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Review Article

INVESTIGATION OF THE CORRECTION FACTORS OF THE THERMAL VOLTAGE CONVERTERS (TVCS) USING ELECTRICAL MODELING AND SIMULATION

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1. Introduction

Metrology is the science of measurement and its application; it is including all theoretical and practical aspects of measurement [1]. The fact is that, metrology has reached a level of unprecedented strategic importance both to the economy and society as a whole. One of the factors that increases the importance of metrology is the trend towards international standards in the different industrial activities. Metrology is essential in scientific research, which forms the basis of the development of metrology itself. The fundamental metrology follows the metrological aspects of the new discoveries. This means ever better metrological tools enabling researchers to continue their discoveries, and only those fields of metrology that do develop can continue to be a partner for industry and research. Correspondingly, scientific, industrial and legal metrology must also develop in order to keep pace with the needs of industry and society and remain relevant and useful [2].

In Metrology domain, the primary electrical standards are those of voltage and current, which are defined in terms of the Josephson Effect and the quantum Hall effect. The DC voltage standards are established using a Josephson voltage standard with uncertainty better than 10^{-7} [3]. This conventional value of the Josephson accuracy used as the starting point of electrical calibrations is fixed by international agreement. On the other hand, it is necessary to provide a means of maintaining the traceability chain when AC measurements are required. This is usually done by a thermal technique although non thermal methods are also used. In order to determine AC quantities in terms of these units accurately, it is necessary to transfer AC to DC,

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hence the importance of the AC-DC transfer standard.

Recent improvements in commercial AC instruments have led to worldwide activities in the field of basic standards for AC-DC transfer measurements by using the thermal converter. Thermal converters are the most accurate devices used by National Metrology Institutes (NMIs) for the transfer of AC voltage and current to equivalent DC quantities. Thermal converters are widely used in both national and industrial laboratories as the basis for AC-DC transfer. Simply, the AC-DC transfer standard is one of the basic electrical standards, by which the AC voltage and AC current are deduced from their DC counterparts in the frequency range between 10 Hz and 1 MHz. AC-DC transfer standards are then required for this purpose, and are fundamental to the electrical system of measurements. The operating principle of the thermal AC-DC transfer standards is based on Joule heating, to convert electrical energy of an AC waveform into heat, which leads to an increase in temperature which can be detected thermoelectrically. The converted AC voltage can be compared with the voltage produced when the same device is operated with DC excitation. Thus, the rms quantity is related to the DC quantity and the technique is commonly referred to ac AC-DC transfer measurement. [4].

According to the definition of the AC signal it is possible to compare the AC voltage with the DC by way of the electrical power. In the thermal method, DC and AC voltages are alternately applied to the heater of a thermal converter. Then the amounts of joule heating are compared by measuring the temperature of the heater by a thermocouple. When DC and AC voltage of equal power are applied to the input of an ideal thermal converter, output electro motive forces (EMFs) should be the same for both of the inputs. However, in the case of an actual thermal converter, the EMFs outputs are influenced by the effect of non-joule heating and frequency characteristic of heater circuit. The “ac-dc transfer difference” is the principal quantity in the ac-dc transfer standard. In the last few years, the source of these correction factors of the thermal converters have been the subject of through investigations.

This article focuses on these sources and the technical methods for determining the transfer differences for the thermal converters by establishing and characterizing a new alternative calibration system for the determination of the AC-DC difference of the TCs. In quest of better understanding of the error sources, the physical structure of TCs can be represented using electrical simulation of the equivalent modeling of LRC circuit. In this review, we will discuss (LT Spice) Simulator, to avoid some of the major problems involved in the routine methods of the AC voltage and current measurements, of these: they are time - consuming, costly, and yield a greater uncertainty value, not to mention the possible damage of the devices during shipping when sending abroad for calibration.

This article discusses the establishment and characterization of a new virtual alternative calibration system for determination of the AC-DC Difference of the Thermal Converter. The virtual mode depends on the technical applications of a reliable simulator, such as LT-Spice IV Simulator. According to previous work in this area Physical structure of Single-Junction Thermal Converter (SJTC can be represented using electrical simulation of an equivalent modeling of LRC circuit.

This virtual system helps to avoid some of the major problems involved in the routine methods of the AC voltage and current measurements. The system of the traditional calibration is very costly, and hence only a few international laboratories can have it. Accordingly, this virtual calibration system will act as a good alternative for the national small laboratories regarding the calibration processes. It is cheap, manageable and easy to construct by the lab's technicians with simple electronics accessories

2. Principle of AC-DC transfer

In practice, the response of the thermoelement (TE) of the AC-DC Transfer Standards is not ideal, due to the presence of thermoelectric effects, frequency dependent effects and other error sources. This deviation in TE from the same response for AC and DC signals is specified in metrology terms as AC-DC Difference (δ). Furthermore, TE respond differently to positive and negative DC voltages. This behavior causes what is known as DC reversal error [5]. Reversal error is eliminated during the measurements by taking the average of the positive and negative supply voltage. The δ, is usually given in (μV/V) and defined in Eq. (1)

$$\delta = \left.\frac{V_{ac} - V_{dc}}{V_{dc}}\right|_{E_{ac} = E_{dc}} \tag{1}$$

Where: δ = AC-DC difference for the TE.

V_{ac} = rms value of AC voltage, V_{dc} = average of the absolute values of DC voltage applied in positive and negative direction across the TE.

In AC-DC Current Transfer Standard, the AC-DC Difference is defined as the ratio of the AC and DC current required to produce the same output on the thermal converter as given in Eq. (2).

$$\delta = \frac{I_{ac} - I_{dc}}{I_{dc}} \tag{2}$$

The relation between the input AC voltage (or current) and the output of the TE is given as in Eq. (3).

$$E = KV^n \tag{3}$$

where, E is the output (emf) of the TE, V is the applied voltage, K varies with large changes in heater current but it is constant over a narrow range where nearly equal AC & DC currents are compared and n is usually 1.6 to 1.9 at the rated heater current for SJTC while equals 2 in MJTC. Therefore, the output (emf) of the TE is used to evaluate the AC-DC Difference using Eq. (4).

$$\delta_{AC-DC} = \frac{E_{AC} - E_{DC}}{nE_{DC}} \tag{4}$$

3. Electrical Modeling and Simulation

Electrical model is a model in the form of a mathematical description or an electrical equivalent circuit that represents the behavior of an electrical device or a system [6]. The topic of modeling has acquired great importance in engineering education because of astronomical increase in computing power. The simulation of the electrical and optical behavior of devices has been established as an essential tool for both the improvement of existing devices and for the development of new ones. There is no doubt that the role of device modeling will increase in the future. Device modeling involves the numerical solution of a set of equations, which form a mathematical model for device operation, together with models that describe the material properties.

Electrical simulation is a field that includes both device and circuit simulation techniques, each of which serves a distinct purpose. Device simulation is a higher fidelity approach, in which a single semiconductor device is represented with a set of coupled partial differential equations (PDEs), discretized on a spatial mesh. Device simulation is intended to be accurate, using models for the behavior of the electrical devices that are based on fundamental physics. However, device simulation is often compute-intensive and is not practical for simulation of entire circuits. Thus, transistor-level models (compact models) are derived from these physics-based simulations that are based on the underlying physics, empirical data (curve-fitting), or tabular data (look-up table). Compact models are much faster to simulate than the original physics-based model and can be integrated into a circuit simulator [7].

3.1 Modeling and Simulation Approach

Indeed, the electrical simulation modeling by using the LT-Spice software [8] has been achieved widely to analyze the physical structure and electrical characteristics of the TE in an effort to better understand the origin of errors in these devices. Another important purpose for using the electrical simulation is performing the building up and building down scaling for the

AC-DC Difference measurements. Therefore, the electrical simulation, then, can be used easily to determine the expected AC-DC difference for that device for different values around the rated value at the same frequency. The values from 40 % to 110 % of the rated value of the device are suggested in this review article for obtaining an accurate theoretical determination of the associated AC-DC differences.

The methodology depends entirely on the comparison between the results given by the practical work inside an accredited laboratory and the simulated results given by the virtual system. Many experimental works will be performed through the actual computerized system, while all theoretical results will be predicted through the virtual system based on the electrical modeling and simulation.

According to previous works in this area [9, 10, 11, 12], through the normal use of the SJTVC (the TE itself without any multiplier resistor), the equivalent electrical circuit was imaged as shown in Fig 1. The equivalent circuit parameters of the TE were accurately measured at 55 Hz, for example, by using a very sensitive digital LCR Meter. The typical results of these parameters are listed in Table 1.

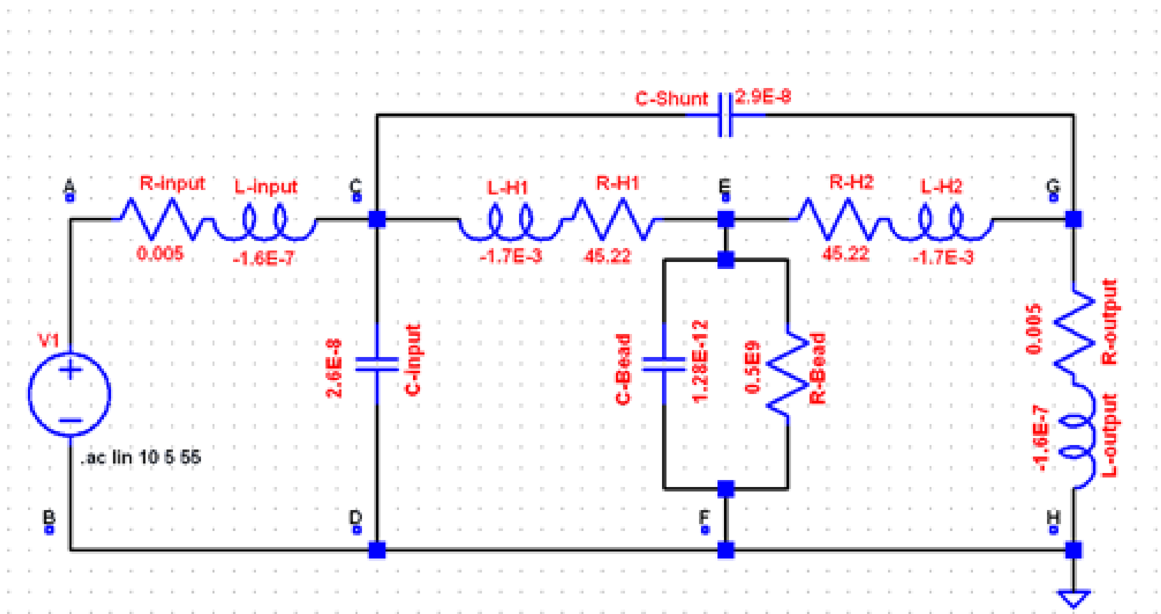

Fig.1: The Suggested Equivalent Circuit of the SJTVC

3.2 Results and Discussion

At the National Institute for Metrology, the thermal converters are characterized or calibrated by the comparison with another converter by the application of dc(+), ac, dc(-) signals in a timed sequence (Fig. 2). In this process, voltage converters are connected in parallel through a coaxial tee, and the current converters or transfer shunts are usually connected in series. This system yields uncertainties range from about 10^{-6} to 7 x 10^{-5} for voltage measurements at 1 MHz [13].

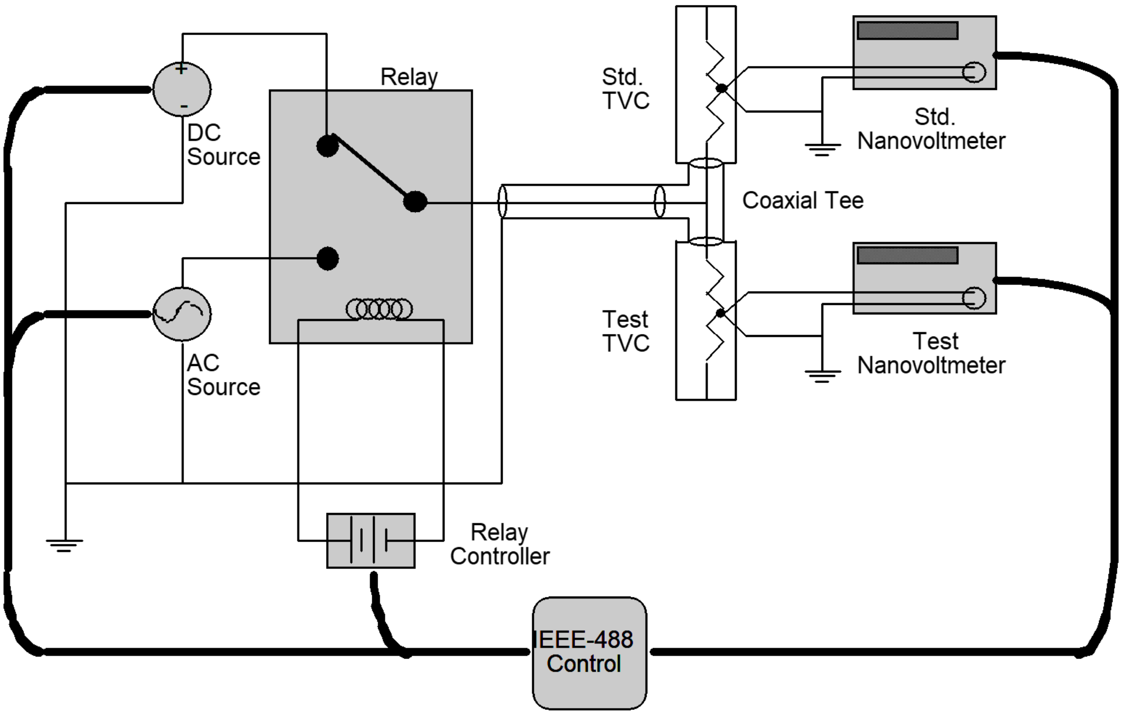

Fig. 2: Block diagram of the automatic ac-dc difference measurement system at NMI

This practical system (computerized or manually) to determine the AC-DC Difference of the Thermal Converters with very small uncertainty at different frequencies. However, many drawbacks were noticed, during this process. The comparison between the results of practical and simulated methods, Fig. 3 and Table 2, at frequencies of 55 Hz, 1 kHz, 10 kHz and 20 kHz, have been analyzed and reflected a good agreement with the results. This, of course, shows the reliability of that method, hence the challenge and motivation

Table 1: The Measured Parameters of the TE at 55 Hz

Symbol	Description	Values
L-input and L-output	Inductance of input and output leads	0.16 µH for each
C-input	Parasitic capacitances across the input terminals of the TE	26 nF
L-H1 and L-H2	The inductances of the two similar parts of the heater	1.7 mH for each
R-H1 and R-H2	The resistances of the two similar parts of the heater	45.22 Ω for each
C-Shunt	The parasitic capacitance across the voltage drop of the TE heater	29 nF
C-Bead	The parasitic capacitance across the insulator bead	1.28 pF
R-Bead	The high resistance of the insulator bead	0.5 GΩ

Table 2: The Comparison between practical and the simulated results

Frequency	Practical results of the AC-DC Difference, (ppm)	Simulation results of the AC-DC Difference, (ppm)	The simulation error, (ppm)
55 Hz	**-81.2**	**-69**	**-12.2**
1 kHz	**-63.7**	**-39.5**	**-24.2**
10 kHz	**-195.5**	**-157.2**	**-38.3**
20 kHz	**-436.3**	**-389.8**	**-46.5**

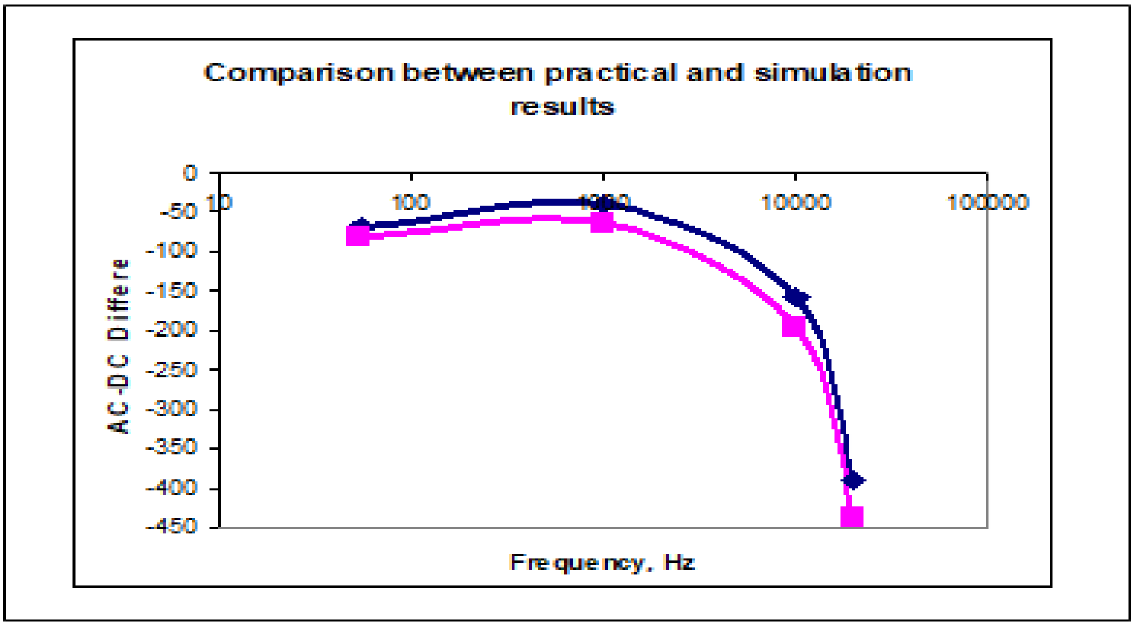

Fig. 3: Comparison between practical and simulated results

To evaluate the efficiency of the characterization and to determine the simulation error at the different frequencies, a comparison between the theoretical and practical results of the TE AC-DC Difference was performed at the rated value (5 mA). The practical results were evaluated based on equation (2). The simulation results were calculated based on the relative different between the heat power (I^2 R) on the TE heater due to the applied DC signal and the real part of the applied AC signal., as defined in Eq. (5) [5]

$$\delta_{sim} = \frac{P_{H,ac} - P_{H,dc}}{nP_{H,dc}} \quad (5)$$

In the same manner, the electrical simulation can be applied and extended by researchers to achieve the calibration process in a more simple way as described in this article.

Conclusion

The results obtained by simulation were in a good agreement with the practical results, this validates the reliability of the new method. Certainly, the new system removed the difficulties accompanying the traditional calibration system. Furthermore, this new method will provide valuable information in predicting the calibration values of these converters in a wide range of frequencies. We are looking forward to repeat the same work for the multi-junction thermal voltage converter (MJTVC) to consider this methodology as a reliable alternative system for the practical one and to overcome all drawbacks of the current systems.

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