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# CONSIDERATIONS ON THE INFLUENCE OF TRAVELLING STANDARDS INSTABILITY IN AN INTERLABORATORY COMPARISON PROGRAM

*Sousa, J.J.L.*[1], *Leitão, L.T.S.* [2], *Costa, M.M.* [3], *Faria, M. C.* [4]

[1] Chesf, Recife, Brasil, joel@chesf.gov.br
[2] Chesf, Recife, Brasil, torres@chesf.gov.br
[3] Eletronorte, Belém, Brasil, marcelo.melo@eletronorte.gov.br
[4] Furnas, SJBarra, Brasil, maria@furnas.com.br

**Abstract:**

This paper has the purpose to show how the instability of travelling standards can affect the results of an interlaboratory comparison program, and how to evaluate its influence in the determination of these results, in order to not compromise the assessing of a laboratory when En value is used for this purpose. In this work are presented and discussed five options of instability compensation of the travelling standard.

**Keywords:** Interlaboratory comparison, instability travelling standard, normalized error.

## 1. INTRODUCTION

Interlaboratory comparisons programs are indispensable for assessing technical competence of laboratories. They follow standards and guides that are based on a fundamental requirement: the repeatability and instability of the travelling standard. Their main goal is to enable laboratories to evaluate their calibrations regarding to: calibration procedures; traceability to the National Metrology Laboratories (NMLs); uncertainty levels; operator procedures; and others. Furthermore, interlaboratory comparison programs allow exchange of technical informations among participants.

In Brazil, there are two major interlaboratory comparison programs designed for laboratories that belong to electric power utilities: one deals with electrical energy calibration, with more than 30 years, and has 24 participants; the other, with 6 years, is related to voltage, current, resistance and electrical frequency calibration, and has 16 participants. Some of the participants of these programs are accredited for the Brazilian NML - Inmetro to perform electrical calibrations in accordance to ISO/IEC 17025 standard, while others perform calibrations that are traceable.

Both interlaboratory comparison programs compare the calibration results of each participant to the results of the reference laboratory to determine if participants' results are compatible to the reference. These programs have one year periodicity. It has been observed that during circulations the travelling standard presents instability. The question is how to consider this instability in the evaluation of laboratories' results.

This paper has the propose to show, in the following sections, how the travelling standard instability affects the value of the normalized error in a interlaboratory comparison program, and shows five options of how to consider this instability.

## 2. CONSIDERATIONS

To assess the technical competence of laboratories, Braziliam Interlaboratory Comparison Programs use the standard DOQ-CGCRE-005 [1], published by the Brazilian NML - Inmetro [1]. The expression used for this purpose is the normalized error En (1).

$$E_n = \left| \frac{E_{lab.} - \mathrm{E}_{\mathrm{ref.}}}{\sqrt{(U_{lab})^2 + (U_{ref})^2}} \right| \leq 1 \qquad (1)$$

Where:
$E_{lab}$=laboratory error
$E_{ref}$=reference laboratory error
$U_{lab}$=laboratory uncertainty
$U_{ref}$=reference laboratory uncertainty

Experiences have shown that the repeatability of a good instrument is below 10% of its accuracy/maximum error. For example, a 0,2% accuracy travelling standard shows variations of random errors below $\bar{x} \pm 0.02\%$, where $\bar{x}$ is the average of the readings during calibration. This implies a small Type A uncertainty in relation to other components. So the numerator in En expression (1) is more influenced by the instability of travelling standard than the involved uncertainties.

1.1. Energy Interlaboratorial Comparison Program data

Each year the results of the Energy Interlaboratorial Comparison Program are reported as shown in the table of Fig.1. For the year 2009, for instance, the uncertainty of the participating laboratories ranged from 0.0082% to 0.09% and the uncertainty of the reference laboratory was 0.0075%. En, in this table, is calculated using (1) considering:

$$E_{ref} = \frac{E_{refI} + E_{refF}}{2} \qquad (2)$$

$$U^2_{\mathrm{Re}f} = \left(\max(U_{refI}, U_{refF})\right)^2 + \left(\frac{E_{refI} - E_{refF}}{\sqrt{3}}\right)^2 \qquad (3)$$

| Energia Ativa Trifásica<br>Ponto: 120V, 5A, FP=1,00 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Nº | Empresa | Elab (%) | Eref I (%) | Eref F (%) | Ulab (%) | Uref I (%) | Uref F (%) | En | Diag |
| 1 | | -0,0111 | -0,0111 | -0,0091 | 0,0075 | 0,0075 | 0,0075 | - | - |
| 2 | | -0,002 | -0,0111 | -0,0091 | 0,014 | 0,0075 | 0,0075 | 0,51 | OK |
| 3 | | -0,004 | -0,0111 | -0,0091 | 0,0149 | 0,0075 | 0,0075 | 0,36 | OK |
| 4 | | -0,013 | -0,0111 | -0,0091 | 0,013 | 0,0075 | 0,0075 | 0,19 | OK |
| 5 | | 0,0006 | -0,0111 | -0,0091 | 0,0585 | 0,0075 | 0,0075 | 0,18 | OK |
| 6 | | -0,009 | -0,0111 | -0,0091 | 0,0599 | 0,0075 | 0,0075 | 0,02 | OK |
| 7 | | -0,0088 | -0,0111 | -0,0091 | 0,0092 | 0,0075 | 0,0075 | 0,11 | OK |
| 8 | | -0,006 | -0,0111 | -0,0091 | 0,014 | 0,0075 | 0,0075 | 0,26 | OK |
| 9 | | -0,0132 | -0,0111 | -0,0091 | 0,0217 | 0,0075 | 0,0075 | 0,13 | OK |
| 10 | | -0,014 | -0,0111 | -0,0091 | 0,0146 | 0,0075 | 0,0075 | 0,24 | OK |
| 11 | | -0,009 | -0,0111 | -0,0091 | 0,021 | 0,0075 | 0,0075 | 0,05 | OK |
| 12 | | -0,0098 | -0,0111 | -0,0091 | 0,0091 | 0,0075 | 0,0075 | 0,03 | OK |
| 13 | | -0,0141 | -0,0111 | -0,0091 | 0,0082 | 0,0075 | 0,0075 | 0,36 | OK |
| 14 | | -0,002 | -0,0111 | -0,0091 | 0,052 | 0,0075 | 0,0075 | 0,15 | OK |
| 15 | | -0,012 | -0,0111 | -0,0091 | 0,021 | 0,0075 | 0,0075 | 0,09 | OK |
| 16 | | -0,002 | -0,0111 | -0,0091 | 0,017 | 0,0075 | 0,0075 | 0,44 | OK |
| 17 | | -0,005 | -0,0111 | -0,0091 | 0,016 | 0,0075 | 0,0075 | 0,29 | OK |
| 18 | | -0,013 | -0,0111 | -0,0091 | 0,05 | 0,0075 | 0,0075 | 0,06 | OK |
| 19 | | 0,038 | -0,0111 | -0,0091 | 0,09 | 0,0075 | 0,0075 | 0,53 | OK |
| 20 | | 0 | -0,0111 | -0,0091 | 0,058 | 0,0075 | 0,0075 | 0,17 | OK |
| 21 | | 0 | -0,0111 | -0,0091 | 0,024 | 0,0075 | 0,0075 | 0,40 | OK |
| 22 | | 0,008 | -0,0111 | -0,0091 | 0,014 | 0,0075 | 0,0075 | 1,14 | NC |
| 23 | | -0,0091 | -0,0111 | -0,0091 | 0,0075 | 0,0075 | 0,0075 | - | - |
| 24 | | -0,0101 | -0,0111 | -0,0091 | 0,0075 | 0,0075 | 0,0075 | - | - |

Fig.1- PCI-Wh-2009, 120V, 5A, pf=1

From the historical behavior of the travelling standard we are able to construct its historical instability, as shown in Fig.2. It is observed that this instability is below the instability informed by the manufacture, that is, ±0,015%.

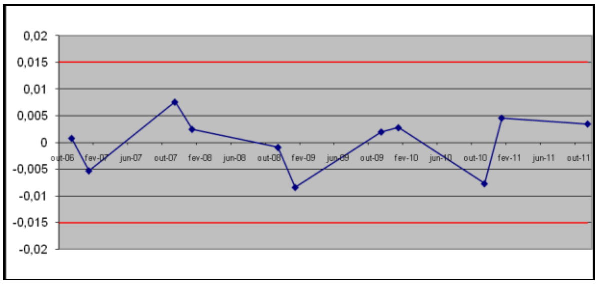


Fig.2-Travelling standard instability

Fig.2 shows, also, that the historical instability is within ±0.010%. So it seems appropriate to consider this value as being the historical instability of the travelling standard for the purpose of this work.

Now we are going to show the influence of the travelling standard instability in the calculation of the normalized error En. Let us consider two examples based on the data of lab 13 shown in Fig.1.

Ex-1:
Laboratory and reference measures perfectly.
Instability of the travelling standard is based on his historical data (0.010% according to Fig.2). So there are the following data:
Travelling standard instability = 0.010%
$E_{lab}$ = e%+ 0.010%
$U_{lab}$ = 0.0082%
$U_{ref}$ = 0.0075%
$E_{ref}$ = e%
Where e% represents the error measured by the reference laboratory in t1 and e%+0.010% represents the error measured by the lab in t2, as shown in Fig.3.

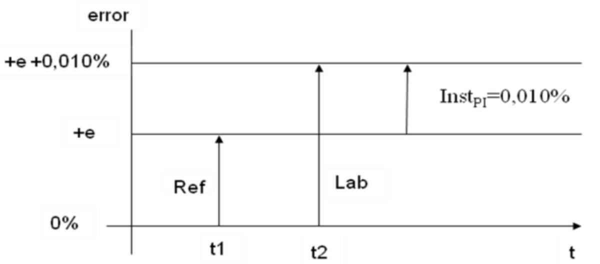


Fig.3-errors measured by Ref and Lab

Using (1), the value of En is calculated as:

$$E_n = \left| \frac{e + 0{,}01 - e}{\sqrt{(0{,}0082_{lab})^2 + (0{,}0075_{ref})^2}} \right| = 0{,}9$$

Ex-2:
Laboratory and reference measures perfectly.
Instability of the travelling standard is the informed by the manufacture (± 0.015%/year). So there are the following data:
Travelling standard instability = 0.015%
$E_{lab}$ = e%+ 0.015%
$U_{lab}$ = 0.0082%
$U_{ref}$ = 0.0075%
$E_{ref}$= e%
Where e% represents the error measured by the reference laboratory in t1 and e%+0.015% represents the error measured by the lab in t2.

Using (1), now the value of En is calculated as being:

$$E_n = \left| \frac{e + 0{,}015 - e}{\sqrt{(0{,}0082_{lab})^2 + (0{,}0075_{ref})^2}} \right| = 1{,}35$$

These two values, En=0,9 and En=1,35, show the possibility of the effect of travelling standard instability on the outcomes of an interlaboratory comparison program.

1.2. Electrical Interlaboratorial Comparison Program data

In this program we do not have sufficient data to construct the historical instability of the travelling standard. Also the manufacture's manual does not present any information about its instability, only about its accuracy specification, such as shown in Fig.4.

■ DC Characteristics

Accuracy Specifications ± ( % of reading + % of range ) [ 1 ]

| Function | Range [ 3 ] | Test Current or Burden Voltage | 24 Hour [ 2 ] 23°C ± 1°C | 90 Day 23°C ± 5°C | 1 Year 23°C ± 5°C | Temperature Coefficient /°C 0°C – 18°C 28°C – 55°C |
|---|---|---|---|---|---|---|
| DC Voltage | 100.0000 mV | | 0.0030 + 0.0030 | 0.0040 + 0.0035 | 0.0050 + 0.0035 | 0.0005 + 0.0005 |
| | 1.000000 V | | 0.0020 + 0.0006 | 0.0030 + 0.0007 | 0.0040 + 0.0007 | 0.0005 + 0.0001 |
| | 10.00000 V | | 0.0015 + 0.0004 | 0.0020 + 0.0005 | 0.0035 + 0.0005 | 0.0005 + 0.0001 |
| | 100.0000 V | | 0.0020 + 0.0006 | 0.0035 + 0.0006 | 0.0045 + 0.0006 | 0.0005 + 0.0001 |
| | 1000.000 V | | 0.0020 + 0.0006 | 0.0035 + 0.0010 | 0.0045 + 0.0010 | 0.0005 + 0.0001 |

Fig.4 – DC characteristics of travelling standard

In Fig.5 we have a table of the results of the electrical interlaboratorial comparison program. En is calculated the same way as table in Fig.1.

**Relatório de 2010** Programa de Comparação Interlaboratorial de Eletricidade

**Grandeza Calibrada: Tensão DC**

| 100 mV | Empresa | Erro(%) | Incerteza(%) | *Erro Ref(%)* | *Inc ref(%)* | *En relativo* | En | Status |
|---|---|---|---|---|---|---|---|---|
| 1 | INMETRO | 0,00060 | 0,00040 | 0,00070 | 0,00042 | -0,2 | 0,17 | OK |
| 2 | Empresa 02 | -0,0019 | 0,0014 | 0,00070 | 0,00042 | -1,8 | 1,78 | NC |
| 3 | Empresa 03 | -0,0010 | 0,0014 | 0,00070 | 0,00042 | -1,2 | 1,16 | NC |
| 4 | Empresa 04 | -0,0011 | 0,0039 | 0,00070 | 0,00042 | -0,5 | 0,46 | OK |
| 5 | Empresa 05 | -0,0007 | 0,0052 | 0,00070 | 0,00042 | -0,3 | 0,27 | OK |
| 6 | Empresa 06 | -0,0073 | 0,0015 | 0,00070 | 0,00042 | -5,1 | 5,14 | NC |
| 7 | Empresa 07 | -0,0010 | 0,0040 | 0,00070 | 0,00042 | -0,4 | 0,42 | OK |
| 8 | Empresa 08 | 0,0015 | 0,0043 | 0,00070 | 0,00042 | 0,2 | 0,19 | OK |
| 9 | Empresa 09 | -0,0024 | 0,0123 | 0,00070 | 0,00042 | -0,3 | 0,25 | OK |
| 10 | Empresa 10 | -0,00009 | 0,0062 | 0,00070 | 0,00042 | -0,1 | 0,13 | OK |
| 11 | Empresa 11 | -0,0019 | 0,0014 | 0,00070 | 0,00042 | -1,8 | 1,78 | NC |
| 12 | Empresa 12 | 0,00062 | 0,0070 | 0,00070 | 0,00042 | 0,0 | 0,01 | OK |
| 13 | Empresa 13 | -0,0024 | 0,0020 | 0,00070 | 0,00042 | -1,5 | 1,52 | NC |
| 14 | Empresa 14 | NR | NR | 0,00070 | 0,00042 | NR | NR | NR |
| 15 | INMETRO | 0,00080 | 0,00040 | 0,00070 | 0,00042 | 0,2 | 0,17 | OK |

Fig.5 – Electrical Interlab. Comparison

## 3. TECHNICAL CONSIDERATIONS

The calculation of En that takes into account the influence of the instability of the travelling standard, which is the purpose of this work, is defined by (6), developed from (1), considering:

$$E_{ref} = \left( \frac{E_i + E_f}{2} \right) \tag{4}$$

$$U_{ref}^2 = \left( \frac{U_i + U_f}{2} \right)^2 + \left( \frac{2 * inst_{PI}}{\sqrt{3}} \right)^2 \tag{5}$$

Where:
$E_i$=lab error at the beginning of the circulation
$E_f$=lab error at the end of the circulation
$U_i$=reference lab uncertainty at the beginning
$U_f$=reference lab uncertainty at the end
$Inst_{PI}$=travelling standard instability

So we obtain the equation below:

$$E_n = \left| \frac{E_{lab} - \left( \frac{E_i + E_f}{2} \right)}{\sqrt{(U_{lab})^2 + (\frac{U_i + U_f}{2})^2 + \left( \frac{2 * inst_{PI}}{\sqrt{3}} \right)^2}} \right| \tag{6}$$

Where InstPI represents the travelling standard instability that must be considered according to one of the five options below:

a. Instability is calculated using the measurements performed by the reference laboratory during circulations, one in the start and the other in the end of the circulation, using (7).

$$inst_{PI} = \left| \frac{E_i - E_f}{2} \right| \tag{7}$$

b. Instability based in the historical behavior of the travelling standard. A minimal number of calibrations of the travelling standards has to be defined as in Fig.2. In this case:
$inst_{PI} = 0{,}010\%$

c. Instability is evaluated using travelling standard's time drift defined by its manufacturer. In this case:
$inst_{PI} = 0{,}015\%$

When we do not know the manufactures' instability, such is the case of the electrical interlaboratorial comparison program, we suggest two additional options, considering data on Fig.4, for 100 mV DC.

d. Take the standard's accuracy divided by 3.

$$Inst_{PI} = \frac{accuracy}{3} = \frac{0{,}0085\%}{3} = 0{,}0028\%$$

e. Take into account the standard's specification for 1 year and for 90 days.

$$Inst_{PI} = (specif_{1year} - specif_{90days}) * 12/9 = 0{,}0013\%$$

3.1. Calculation of En for Energy Interlaboratorial Comparison

Repeating the example Ex-2 of the previous section, now applying (6), we have three situations:

1) Travelling standard instability during the circulation (using option-a)

$$\rightarrow inst_{PI} = \left| \frac{E_i - E_f}{2} \right| = \left| \frac{0\% - 0\%}{2} \right| = 0\%$$

$$E_n = \left| \frac{0{,}015\% - \left( \frac{0\% + 0\%}{2} \right)}{\sqrt{(0{,}0082\%)^2 + (\frac{0{,}0075\% + 0{,}0075\%}{2})^2 + \left( \frac{2 * 0\%}{\sqrt{3}} \right)^2}} \right| = 1.35$$

In this situation we used as instPI the instability of the circulation. In this particular case it was admitted the hypothesis that the reference laboratory measured the same value at the beginning and at the end of the circulation. Although the lab measured correctly, the value of En indicated the contrary.

2) Instability based in the historical behavior of the travelling standard (using option-b)
➔ $inst_{PI} = 0{,}01\%$

$$E_n = \left| \frac{0{,}015\% - \left(\frac{0\% + 0\%}{2}\right)}{\sqrt{(0{,}0082\%)^2 + (\frac{0{,}0075\% + 0{,}0075\%}{2})^2 + \left(\frac{2 * 0{,}01\%}{\sqrt{3}}\right)^2}} \right| = 0.94$$

In this situation, where we used the historical instability of the travelling standard, which value was 0.01%, according to Fig.2, the value of En has already indicated a compliance of the laboratory.

3) Travelling standard instability defined by its manufacturer (using option-c)
➔ $inst_{PI} = 0{,}015\%$

$$E_n = \left| \frac{0{,}015\% - \left(\frac{0\% + 0\%}{2}\right)}{\sqrt{(0{,}0082\%)^2 + (\frac{0{,}0075\% + 0{,}0075\%}{2})^2 + \left(\frac{2 * 0{,}015\%}{\sqrt{3}}\right)^2}} \right| = 0.73$$

In this situation, where it was used the instability provided by the manufacturer, which value was 0.015%, the value of En also indicated a compliance of the laboratory.

Thus, in situations 2 and 3, where it was taken into account the instability of the travelling standard in calculation of En, we observe that the results of the laboratory was considered as correct. The effect of instability of the traveling standard has been eliminated.

### 3.2. Calculation of En for Electrical Interlaboratorial Comparison

From Fig.5 we chose *empresa-2* as example, whose data are:

Elab = -0.0019%
Ulab = 0.0014%
Ui=Uf= 0.0004%
Ei=0,0006%
Ef=0,0008%

Applying (6) we have two additional situations as following:

4) $Int_{PI}$=0,0028% (using option-d)

En=0,73

In this situation there was a compensation of the effect of the travelling standard instability.

5) $Int_{PI}$=0,0013% (using option-e)

En=1,24

In this situation there was not a compensation of the effect of the travelling standard instability.

### 3.3. Maximum instability

The maximum instability that the travelling standard has to have so that it does not interfere in the assessing of a laboratory is given by expression (8).

$$inst \leq \sqrt{(U_{lab})^2 + (U_{ref})^2} \qquad (8)$$

## 4. CONCLUSIONS

This paper shows that in an interlaboratory comparison program it is mandatory to analyse if the instability of the travelling standard interferes in the labs' results.

If the instability is to be considered this work presents five suggestions of how to take them into account. One of them is best suitable for each case.

In principle we should use the instability provided by the manufacturer, if available. If not, we should use the historical instability of the travelling standard. In the absence of those instabilities we can adopt, for the travelling standard instability, the options d and e of this work.

The instability of the circulation is an alternative that is commonly used although it may not capture the travelling standard instability that might occur during the circulation.

## 5. REFERENCES


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