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Establishment of new automated multi range thermal current converter

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ABSTRACT

A new automated multirange thermal current converter (TCC) has been designed and implemented at the National Institute of Standards (NIS), Egypt. Five single junction thermal current converters (SJTCCs) have been connected in parallel on PCB with an LCD, keypad and a microcontroller to control a five fast switching relays. This TCC has been designed to cover the ac current ranges from 500 mA to 5 A at frequencies from 40 Hz up to 100 kHz. The construction of the new automated TCC has been presented to solve some problems of using shunt resistance at high currents. Furthermore, a new automatic calibration system has been established to calibrate the established TCC against another standard TCC. This software program has been specially designed using MATLAB program to overcome the problems of manual calibration and measurement. The expanded uncertainties are estimated for all ranges at different frequencies and also, the ac-dc differences. The performance of the new automated TCC is also evaluated by comparing its accuracy by measuring ac currents at different frequencies with the performance of a traditional TCC.

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1. INTRODUCTION

Measurement of ac current is very important as it is used in many fields such as industry, generation, transmission, distribution of electrical power, communication, and electronics [1]. Thermal transfer standards are considered the accurate devices for the measurement and calibration of alternating voltage and current in terms of fundamental dc standards at national metrology institutes [2], [3]. These electrical quantities require a standard to compare the energy dissipated from them to that of dc equivalents quantity, so the ac quantity can be calculated from its dc equivalent and the ac-dc transfer difference of the transfer standards [4].

Thermal transfer techniques based on thermal converters is the most accurate [4]–[6], where each thermal converter consists of evacuated glass bulb with heater and thermocouple embedded in it. The heater, where the ac and dc current are passed through it, is a short resistive straight wire, and the thermocouple is fastened by a ceramic bead in its middle point, to provides electrical insulation between the heater and thermocouple circuits [7], [8]. The number of thermocouples varies where it is one in single-junction thermal converters (SJTCs) and from 50 to 200 for multijunction thermal converters (MJTCs) [9]. for current levels between 1 mA and up to 10 mA, thermal current converters (TCCs) are excellent to be used.

To extend the range of the current, TCCs are used with commercially available set of current shunts. These commercial standard shunts its design limited calibration current and frequency ranges to 20 A at 20–30 kHz. Due to appearing new calibration commercial instruments that required calibrations at higher current and frequency ranges, up to100 A at 100 kHz, an ac-dc current transfer comparator and high current standard shunt were designed [10]. However, these shunts extend the range of the current measurements, but they have many drawbacks at higher currents such as the variation of the resistance as a function of the frequency, thermal drifts, the inductance of the resistive element and greater errors from skin effect especially at high frequencies [11]. Also, its cost is very high. SJTCs are widely used for ac-dc transfer because its design is simple, ready availability and it is not expensive [12].

So, this paper will illustrate a new design that using SJTC as the main element in the construction of the new multi range thermal current converter. This new design has been constructed to achieve the ac current measurements ranges from 500 mA up to 5 A at frequencies up to 100 kHz. Furthermore, a new automatic calibration system has been established to achieve the calibration system procedures. This automatic system has been specially designed using MATLAB software program, which is made for the first time at National Institutes of Standards (NIS), Egypt to automatically control the devices through GPIB card and cables [13], [14].

The automated programmable system is performed as programmable instruments are now widely employed to overcome a lot of manual measurements problems that eliminates the operator’s mistakes and also saving time and efforts [15]. The calibration of all the current ranges of the new automated thermal current converters at different frequencies are fully investigated by determining their ac-dc differences, and also their uncertainty budgets at different frequencies from 55 Hz to 5 kHz have been evaluated. The performance evaluation of the new automated TCC has also been done at 1 A and 3 A as an example by measuring ac current sources at these ranges using the new TCC and the traditional TCC. The obtained results are compared with 1 A and 3 A actual values.

2. CONSTRUCTION OF THE NEW AUTOMATED MULTIRANGE TCC

A new automated multi-range thermal current converter was designed and tested at NIS to overcome some of the disadvantages of the traditional thermal current converters that is due to using shunt resistance at highe currents from 1 A to 5 A, as well as it has many other advantages such as it operates automatically to detect the required range by pressing on a keypad. It is multi ranges and it has a program to calibrate it and record the results automatically. It also provides fast switching between ac and dc signals to keep constant thermal conditions. Furthermore, the switching between ac and dc currents is done at constant regular time intervals [16], [17]. Main idea of the proposed design is using single junction thermal converters to obtain the required output current without shunt resistor. This new TCC is controlled by using a number of relays worked as latch switch through a microcontroller to get the required measured current. Each relay was protected with a ULN2003A diode to prevent from reversed currents and it is a driver to the relies, and the input current can be easily determined by clicking on a keypad, and the entered current is displayed on an LCD. All the system is automatically operated and Schematic diagram of the new TCC has been designed by Orcad program as shown in Figure 1. This construction is mainly based on five modules; thermal elements, reed relays, microcontroller, keypad, and LCD. The used microcontroller ATMEGA32A-PU1206-40-pin has been used in this design to transmit control signals to relays to operates as automatic switches. Its pins connections and how to programe it has been described in details [18], [19]. The microcontroller input signal comes from a keypad to controls five reed relays to achieve the automatic control of the input current ranges, also values are displayed in ampere (A) on the LCD display. This automatic control achieved by using a C program is uploaded on the microcontroller.

The new automated TCC consists of five single junction thermal current converters (SJTCCs), Their thermoelements (TE) are specially designed. The specifications of each used TEs are 1 A nominal heater current and 0.25 Ω heater resistance [20], that is produced by Best Technologies. Each SJTCC of them can be used from 50% and loaded up to 120% of its rated value which means from 0.5 A up to 1.2 A. The output emf of each one of these thermal elements is in the range of 18 mV. These SJTCCs are connected in parallel and they controlled by reed relays to get the required current measurement. for measuring 1 A ac current, only one relay is closed and current passing through one thermal element, this obtained by pressing button number (1) on the keypad. Two relays will be closed if 2 A is required to be measured and passed through two thermal elements, and so on up to 5 A. All the five modules; thermal elements, reed relays, microcontroller, keypad, and LCD are built on PCB as shown in Figure 2, also PCB placed on an acrylic box as shown in Figure 2.

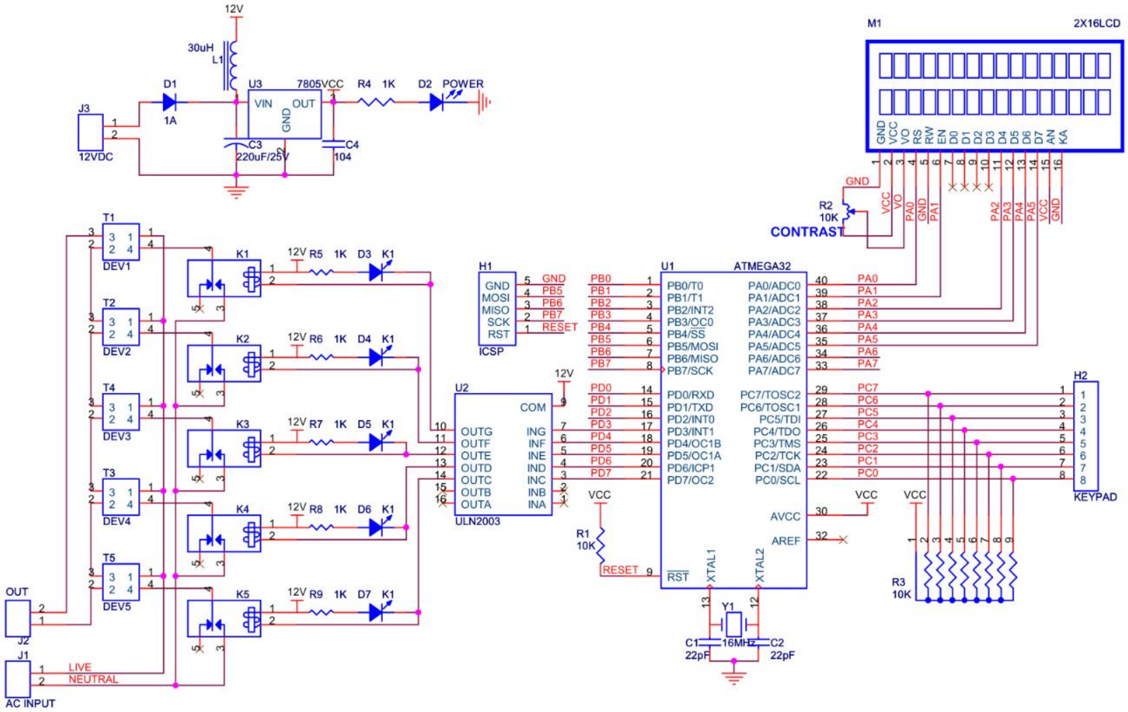


Figure 1. Schematic diagram of the new automated TCC

(a) (b)

Figure 2. The new automated TCC: (a) PCB and (b) module

3. CALIBRATION PROCEDURE AND DISCUSSION

Calibration of ac-dc transfer standard is achieved by comparing the standard under calibration to another standard transfer instrument whose correction is known from its certificate to determine its ac-dc transfer difference. Our used standard TCC is calibrated in physikalisch-technische bundesanstalt (PTB), Germany, so, our new automated TCC is traceable to PTB. The calibration system setup consists of a programmable ac/dc source, multifunction calibrator FLUKE for both ac and dc currents, and two similar high accuracies digital multimeters (DMM) FLUKE which are connected to the output of each TCC to measure the output emf of the two transfer. The two ac-dc current transfer standards; standard and under calibration are connected in series to carry the same current, the experimental setup is shown in Figure 3. In order to obtain the optimum performance of the measurements, an advanced automatic system has been developed for the calibrations of ac-dc current transfer standards. MATLAB software program has been especially designed to perform this automatic calibration which controls all the system through GPIB card and GPIB cables [13]. Then, MATLAB software program was prepared to automatically obtained the accurate values of the ac-dc differences (δ) and type A uncertainty due to repeatability of the new design at different current ranges and frequencies. The thermal converters (TCs) respond differently to positive and negative dc current, so transfer difference errors can be reduced by applying a sequence such as ac, +dc, -dc, ac, and in order to obtain the accurate values of ac current [21]–[23]. For best measurement accuracy after switching the source on, apply warming up time to the TCCs and also wait time period usually from 40s to 60s for steady state time before taking the reading of the e.m.f output for ac and dc current [16], [24]. For our new TCC, this test is performed to obtain its steady state time. It is found that its value is 50 second. So, this time is waited before recording the values of the output emf. By using this new automatic MATLAB program, switching between ac, dc and the reading of the devices can take place at regular and precise intervals. The range selection and the frequency for each range are software-controlled, also the results are recorded in excel file that are determined in the software program.

Figure 3. Experimental setup

3.1. Calibration and uncertainty evaluation results

The values of the n-factor test of the new design are firstly measured at different current ranges by changing in the output e.m.f, ΔE, when the dc nominal input current is varied by ±0.5%. Where the relation between the input current of the source and its output e.m.f is expressed as [17]:

$$E = kI^n \tag{1}$$

$$n = \frac{\Delta E/E}{\Delta I/I} \tag{2}$$

where:
E: is the output emf of the TE,
I: is the heater current,
k: a constant varies somewhat with large changes in heater current but it is constant over a narrow range where nearly equal AC and DC currents are compared.
n: is usually 1.6 to 1.9 at rated heater current.

It is found that the values of the n-factor test of our new design were from 1.8 to 1.9 at the different current ranges. And the ac-dc differences (δm) for the new TCC from 1 A to 5 A at different frequencies from 55 Hz to 5 kHz are also determined from the following [17], [25]:

$$\delta_m \frac{E_{ac}-E_{dc}}{nE_{dc}} \tag{3}$$

where,
E_{ac}: is the emf output when applying ac current
E_{dc}: is the average of emf output when applying dc and -dc current

All components of the uncertainty budget (Type A and Type B) are taken into consideration and the expanded uncertainty is obtained by multiplying the combined uncertainty by coverage factor “k”. The value of coverage factor gives the confidence level for the expanded uncertainty. Most commonly, we scale the overall uncertainty by using the coverage factor k=2, to give a level of confidence of approximately 95% according to the ISO GUM, guide to the expression of uncertainty in measurement [26]. All the measured values are usually the average of 30 determinations of ac-dc differences. The uncertainty budget for the 3 A at 120 Hz is given in Table 1 as an example. The considered expanded uncertainty (Uexp) for the new design and the ac-dc differences (δ) of all the calibrated ranges from 1 A to 5 A at the frequencies from 55 Hz to 5 kHz (due to the limited capability of the using source) are illustrated in Table 2.

Table 1. Uncertainty budget for 3 A at 120 Hz

Uncertainty sources	Probability distribution	Divisor	Degree of freedom	Uncertainty contribution (µV/V)
Repeatability	Normal (Type A)	1	n-1	0.8
Calibration of standard TCC	Normal (Type B)	2	∞	6.5
Calibration of DC Current	Normal (Type B)	2	∞	3.2
Level Dependence	Rectangular (Type B)	√3	∞	3.8
Combined standard uncertainty				7.6
Expanded uncertainty at confidence level 95%, (k = 2)			∞	15.2≈16

Table 2. Measured AC-DC difference δm (µV/V) and expanded uncertainties uexp (µV/V) of all ranges at different frequencies

Current range	Frequency									
	55 Hz		120 Hz		500 Hz		1 kHz		5 kHz	
	δ	U_{exp}	δ	U_{exp}	δ	U_{exp}	δ	U_{exp}	δ	U_{exp}
1 A	-33	28	-21	31	-106	29	-206	28	-1272	28
2 A	-95	29	-98.6	30.8	-143.1	29	-269	28	-1210	28
3 A	-97	16	-105	15	-159	15	-252	15	-1934	25
4 A	-114	16	-110	16	-145	16	-272	15	-1632	25
5 A	-142	17	-180	17	-205	18	-272	19	-1276	22

3.2. Evaluation of the new automated TCC performances

The evaluation performance of the new automated TCC is studied for ac current measurements at 1 A 3 A and 5 A as an example. The results of ac current measured by the two TCCs (the new automated TCC and a traditional TCC) are compared to the actual values obtained from the calibrator (the source) at four different frequencies. the actual values of the measured current from the calibrator obtained by calibrating it at Cesky Metrologicky Institut (CMI) at frequencies 55 Hz, 500 Hz, 1 kHz, and 5 kHz. The measured value of the ac current by using the TCCs is obtained from [17]:

$$I_{ac} = I_{dc}(1 + \delta_n) \tag{4}$$

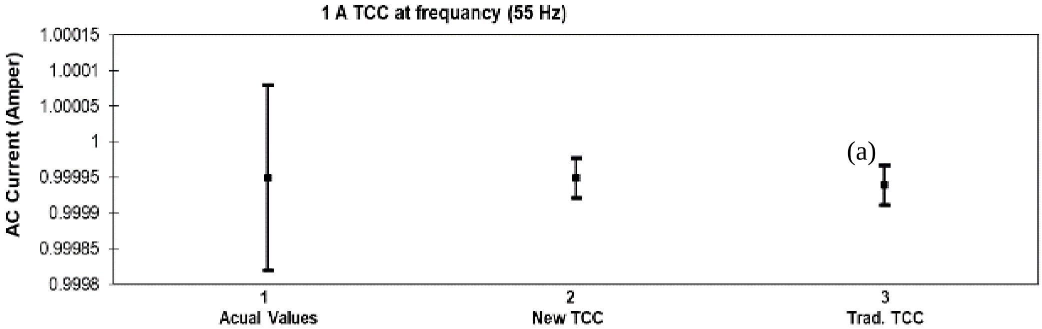
$$\delta_n = \delta_c + \delta_m \tag{5}$$

where I_{dc} is the traceable and standard dc current to CMI; δ_c is the ac–dc difference correction of the TCC which determined comparing it to a similar standard instrument whose correction is known; and δ_m is the difference response between the applied ac and dc currents which obtained from (3).

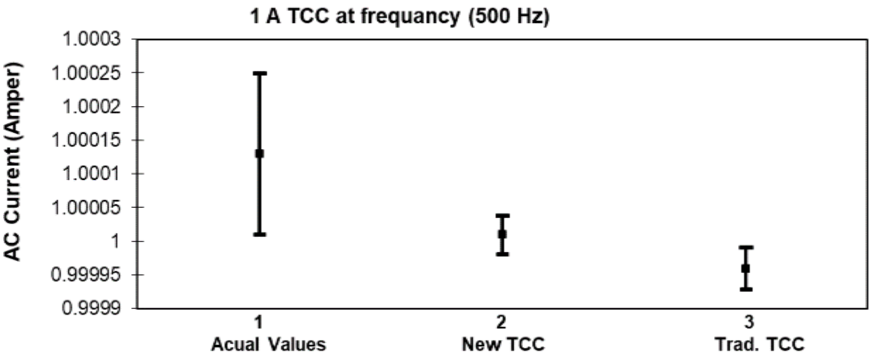
The expanded uncertainty is determined for the measurement by using the new automated TCC and the traditional TCC in accordance with the GUM; guide to the expression of uncertainty in measurement [26]. Figures 4 to 6 shows a comparison between the ac current obtained from CMI, the measured values using the new automated TCC, and the values obtained by the traditional TCC at 1 A, 3 A and 5 A respectively. This comparison is represented by the error bars and the results are associated with their expanded uncertainty as illustrated by the three columns (the measured values are in the midpoints in the columns and the upper and lower limits show the expanded uncertainty). The error bars demonstrate that the measured values using the new TCC and the actual values of the measured current are almost equal. It ensures that the new automated TCC is more accurate and precise than the traditional TCC. Furthermore, it reduces the estimated expanded uncertainty.

3.2.1. Discussion

Hence, from Figures 4 to 6 which illustrate the error bars of the values of ac current measured by the new automated TCC and the traditional TCC versus the actual values of CMI (values from the calibrator), the results are associated with their expanded uncertainty. It is obvious that at higher frequencies, the value of the ac current is strongly affected by the frequency especially when using the traditional TCC, while its accuracy decreases with increasing the frequency at all current ranges 1 A, 3 A and 5 A. But in the case of the new automated, its accuracy almost constant for higher frequencies. At lower frequencies, the measured values via the traditional TCC, and the new TCC are close to the actual value within the range of 55 Hz to 500 Hz at all the measured current ranges. The error bars mean that the new automated TCC is more accurate than the traditional TCC and it has the lowest uncertainty for current ranges from 1 A to 5 A mainly at frequencies from 55 Hz to 5 kHz. Also, the measurements of ac currents by the new automated TCC are roughly equal to the actual values that obtained from the calibrator.



(a)



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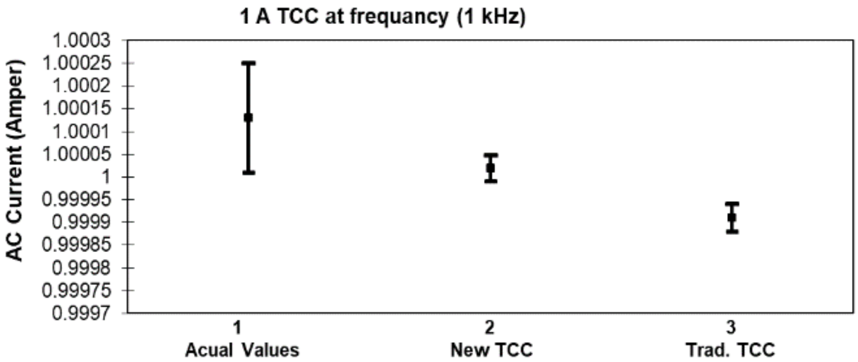

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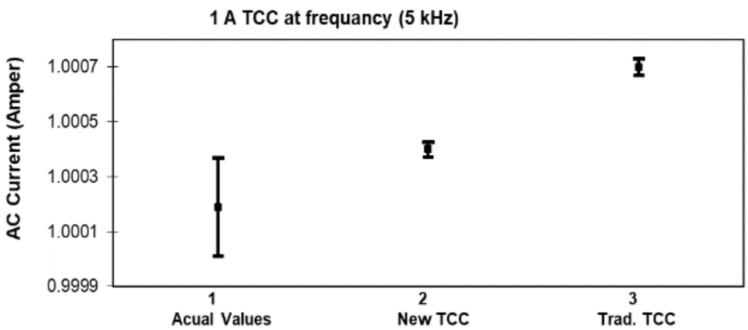


(d)

Figure 4. Comparison of 1 A measurements at (a) 55 Hz, (b) 500 Hz, (c) 1 kHz, and (d) 5 kHz

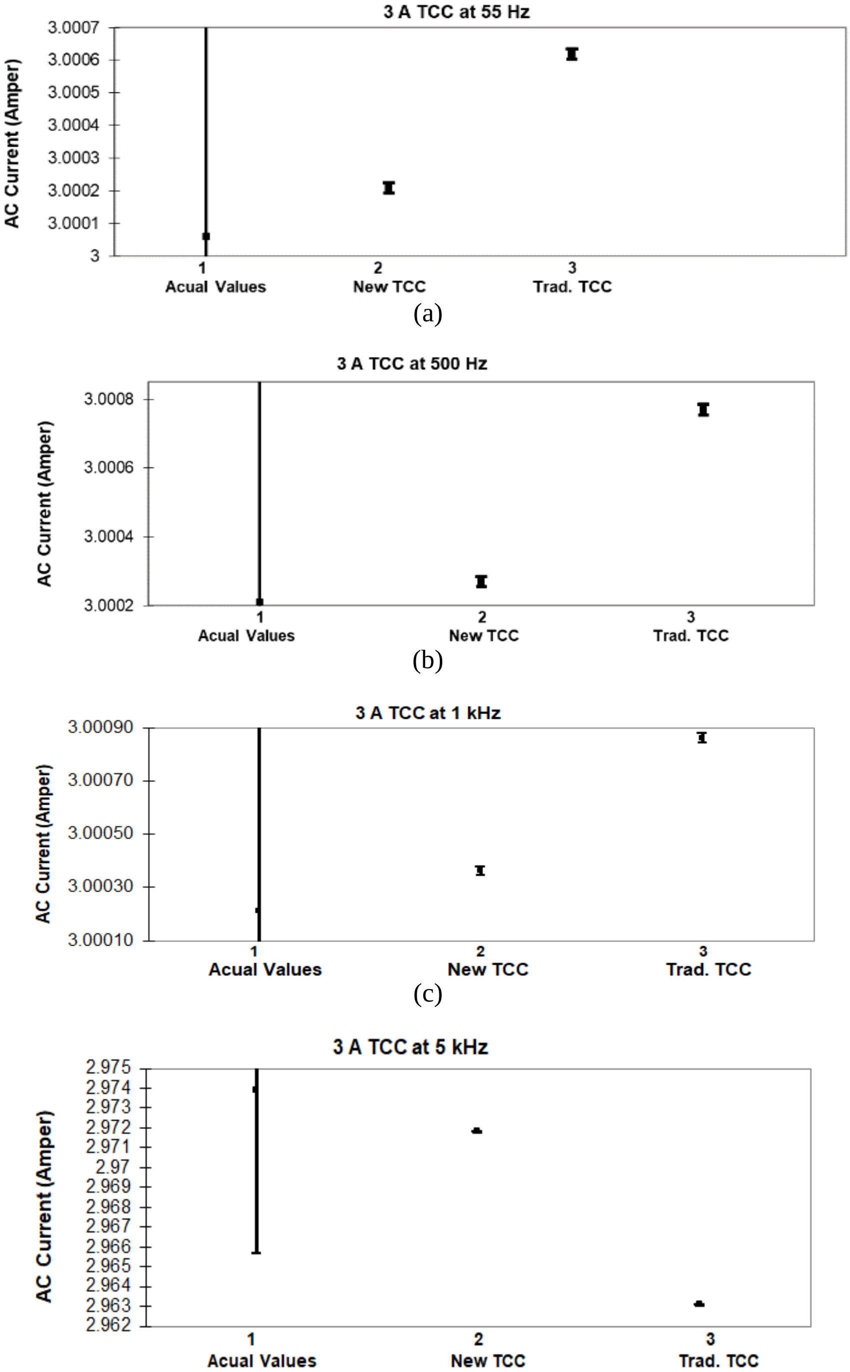
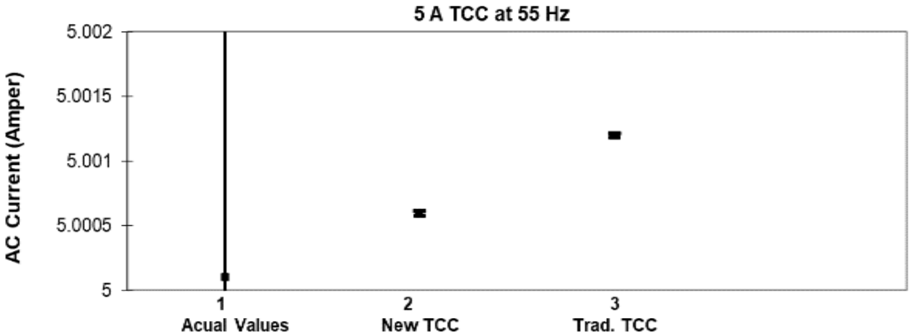


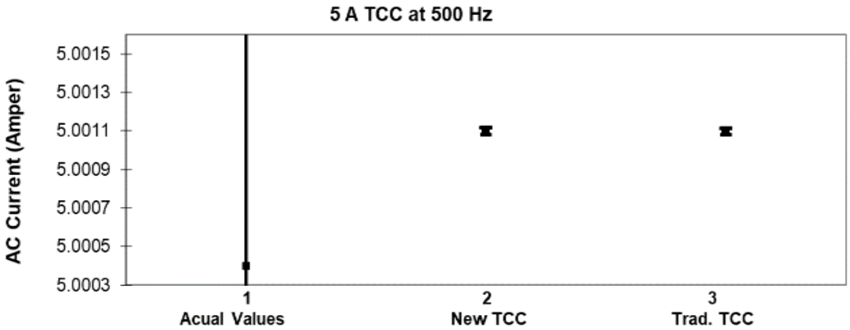
Figure 5. Comparison of 3 A measurements at (a) 55 Hz, (b) 500 Hz ,(c) 1 kHz, and (d) 5 kHz

3.2.2. Advantages of the new TCC

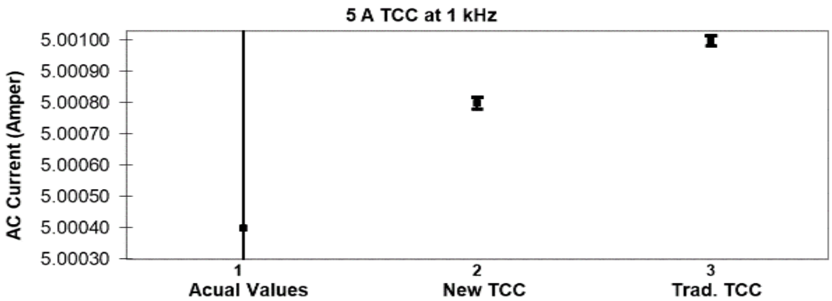
From the previous illustration we can show the advantages of the new automated multi range TCC that we designed it which is simple as it is only one box including PCB built on it the thermoelements that used to get the ranges of the current from 1 A to 5 A, while the traditional is two boxes and two shunts are used to get the same range. It is automated with keypad and LCD. Also, it is multi range. The new TCC reducing the inductive and capacitive errors, skin effect, and leakage current, as we cancelled the shunt resistance that used with the traditional TCC which increase the heating effect and then it affects the accuracy of the measurements. So, the new TCC has high accuracy and low uncertainty as showing in the previous figures.



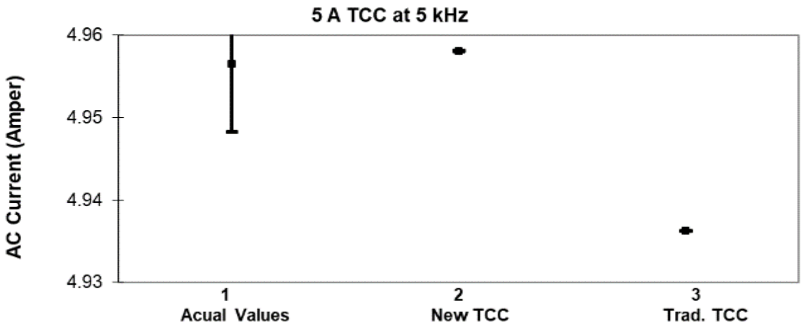
(a)



(b)



(c)



(d)

Figure 6. Comparison of 5 A measurements (a) 55 Hz, (b) 500 Hz, (c) 1 kHz, and (d) 5 kHz

4. CONCLUSION

In this paper AC currents are measured by two different TCCs, the new automated multirange TCC and a traditional TCC and their results are compared with the actual values of the AC current which are obtained from multifunction calibrator traceable to CMI. The results show that the new TCC improve the accuracy and the uncertainty of the AC current because it overcome the disadvantages of the shunt resistor which used with the traditional TCC to extend the current range. Also, it is operating automatically and this decreasing the manual operator mistakes. Then this paper proves that this new automated multirange TCC design has a good effect on improving the accuracy and reducing the uncertainty of the AC current measurement at current ranges from 1 A to 5 A at frequencies from 40 Hz up to 100 kHz.

REFERENCES

[1] M. Klonz, H. Laiz, and E. Kessler, "Development of thin-film multijunction thermal converters at PTB/IPHT," *IEEE Trans. Instrum. Meas.*, vol. 50, no. 6, pp. 1490–1498, 2001, doi: 10.1109/19.982933.

[2] M. Klonz, H. Laiz, T. Spiegel, and P. Bittel, "AC-DC current transfer step-up and step-down calibration and uncertainty calculation," *IEEE Trans. Instrum. Meas.*, vol. 51, no. 5, pp. 1027–1034, 2002, doi: 10.1109/TIM.2002.806008.

[3] T. E. Lipe, "50 Ohm multijunction thermal converters for AC voltage measurements up to 100 MHz," *XXI IMEKO World Congr. Measurement Res. Ind.*, August 30-September 4, 2015, Prague, Czech Republic.

[4] R. S. M. Ali, "Effect of modified multipliers resistors on measurement of AC voltages above 50 V," *Meas. J. Int. Meas. Confed.*, vol. 126, no. May, pp. 378–381, 2018, doi: 10.1016/j.measurement.2018.05.088.

[5] K. E. Rydler, "High precision automated measuring system for ac-dc current transfer standards," *IEEE Trans. Instrum. Meas.*, vol. 42, no. 2, pp. 608–611, 1993, doi: 10.1109/19.278637.

[6] T. F. Wunsch, R. P. Manginell, O. M. Solomon, J. R. Kinard, T. E. Lipe, and K. C. Jungling, "Evaluation of coaxial single range thermal voltage converters with multijunction thin-film thermoelements," *Conf. Rec. - IEEE Instrum. Meas. Technol. Conf.*, vol. 1, pp. 449–452, 2001, doi: 10.1109/IMTC.2001.928858.

[7] A. Haroutunian, M. Halawa, A. Hassan, R. Attyia, and H. A. Mageed, "Comparison of the technical performance for different designs of single junction thermal converters," *CPEM Dig. (Conference Precis. Electromagn. Meas.*, no. May 2014, pp. 246–247, 2008, doi: 10.1109/CPEM.2008.4574745.

[8] R. S. M. Ali, "Development of electrical quantities primary standards," *Trans. Inst. Meas. Control*, vol. 44, no. 3, pp. 539–561, 2022, doi: 10.1177/01423312211030109.

[9] P. S. Filipski, and M. Boecker, "Ac-dc current shunts and system for extended current and frequency ranges," *Conf. Rec. - IEEE Instrum. Meas. Technol. Conf.*, vol. 2, no. May, pp. 991–995, 2005, doi: 10.1109/imtc.2005.1604287.

[10] U. Pogliano, G. C. Bosco, and D. Serazio, "Coaxial shunts as AC-DC transfer standards of current," *IEEE Trans. Instrum. Meas.*, vol. 58, no. 4, pp. 872–877, 2009, doi: 10.1109/TIM.2008.2008469.

[11] T. E. Lipe, "A new generation of multijunction thermal current converters," *IEEE Trans. Instrum. Meas.*, vol. 66, no. 6, pp. 1232–1236, 2017, doi: 10.1109/TIM.2016.2613405.

[12] V. N. Zachovalova, S. Maslan, M. Sira, and J. Streit, "Development of primary standard for ac-dc current transfer difference," *CPEM 2016 - Conf. Precis. Electromagn. Meas. Conf. Dig.*, 2016, pp. 1–2, doi: 10.1109/CPEM.2016.7540674.

[13] E. Gorrostieta *et al.*, "Event discrete control strategy design of overhead crane embedded in programmable logic controller," *Am. J. Eng. Res.*, vol. 7, no. 1, pp. 942–948, 2013, [Online]. Available: http://dx.doi.org/10.1016/j.mechatronics.2012.10.002%0Awww.mathworks.com.

[14] "Computation visualization programming getting started with MATLAB the language of technical computing," MathWorks, Inc, 1996. [Online]. Available: http://www-eio.upc.es/lceio/manuals/matlab/TECHDOC/PDFDOCS/GETSTART.PDF

[15] U. Pogliano, G. C. Bosco, and M. Lanzillotti, "Generalized automatic system for ac/dc transfer, ac voltage and ac current measurements," *Conf. Rec. - IEEE Instrum. Meas. Technol. Conf.*, vol. 1, no. May, pp. 395–399, 2004, doi: 10.1109/imtc.2004.1351072.

[16] R. S. M. Ali, H. A. Mageed, and N. N. Tadros, "Automated multi-meter method for the scaling of low AC voltage from 200 mV to 2 mV," *Energy Power Eng.*, vol. 5, pp. 129–134, 2013, doi: 10.4236/epe.2013.52012.

[17] J. R. Kinard, E. S. Williams, and T. E. Lipe, "Automated thermal voltage converter intercomparisons," *Proc. IEEE*, vol. 74, no. 1, pp. 105–107, 1986, doi: 10.1109/PROC.1986.13412.

[18] A. Hussain, M. Hammad, K. Hafeez, and T. Zainab, "Programming a microcontroller," *Int. J. Comput. Appl.*, vol. 155, no. 5, pp. 21–26, 2016, doi: 10.5120/ijca2016912310.

[19] A. Wild *et al.*, "A 0.9V Microcontroller for Portable Applications," *ESSCIRC '96: Proceedings of the 22nd European Solid-State Circuits Conference*, 1996, pp. 264-267.

[20] Best Technology International, Inc. https://www.besttech.com, Accessed: 2023-01-03.

[21] H. A. Mageed, M. Halawa, A. F. Zobaa, and M. M. AbdelAziz, "Establishment and characterization of a traceable ac voltage source at nis, Egypt," *Proc. Univ. Power Eng. Conf.*, 2008, doi: 10.1109/UPEC.2008.4651511.

[22] A. K. Govil, S. Ahmad, B. Pal, and P. C. Kothari, "Development of an automated AC-DC transfer measurement system for voltage and current at low frequencies," *CPEM Dig. (Conference Precis. Electromagn. Meas.*, 2008, pp. 590–591, doi: 10.1109/CPEM.2008.4574917.

[23] R. S. M. Ali, "Comparison between two different designs in the AC voltage measurement," *Meas. J. Int. Meas. Confed.*, vol. 44, no. 9, pp. 1539–1542, 2011, doi: 10.1016/j.measurement.2011.06.005.

[24] M. Halawa, and N. Al-Rashid, "Performance of single junction thermal voltage converter (SJTVC) at 1 MHz via equivalent electrical circuit simulation," *UKSim2010 - UKSim 12th Int. Conf. Comput. Model. Simul.*, 2010, pp. 631–636, doi: 10.1109/UKSIM.2010.120.

[25] B. Pal, S. Ahmad, and A. K. Govil, "Automation and evaluation of two different techniques to calibrate precision calibrators for low frequency voltage using thermal devices," *Mapan - J. Metrol. Soc. India*, vol. 28, no. 1, pp. 31–36, 2013, doi: 10.1109/CPEM.2010.5543595.

[26] "Uncertainty guide to the expression of uncertainty in measurement," JCGM 100, Sept. 2008. [Online]. Available: https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6.

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