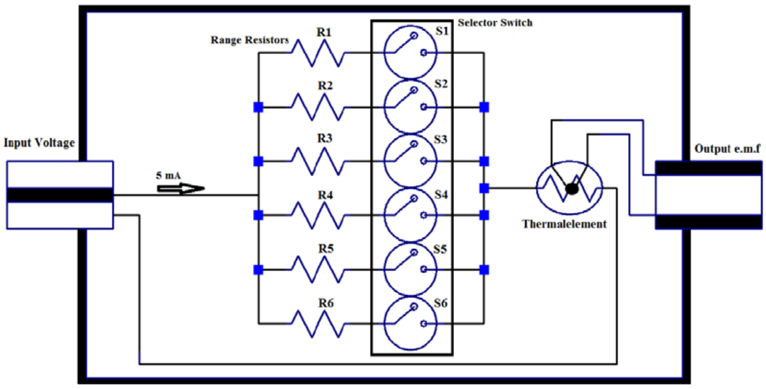

Figure 1. Construction of TVC with new multi-range internal range resistors.

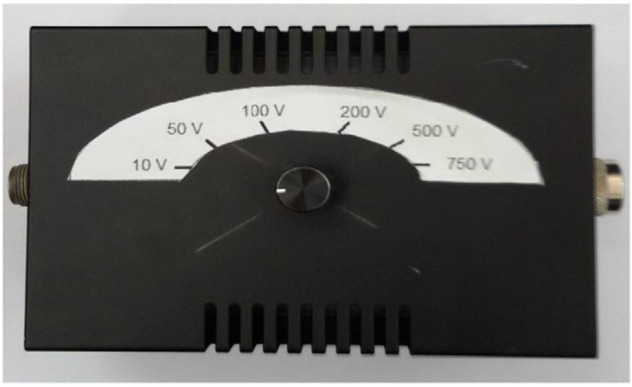

Figure 2. Implementation of the new range resistors by using a six-pin selector.

box. The range resistor which covers the required ac voltage is selected by using a six-position selector switch.

2. Construction of the internal multi-range resistors

The new TVC is constructed from a set of multi-range resistors, a six-pin selector switch, and a TE mounted in the same box, as shown in figure 1. The TE is an ultra-high frequency type with a rating of 5 mA, 90 Ω. It employs an evanohm heater with a small Thomson effect and cold setting ceramic bead to eliminate Peltier and Seebeck effects [5].

The multi-range resistors consist of six range resistors. Each range resistor is connected to a pin of the six-position selector switch; S_1, S_2, S_3, S_4, S_5, and S_6, as illustrated in figure 1. This selector switch allows an output connection, TE, to be connected to one of the possible input connections; range resistors R_1, R_2, R_3, R_4, R_5, and R_6. The resistors are non-inductive metal-film resistors and have excellent long-term stability. Their power ratings are from 0.25 to 6 W. The range resistor values are 2 kΩ, 10 kΩ, 20 kΩ, 40 kΩ, 100 kΩ, and 150 kΩ to cover the voltage ranges 10 V, 50 V, 100 V, 200 V, 500 V, and 750 V, respectively, as shown in figure 2. Each range resistor is used to measure the ac voltage in the range from 50% to 120% of the rated voltage value.

The advantage of the internal range resistors combined with the TE is the removal of the unavoidable contact resistance between the range resistor connector box and the thermo-element connector box if they mounted separately. It also protects the connector from damage or wear during the connection and separation of the two boxes. The implementation of multi-range internal range resistors allows one TE to cover a wide range of ac voltages and consequently reduces the cost.

3. New TVC calibration results and uncertainty estimation

The new TVC on all its ranges is calibrated against other standard TVCs to determine its ac–dc transfer difference, δ_t on the different ranges automatically via GPIB cards and cables by using a LabVIEW program. This program requires taking into consideration the specific characteristic of the TVC at each range such as its warm-up time and steady state time. For accurate calibration, the output e.m.f must be detected with a high-accuracy digital voltmeter and separated from noise and drift. The dc voltage source used in the calibration should also be stable and known at the level desired for the ac voltage range [6]. In this work, a Fluke model 5720A programmable calibrator with a Fluke model 5725A amplifier is used. The dc and the ac voltages are supplied to the standard TVC and the new TVC under test through a Tee connector. The output voltages of the two TVCs are measured simultaneously using two Fluke model 8508A multimeters. The system is operated under computer control, as shown in figure 3 and the data are recorded automatically in an excel file.

The ac–dc differences, δ_t of the new TVC is calculated for the different voltage ranges at frequencies 40 Hz, 55 Hz, 1 kHz, 10 kHz, 20 kHz, and 100 kHz by using the following equation [7]:

$$\delta_t = \frac{E_{as} - E_{ds}}{n_s E_{ds}} - \frac{E_{at} - E_{dt}}{n_t E_{dt}} + \delta_s, \quad (1)$$

where δ_s = ac–dc transfer difference of the standard TVC.
E_{as}, E_{at} = average value of the two readings of r.m.s value of ac voltage applied to the standard and the new TVC respectively.
E_{ds}, E_{dt} = average values of positive and negative dc voltage applied to the standard and the new TVC, respectively.
n_s, n_t = exponents of the standard and the new TVC.

Figure 4 shows the results of the ac–dc transfer difference (δ_t) for the new TVC at different voltage ranges and frequencies.

Figure 3. Automatic system for the new TVC calibration.

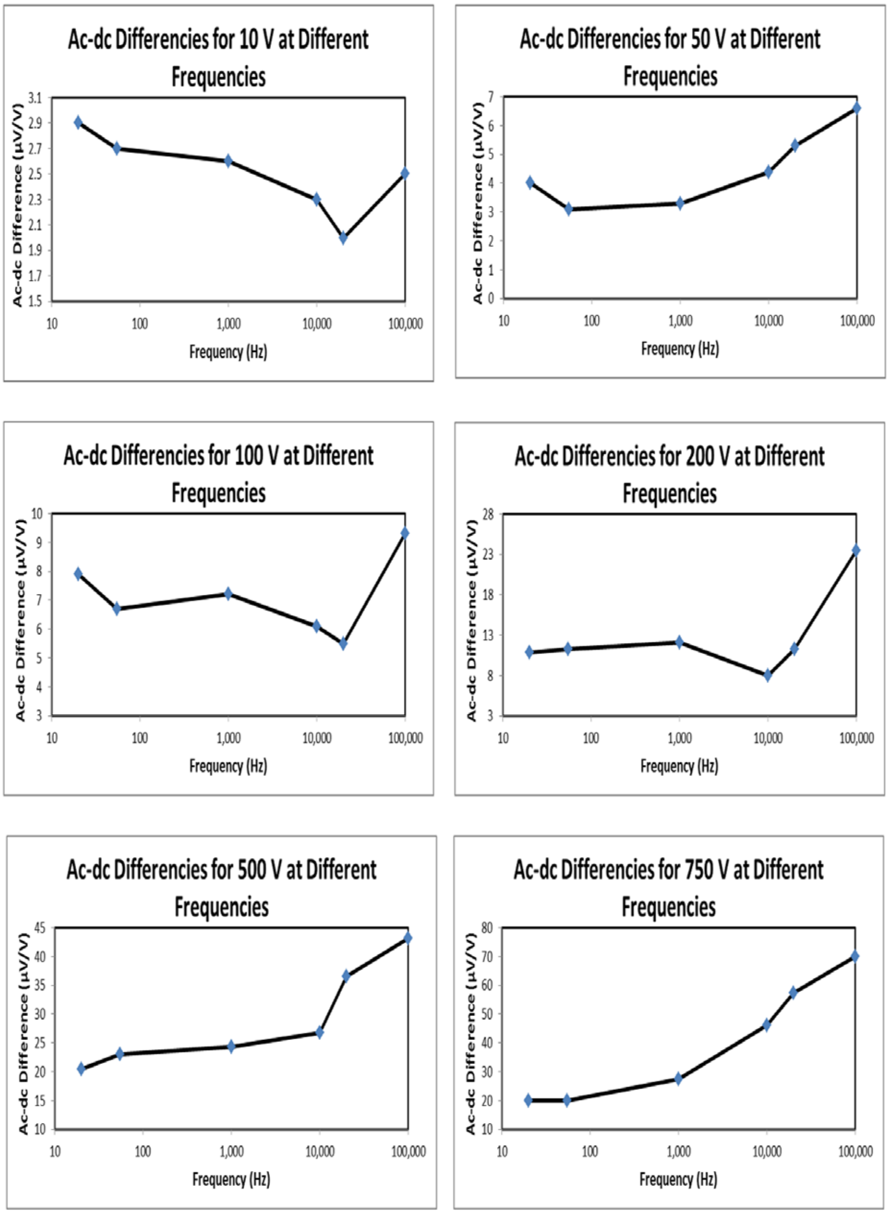

Figure 4. δ_t for the new TVC at different voltage ranges and frequencies.

Table 1. Uncertainty budget for the 10 V range at frequency 1 kHz.

Uncertainty sources	Standard uncertainty (μV V^{-1})	Probability distribution	Divider	C_i	Degree of freedom	Uncertainty contribution (μV V^{-1})
Repeatability	0.48	Normal	1	1	19	0.48
Standard TVC Calibration	7	Normal	2	1	∞	3.5
Dc voltage Calibration	0.38	Normal	2	1	∞	0.19
Level dependence	1.88	Rectangular	$\sqrt{3}$	1	∞	1.1
Freq. calibration	0.18	Normal	2	1	∞	0.09
Combined standard uncertainty:						$\pm$ 3.7 (μV V^{-1})
Effective degrees of freedom:						∞
Expanded uncertainty at confidence level 95%, (k = 2):						$\pm$ 7.4 (μV V^{-1})

Table 2. Ac–dc transfer differences results and their expanded uncertainties.

	10 V		50 V		100 V		200 V		500 V		750 V	
Freq.	δ_t	U	δ_t	U	δ_t	U	δ_t	U	δ_t	U	δ_t	U
40 Hz	2.9	20.7	4	21.2	7.9	20.6	10.9	23.3	20.5	21.2	20.1	27.0
55 Hz	2.7	8.0	3.1	12.4	6.7	11.1	11.3	18.6	23.1	15.2	20.0	20.7
1 kHz	2.6	7.4	3.3	12.1	7.2	10.3	12.1	19.1	24.3	16.3	27.5	20.3
10 kHz	2.3	7.4	4.4	12.1	6.1	10.3	8.0	17.7	26.7	16.6	46.0	20.9
20 kHz	2.0	7.4	5.3	12.1	5.5	11.7	11.3	18.3	36.6	15.7	57.3	21.5
100 kHz	2.5	26.7	6.6	26.3	9.3	26.4	23.5	33.6	43.1	30.1	70.0	42.8

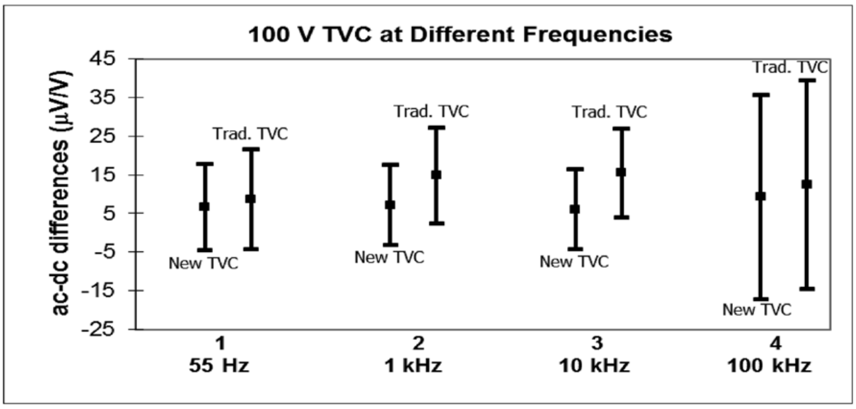

Figure 5. δ_t comparison in the range 100 V at different frequencies.

The expanded uncertainty for δ_t of the new TVC on the different ranges and at different frequencies is estimated. The uncertainty budget consists of type A, repeatability, and type B such as the calibration of the standard TVC, the calibration of the reference dc voltage, level dependence, and frequency calibration. Table 1 shows the uncertainty budget for the 10 V range at frequency 1 kHz as an example according to the GUM [8].

Table 2 shows the ac–dc differences, δ_t for all the voltages ranges at the different frequencies and their associated expanded uncertainties, U. All values are in μV V^{-1}.

It is found from the results that the frequency dependence of the new TVC is good, and this new construction improves the performance of the TVC at different frequencies due to smaller distributed capacitances and inductances. The behavior of the new TVC in the higher ac voltage ranges at frequencies above 20 kHz can be improved by shielding the high voltage end of the specific range resistors [9].

4. New TVC performance evaluation

The performance of the new TVC is evaluated by comparing its δ_t at different frequencies with a traditional TVC. A 100 V traditional TVC is used in this evaluation at frequencies 55 Hz, 1 kHz, 10 kHz, and 100 kHz as an example.

Figure 5 shows a comparison between δ_t associated with its U for the 100 V new TVC and the traditional TVC at different frequencies.

It is found that δ_t of the new TVC is lower than the traditional TVC, whereas their difference span is from 2 to 9 μV V^{-1}. This is due to the removal of contact and lead resistance in the new TVC design. The elimination of contact resistance

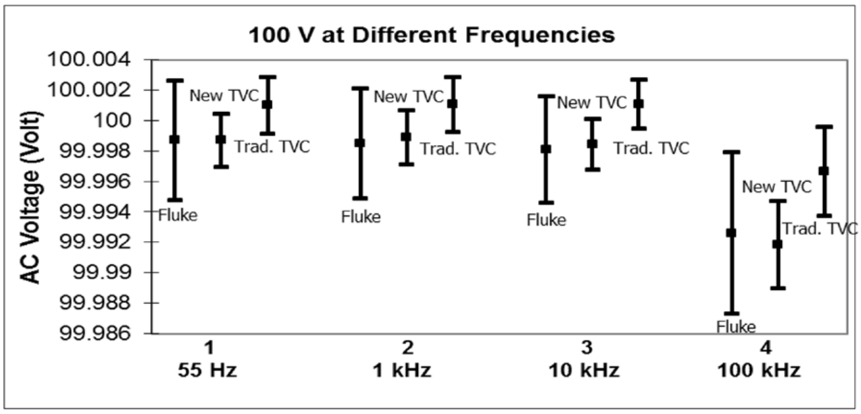

Figure 6. 100 V ac voltage measurements at different frequencies.

reduces the skin effect, which increases the ac resistance than the dc resistance [10], and is a major source of error in traditional TVCs, which use a separate range resistor.

The accuracy of the new TVC is also evaluated by measuring a 100 V ac voltage at different frequencies. The results which are obtained by using the new TVC and the traditional TVC are compared with those obtained from calibrating this ac voltage at Fluke accredited by DKD, Germany.

Figure 6 shows a comparison of the ac voltage results obtained from Fluke and the measured values by using the new TVC and the traditional TVC associated with their *U* which are represented by three columns (error bars) at different frequencies.

It is shown that the measured values using the new TVC are in agreement with the results obtained from the ac voltage calibration and closer to it than the traditional TVC. It indicates that the new TVC is more accurate than the traditional TVC. The accuracy and the expanded uncertainty of the new TVC can be additionally improved by using four thermo-elements connected in series with the new multi-range internal range resistors to increase the output e.m.f [11].

5. Conclusion

A new TVC using internal range resistors connected in series with a TE in the same box has been designed and implemented in NIS, Egypt to extend the accurate measurement of the ac voltage ranges. The advantage of the internal range resistors combined with the thermo-element is the removal of the contact resistance between the range resistor connector and the thermo-element connector. It also protects the connector from wear due to repeat connection cycles. The implementation of multi-range internal range resistors limits the number of TEs and reduces the cost. It is found that the frequency dependence of the new TVC by using the new internal range resistors is good, especially at the frequencies up to 20 kHz for higher ac voltages due to smaller distributed capacitances and inductances. It is also found that δ_t of the new TVC is lower than the traditional TVC due to eliminating the contact resistance. Furthermore, the new TVC has been validated by measuring a traceably calibrated 100 V ac voltage at different frequencies. It is shown that the measured values using the new TVC are in agreement with the results obtained from the ac voltage calibration at Fluke and closer to it than the traditional TVC. This indicates that the new TVC is more accurate and has a better performance than traditional TVCs.

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