Expression of the Measurement Accuracy in Calibration with using Calmet's instruments - calibration of meter on-site

Calmet
Calibration

Application Note No18

What is the Accuracy and how to express it?

Accuracy is a qualitative expression of the closeness of a measurement's result to the true value. In the recent times, accuracy of measuring instruments is described using two quantitative terms:

- **limits of error** EN 60359 [1], which is the traditional description of the accuracy used in power engineering and industries associated with it,
- **uncertainty** EA-4/02 [2], which is a new description of the accuracy used in laboratories.

Calmet Ltd provides the broad range of calibrators, meters and testers for use in laboratories and factories as well as on site. Therefore, the accuracy of some Calmet's measuring instruments is expressed by the specification of uncertainty (mainly calibrators) and the second – the specification of the limits of error (mainly testers).

This application note presents how to calculate the uncertainty from error limits.

[1] EN 60359 Electrical and electronic measurement equipment – Expression of performance.

[2] EA-4/02 Expression of the Uncertainty of measurement in Calibration

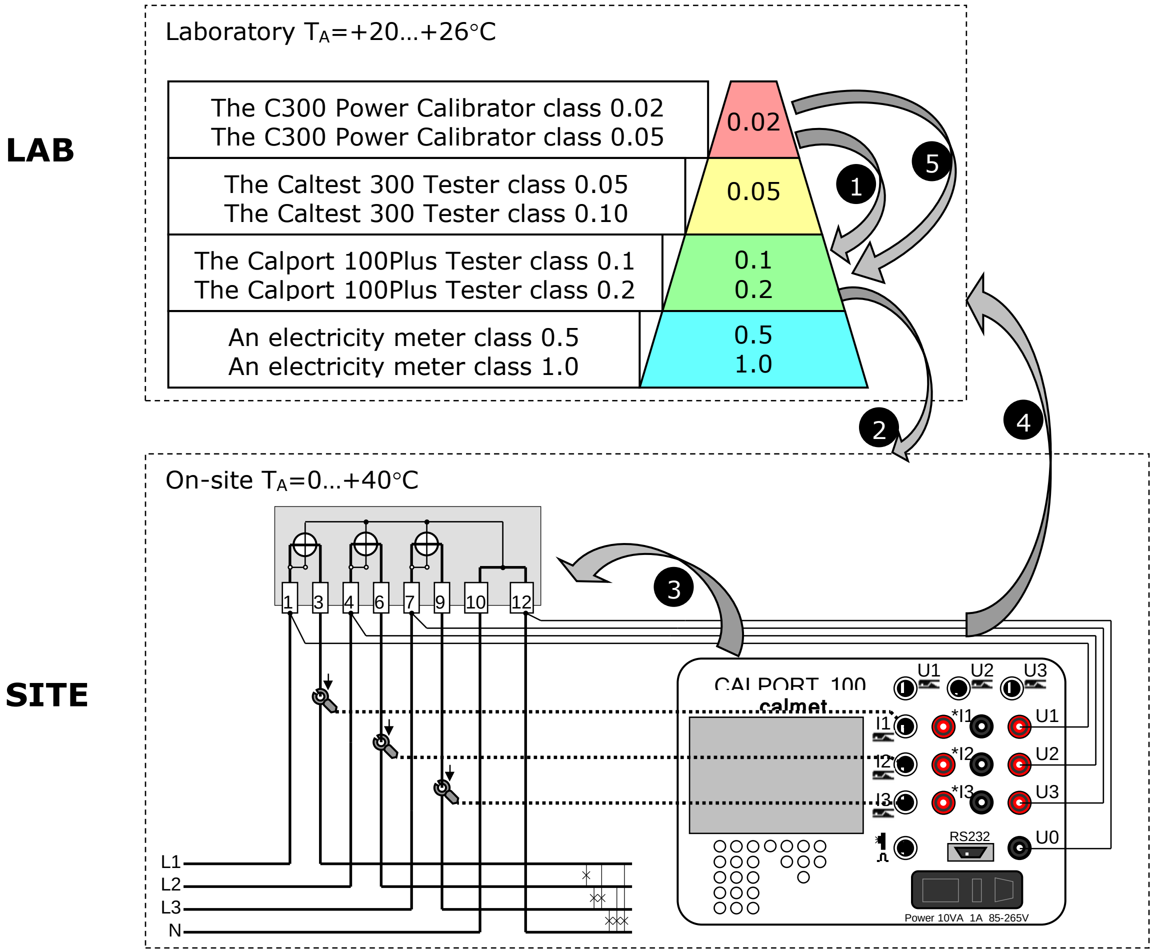
What is the Transportation Error and how to express it?

Calibration of connected to the power network electricity meter on-site can be performed in steps:

❶ Calibration #1 of the Calport 100Plus Tester in laboratory with reference to the C300 Calibrator,
❷ Transportation of the Calport 100Plus Tester from laboratory to site of an electricity meter installation,
❸ Calibration of the electricity meter on-site with reference to the Calport 100Plus Tester,
❹ Transportation of the Calport 100Plus Tester from site of the electricity meter installation to laboratory,
❺ Calibration #2 of the Calport 100Plus Tester in laboratory with reference to the C300 Calibrator.

Transportation error can be defined as $\delta E_{TRANS} = \delta E_{CAL\#2} - \delta E_{CAL\#1}$

where $\delta E_{CAL\#1}$ and $\delta E_{CAL\#2}$ are the Calport 100Plus calibration results in steps marked as ❶ and ❺



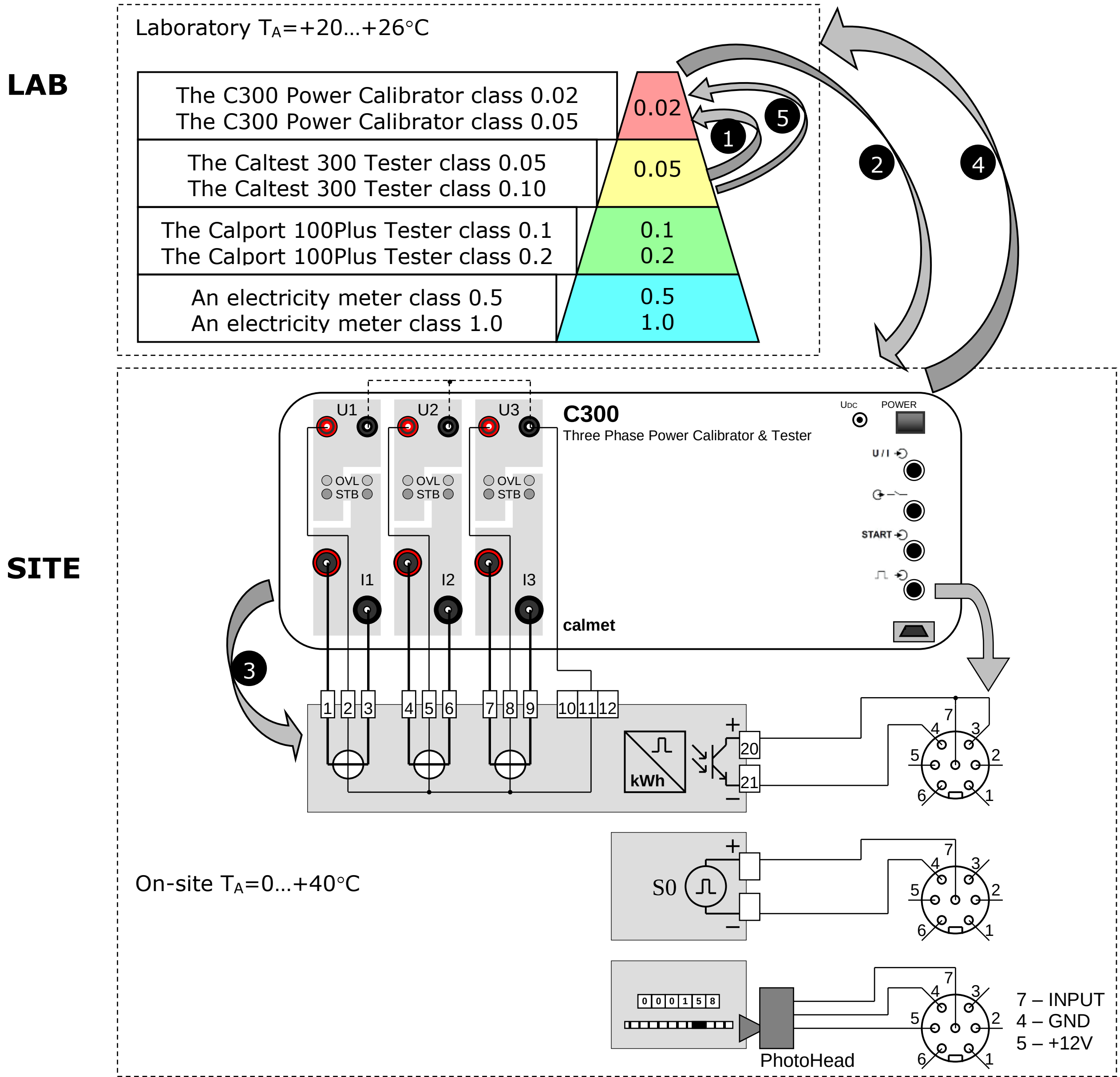
Calibration of the electricity meter on-site in all measurement points required by standards such as EN 50470

This calibration can be performed in steps:

❶ Calibration #1 of the C300 Calibrator in laboratory with reference to the Caltest 300 Tester,
❷ Transportation of the C300 Calibrator from laboratory to site of an electricity meter installation,
❸ Calibration of the electricity meter on-site with reference to the C300 Calibrator,
❹ Transportation of the C300 Calibrator from site of the electricity meter installation to laboratory,
❺ Calibration #2 of the C300 Calibrator in laboratory with reference to the Caltest 300 Tester.

Transportation error can be defined as $\delta E_{TRANS} = \delta E_{CAL\#2} - \delta E_{CAL\#1}$

where $\delta E_{CAL\#1}$ and $\delta E_{CAL\#2}$ are the Caltest 300 calibration results in steps marked as ❶ and ❺



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6. An electricity meter class 1 uncertainty budget, which is calibrated with use the C300 as reference on Site

Specification

Active power/energy accuracy of the C300 is expressed as an absolute extended basic uncertainty under confidence level of 95% (with coverage factor k=2) and it covers:

- reference uncertainty of standards – the traceability of the external standards used for calibration,
- stability in 12 months,
- influence of ambient temperature in range +20…+26°C,
- influence of humidity in range to 90%@+5…+30°C and to 75%@+30…+40°C,
- line regulation - influence of power supply voltage in voltage range 90…264V and frequency range 47…63Hz,
- load regulation - influence of load in range from zero to maximum load,
- nonlinearity.

Ambient temperature influence in temperature range +5…+20°C and +26…+40°C is 0.1 of the absolute extended basic uncertainty per 1°C.

Model equation

$\delta E_X = \delta E_{SB} + \delta E_{ST}$

List of values

Parameter	Unit	Definition	Description
δE_X	%	Measuring uncertainty of the C300	
δE_{SB}	%	Basic uncertainty from the C300 specification	Type B Rectangular distribution Extended measuring uncertainty: 0.02% Coverage factor: 2
δE_{ST}	%	Temperature uncertainty from the C300 specification	Type B Rectangular distribution Extended measuring uncertainty: 0.002%/°C Coverage factor: 2

Example 1. C300 class 0.02, voltage U=3x230V @ 280V range, current I=3x100A @ 120A range, frequency 50Hz, cosφ=1 (φ=0°), T_A=+40°C

Measuring uncertainty budgets for example 1

Parameter	Value [W]	Standard measuring uncertainty [%]	Distribution	Sensitivity coefficient	Uncertainty contribution [%]
δE_{SB}	69000 [1)]	0.0100 [2)]	Rectangle	1	0.0100
δE_{ST}	0	0.0140 [3)]	Rectangle	1	0.0140
δE_X	69000	0.0172 [4)]			

1) Output value E_S=3xUxIxcosφ=3x230Vx100Ax1=69000W
2) Basic uncertainty δE_{SB}=0.02%/2=0.01%
3) Temperature uncertainty δE_{ST}=[(0.002%/2)/°C]x(40°C-26°C)=0.0140%
4) Measuring uncertainty $\delta E_X=\sqrt{(\delta E_{SB}^2+\delta E_{ST}^2)}=\sqrt{(0.01^2+0.014^2)}$=0.0172%

Results for example 1

Parameter	Value [W]	Extended measuring uncertainty *U* [%]	Coverage factor	Coverage probability [%]
δE_x	69000	0.0340 [1)]	2	95

1) $U=2\text{x}\sqrt{(\delta E_{SB}^2+\delta E_{ST}^2)}$

The calibration result is: E_X = 69000W±0.0340%

Example 2. C300 class 0.02, voltage U=3x230V @ 280V range, current I=3x100A @ 120A range, frequency 50Hz, cosφ=1 (φ=0°), T_A=+23±3°C

Measuring uncertainty budgets for example 2

Parameter	Value [W]	Standard measuring uncertainty [%]	Distribution	Sensitivity coefficient	Uncertainty contribution [%]
δE_{SB}	69000 [1)]	0.0100 [2)]	Normal	1	0.0100
δE_X	69000	0.0100 [3)]			

1) Output value E_S=3xUxIxcosφ=3x230Vx100Ax1=69000W
2) Basic uncertainty δE_{SB}=0.02%/2=0.01%
3) Measuring uncertainty $\delta E_X=\sqrt{(\delta E_{SB}^2)}=\sqrt{(0.01^2)}$=0.0100%

Results for example 2

Parameter	Value [W]	Extended measuring uncertainty *U* [%]	Coverage factor	Coverage probability [%]
δE_x	69000	0.0200 [1)]	2.0	95

1) $U=2\text{x}\sqrt{(\delta E_{SB}^2)}$

The calibration result is: E_X = 69000W±0.0200%

Specification

Active power/energy accuracy of the Calport 100Plus with 100A current clamps for "I:" input is expressed as limits of intrinsic error and it covers:

- reference uncertainty of standards – the traceability of the external standards used for calibration,
- stability in 12 months,
- influence of ambient temperature in range +20…+26°C,
- influence of humidity in range to 90%@+0…+30°C and to 75%@+30…+50°C,
- line regulation - influence of power supply voltage in voltage range 85…265V and frequency range 45…65Hz or DC.

Ambient temperature influence in temperature range -5…+20°C and +26…+50°C is 0.1 of the limits of intrinsic error per 1°C.

Model equation

$\delta E_X = \delta E_{SI} + \delta E_{ST}$

List of values

Parameter	Unit	Definition	Description
δE_X	%	Measuring uncertainty of the Calport 100Plus	
δE_{SI}	%	Intrinsic error from the Calport 100Plus specification	Type B Rectangular distribution Intrinsic error limit: 0.2%
δE_{ST}	%	Temperature error from the Calport 100Plus specification	Type B Rectangular distribution Temperature error limit: 0.02%/°C

Example 3. Calport 100Plus class 0.1 with 100A current clamps class 0.2, voltage U=3x230V, current I=3x100A, frequency 50Hz, cosφ=1 (φ=0°), t_A=+40°C

Measuring uncertainty budgets for example 3

Parameter	Value [W]	Standard measuring uncertainty [%]	Distribution	Sensitivity coefficient	Uncertainty contribution [%]
δE_{SI}	69000 [1)]	0.115 [2)]	Rectangle	1	0.12
δE_{ST}	0	0.162 [3)]	Rectangle	1	0.16
δE_X	69000	0.244 [4)]			

[1)] Output value E_{SB}=3xUxIxcosφ=3x230Vx100Ax1=69000W
[2)] Intrinsic uncertainty $\delta E_{SI}=0.2\%/\sqrt{3}=0.115\%$
[3)] Temperature uncertainty $\delta E_{ST}=[(0.02\%/\sqrt{3}/°C)]x(40°C-26°C)=0.162\%$
[4)] Measuring uncertainty $\delta E_X=\sqrt{(\delta E_{SI}^2+\delta E_{ST}^2)}=\sqrt{(0.12^2+0.16^2)}=0.199\%$

Results for example 3

Parameter	Value [W]	Extended measuring uncertainty *U* [%]	Coverage factor	Coverage probability [%]
δE_X	69000	0.40 [1)]	2.0	95

[1)] $U=2x\sqrt{(\delta E_{SI}^2+\delta E_{ST}^2)}$

The calibration result is: δE_X = 69000W±0.40%

Example 4. Calport 100Plus class 0.1 with 100A current clamps class 0.2, voltage U=3x230V, current I=3x100A, frequency 50Hz, cosφ=1 (φ=0°), t_A=+23±3°C

Measuring uncertainty budgets for example 4

Parameter	Value [W]	Standard measuring uncertainty [%]	Distribution	Sensitivity coefficient	Uncertainty contribution [%]
δE_{SI}	69000 [1)]	0.115 [2)]	Rectangle	1	0.12
δE_X	69000	0.115 [3)]			

[1)] Output value E_{SB}=3xUxIxcosφ=3x230Vx100Ax1=69000W
[2)] Intrinsic uncertainty $\delta E_{SI}=0.2\%/\sqrt{3}=0.115\%$
[3)] Measuring uncertainty $\delta E_X=\sqrt{(\delta E_{SI}^2)}=\sqrt{(0.115^2)}=0.115\%$

Results for example 4

Parameter	Value [W]	Extended measuring uncertainty *U* [%]	Coverage factor	Coverage probability [%]
δE_X	69000	0.23 [1)]	2.0	95

[1)] $U=2x\sqrt{(\delta E_{SI}^2)}$

The calibration result is: δE_X = 69000W±0.23%

Specification

Active power/energy accuracy of the Caltest 300 is expressed as limits of intrinsic error and it covers:

- reference uncertainty of standards – the traceability of the external standards used for calibration,
- stability in 12 months,
- influence of ambient temperature in range +20…+26°C,
- influence of humidity in range to 90%@+0…+30°C and to 75%@+30…+50°C,
- line regulation - influence of power supply voltage in voltage range 85…265V and frequency range 45…65Hz or DC.

Ambient temperature influence in temperature range 0…+20°C and +26…+50°C is 0.1 of the limits of intrinsic error per 1°C.

Model equation

$\delta E_X = \delta E_{SI} + \delta E_{ST}$

List of values

Parameter	Unit	Definition	Description
δE_X	%	Measuring uncertainty of the Caltest 300	
δE_{SI}	%	Intrinsic error from the Caltest 300 specification	Type B Rectangular distribution Intrinsic error limit: 0.05%
δE_{ST}	%	Temperature error from the Caltest 300 specification	Type B Rectangular distribution Temperature error limit: 0.005%/°C

Example 5. Caltest 300 class 0.05, voltage U=3x230V, current I=3x100A, frequency 50Hz, cosφ=1 (φ=0°), t_A=+40°C

Measuring uncertainty budgets for example 5

Parameter	Value [W]	Standard measuring uncertainty [%]	Distribution	Sensitivity coefficient	Uncertainty contribution [%]
δE_{SI}	69000 [1]	0.0288 [2]	Rectangle	1	0.029
δE_{ST}	0	0.0404 [3]	Rectangle	1	0.040
δE_X	69000	0.0494 [4]			

[1] Output value E_{SB}=3xUxIxcosφ=3x230Vx100Ax1=69000W
[2] Intrinsic uncertainty δE_{SI}=0.05%/√3=0.0288%
[3] Temperature uncertainty δE_{ST}=[(0.005%/√3/°C)]x(40°C-26°C)=0.0404%
[4] Measuring uncertainty $\delta E_X=\sqrt{(\delta E_{SI}^2+\delta E_{ST}^2)}=\sqrt{(0.029^2+0.04^2)}$=0.0494%

Results for example 3

Parameter	Value [W]	Extended measuring uncertainty *U* [%]	Coverage factor	Coverage probability [%]
δE_X	69000	0.099 [1]	2.0	95

[1] $U=2\text{x}\sqrt{(\delta E_{SI}^2+\delta E_{ST}^2)}$

The calibration result is: δE_X = 69000W±0.099%

Example 6. Caltest 300 class 0.05, voltage U=3x230V, current I=3x100A, frequency 50Hz, cosφ=1 (φ=0°), t_A=+23±3°C

Measuring uncertainty budgets for example 6

Parameter	Value [W]	Standard measuring uncertainty [%]	Distribution	Sensitivity coefficient	Uncertainty contribution [%]
δE_{SI}	69000 [1]	0.0288 [2]	Rectangle	1	0.029
δE_X	69000	0.0288 [3]			

[1] Output value E_{SB}=3xUxIxcosφ=3x230Vx100Ax1=69000W
[2] Intrinsic uncertainty δE_{SI}=0.05%/√3=0.0288%
[3] Measuring uncertainty $\delta E_X=\sqrt{(\delta E_{SI}^2)}=\sqrt{(0.0288^2)}$=0.0288%

Results for example 6

Parameter	Value [W]	Extended measuring uncertainty *U* [%]	Coverage factor	Coverage probability [%]
δE_X	69000	0.058 [1]	2.0	95

[1] $U=2\text{x}\sqrt{(\delta E_{SI}^2)}$

The calibration result is: δE_X = 69000W±0.058%

Measuring principle

The Meter Test System MTS is controlled by a personal computer with *Calpro 300* PC software and contains: the C300 Three Phase Power Calibrator and the Calport 100Plus with 100A current clamps as a Device Under Test DUT. The DUT converts the power into performance-related impulses and then transmit them to impulse input of the C300. The error calculator uses the number of impulses to calculate a relative measuring deviation (percentage error) of the DUT using the error formula:

$$E_X\% = \frac{E_M - E_R}{E_R}\cdot 100\%$$

where:

E_M = value of the energy measured by the DUT,

E_R = reference value of the energy (generated by the C300).

The C300 settings are as follow: voltages 3x230V, currents 3x100A, frequency 50.3Hz, phase angles 0° (cosφ=1), angles between voltages 120° and 240°. Fifty seconds were chosen as an integration time – setting Test method/Time=50s in Calpro300/Electricity meter/Procedure/Error test.

Model equation

$\delta E_X = \delta E_{XMTS} + \delta E_S + \delta E_{SRES}$

List of values

Parameter	Unit	Definition	Description
δE_X	%	Relative measuring deviation	
δE_{XMTS}	%	Relative measuring deviation of the DUT in % as calculated by the C300	Type A Number of observations: 10 [1)] Mean: 0.039% [2)] Sample standard deviation: 0.018% [3)] Standard deviation of mean: 0.0057% [4)] Degree of freedom: 9
δE_S	%	Specification of the C300 Calibrator	Type B Rectangular distribution Extended measuring uncertainty: 0.02% Coverage factor:2
δE_{SRES}	%	Resolution of energy meter error measurement of Calpro300	Type B Rectangular distribution Half-width of resolution: 0.0005%

1) Setting Test duration=10 cycles in Calpro300/Electricity meter/Procedure/Error test

2) Marked as $\bar{\varepsilon}$ in Calpro300/Electricity meter/Auto test

3) Marked as ε_S in Calpro300/Elctricity meter/Auto test

4) Standard deviation of mean δE_{XMTS}=0.018%/√10=0.0057%

Measuring uncertainty budgets

Parameter	Value [%]	Standard measuring uncertainty [%]	Distribution	Sensitivity coefficient	Uncertainty contribution [%]
δE_{XMTS}	0.0390	0.0057	Normal	1	0.0057
δE_S	0	0.0115 [1)]	Rectangle	-1	0.0120
δE_{SRES}	0	0.0003 [2)]	Rectangle	-1	0.0003
δE_X	0.0390	0.0133 [3)]			

1) δE_S=0.02%/√3=0.0115%

2) δE_{SRES}=0.0005%/√3=0.0003%

3) Measuring uncertainty $\delta E_X=\sqrt{(\delta E_{XMTS}^2+\delta E_S^2+\delta E_{SRES}^2)}=\sqrt{(0.0057^2+0.0120^2+0.0003^2)}=0.0133\%$

Results

Parameter	Value [%]	Extended measuring uncertainty *U* [%]	Coverage factor	Coverage probability [%]
δE_x	0.0390	0.027 [1)]	2.0	95

1) $U=2\text{x}\sqrt{(\delta E_{XMTS}^2+\delta E_S^2+\delta E_{SRES}^2)}$

Evaluation

The calibration result is: δE_X = 0.039%±0.027%.

At this point, the Calpro 100Plus Tester with 100A current clamps lies inside the range of 0.23% (see example 4).

An electricity meter class 1 uncertainty budget, which is calibrated with use the Calport 100Plus as reference on Site

Measuring principle

The Meter Test System MTS contains: a three phase power network 3x230V, the Calport 100Plus Tester with 100A current clamps as a reference meter and an electricity meter class 1 as a Device Under Test DUT. The DUT converts the power into performance-related LED impulses and then transmit them via scanning head to the impulse input of the Calport 100Plus. The error calculator uses number of impulses to calculate a relative measuring deviation (percentage error) of the DUT using the error formula:

$$E_X\% = \frac{E_M - E_R}{E_R} \cdot 100\%$$

where:

E_M = value of the energy measured by the DUT,

E_R = reference value of the energy (measured by the Calport 100Plus).

The three phase power network parameters are as follow: voltages 3x230V, currents 3x100A, frequency 50Hz, phase angles 0° (cosφ=1), angles between voltages 120° and 240°. Ten seconds were chosen as an integration time – setting Period T:10s in Parameterization page/Soft key imp.

Model equation

$\delta E_X = \delta E_{XMTS} + \delta E_S + \delta E_{SRES}$

List of values

Parameter	Unit	Definition	Description
δE_X	%	Relative measuring deviation	
δE_{XMTS}	%	Relative measuring deviation of the DUT in % as calculated by the Calport 100Plus for each observation	Type A Number of observations: 10 1) Mean: 0.3140% 2) Sample standard deviation: 0.1100% 3) Standard deviation of mean: 0.0348% 4) Degree of freedom: 9
δE_S	%	Specification of the Calport 100Plus	Type B Rectangular distribution Extended measuring uncertainty: 0.40%5) Coverage factor:2
δE_{SRES}	%	Resolution of energy meter error measurement of Calport 100Plus	Type B Rectangular distribution Half-width of resolution: 0.0005%

1) Marked as ε in the Calport 100Plus display

2) Mean $\bar{x} = \sum_{i=1}^{10} x_i \Big/ 10$ where x_i is value of individual observation

3) Sample standard deviation $s = \sqrt{\sum_{i=1}^{10} (x_i - \bar{x})^2 \Big/ (10-1)}$

4) Standard deviation of mean δE_{XMTS}=0.1100%/√10=0.0348%

5) See example 3

Measuring uncertainty budgets

Parameter	Value [%]	Standard measuring uncertainty [%]	Distribution	Sensitivity coefficient	Uncertainty contribution [%]
δE_{XMTS}	0.3140	0.0348	Normal	1	0.0348
δE_S	0	0.2309 1)	Rectangle	-1	0.2300
δE_{SRES}	0	0.0003 2)	Rectangle	-1	0.0003
δE_X	0.3140	0.2326 3)			

1) δE_S=0.40%/√3=0.2309%

2) δE_{SRES}=0.0005%/√3=0.0003%

3) Measuring uncertainty $\delta E_X=\sqrt{(\delta E_{XMTS}^2+\delta E_S^2+\delta E_{SRES}^2)}=\sqrt{(0.0348^2+0.23^2+0.0003^2)}$=0.2326%

Results

Parameter	Value [%]	Extended measuring uncertainty *U* [%]	Coverage factor	Coverage probability [%]
δE_X	0.31	0.47 1)	2.0	95

1) $U=2\times\sqrt{(\delta E_{XMTS}^2+\delta E_S^2+\delta E_{SRES}^2)}$

Evaluation

The calibration result is: δE_X = 0.31%±0.47%.

At this point, the electricity meter lies inside the range of 1%.

Measuring principle

The Meter Test System MTS is controlled by a personal computer with *Calpro 300* PC software and contains: the C300 as a source and reference meter and an electricity meter class 1 as a Device Under Test DUT. The DUT converts the power into performance-related LED impulses and then transmit them via scanning head to impulse input of the C300. The error calculator uses them impulses to calculate a relative measuring deviation (percentage error) of the DUT using the error formula:

$$E_X\% = \frac{E_M - E_R}{E_R} \cdot 100\%$$

where:

E_M = value of the energy measured by the DUT,

E_R = reference value of the energy (generated by the C300).

The C300 settings are as follow: voltages 3x230V, currents 3x100A, frequency 50Hz, phase angles 0° (cosφ=1), angles between voltages 120° and 240°. Ten seconds were chosen as an integration time – setting Test method/Time=10s in Calpro300/Electricity meter/Procedure/Error test.

Model equation

$\delta E_X = \delta E_{XMTS} + \delta E_S$

List of values

Parameter	Unit	Definition	Description
δE_X	%	Relative measuring deviation	
δE_{XMTS}	%	Relative measuring deviation of the DUT in % as calculated by the C300	Type A Number of observations: 10 [1)] Mean: 0.2850% [2)] Sample standard deviation: 0.0550% [3)] Standard deviation of mean: 0.0174% [4)] Degree of freedom: 9
δE_S	%	Specification of the C300	Type B Rectangular distribution Extended measuring uncertainty: 0.034%[5)] Coverage factor:2

1) Setting Test duration=10 cycles in Calpro300/Electricity meter/Procedure/Error test
2) Marked as $\bar{\varepsilon}$ in Calpro300/Electricity meter/Auto test
3) Marked as ε_S in Calpro300/Elctricity meter/Auto test
4) Standard deviation of mean δE_{XMTS}=0.055%/√10=0.0174%
5) See example 1

Measuring uncertainty budgets

Parameter	Value [%]	Standard measuring uncertainty [%]	Distribution	Sensitivity coefficient	Uncertainty contribution [%]
δE_{XMTS}	0.2850	0.0174	Normal	1	0.0174
δE_S	0	0.0196 [1)]	Rectangle	-1	0.0200
δE_X	0.2850	0.0265			

1) δE_S=0.034%/√3=0.0196%
2) δE_{SRES}=0.0005%/√3=0.0003%
3) Measuring uncertainty $\delta E_X=\sqrt{(\delta E_{XMTS}^2+\delta E_S^2)}=\sqrt{(0.0174^2+0.02^2)}$=0.0265%

Results

Parameter	Value [%]	Extended measuring uncertainty *U* [%]	Coverage factor	Coverage probability [%]
δE_X	0.28	0.053 [1)]	2.0	95

1) $U=2\text{x}\sqrt{(\delta E_{XMTS}^2+\delta E_S^2)}$

Evaluation

The calibration result is: δE_X = 0.280%±0.053%.

At this point, the electricity meter lies inside the range of 1%.

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