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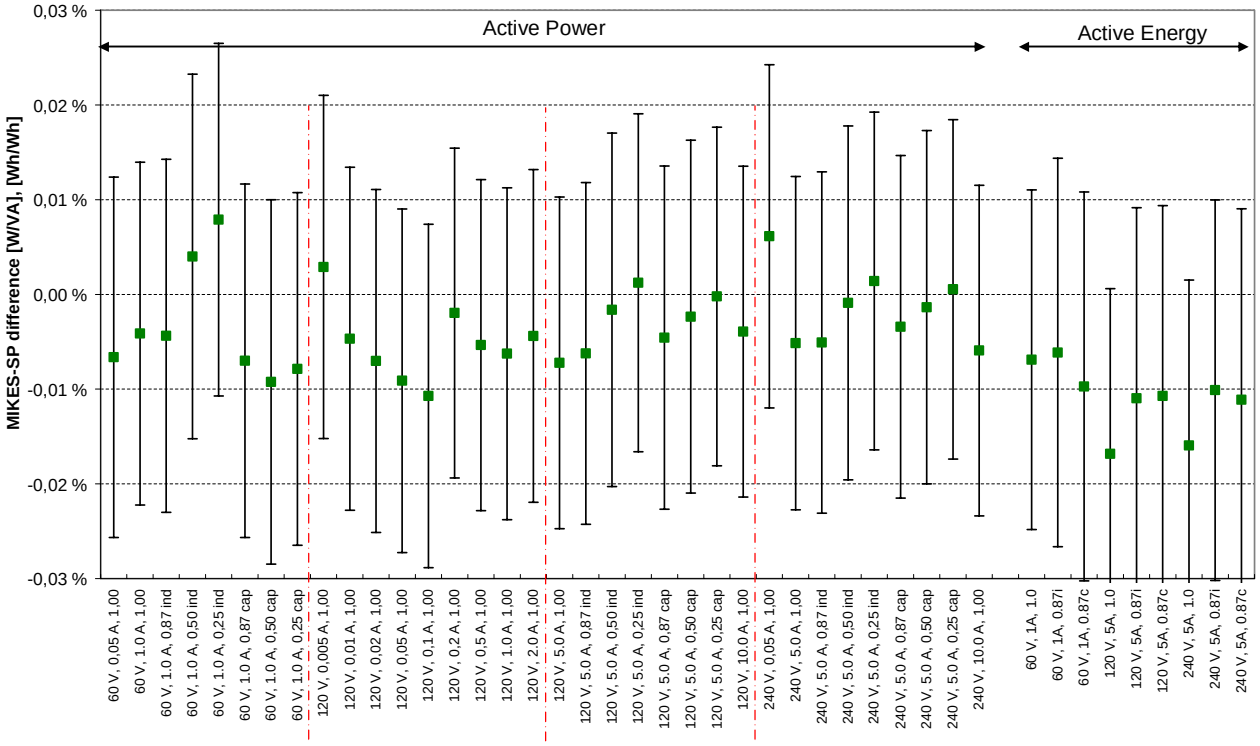

EURAMET #1172
Bilateral three-phase AC power and energy comparison at power frequency

Jari Hällström, Esa-Pekka Suomalainen, Pekka Immonen and Stefan Svensson

Centre for Metrology and Accreditation
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Bilateral three-phase AC power and energy comparison at power frequency

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Abstract

The report summarizes the results of EURAMET project # 1172 on a bilateral comparison of power and energy measurement capabilities in MIKES, Finland and SP, Sweden in 2010 - 2011. A portable three phase reference energy meter was calibrated by the two institutes. Both active and reactive power as well as active and reactive energy measurements were compared. The expanded comparison uncertainty (k=2) ranged from 0.015 % for active power up to 0.06 % for some reactive power measurements. All measured values agreed within the expanded comparison uncertainties.

Contents

1 Introduction

This bilateral comparison was triggered by MIKES's need to get support for their planned extension electrical power and energy CMC claims to three phase calibrations. SP provided a travelling standard, which was calibrated by both participants.

2 Travelling standard

The travelling standard was a precision three-phase reference electricity meter.

Manufacturer:	ZERA
Type:	TPZ303
SP reference:	96-610-12

Figure 1. Transfer reference, TPZ303

3 Measurands

The quantities measured and compared are listed in Table 1.

Table 1 - Measurands

Quantity	Unit
Active power	W
Reactive power	VAr
Active energy	Ws
Reactive energy	VArh

4 Time schedule

Comparison time schedule is shown in Table 2.

Table 2 - Time schedule

SP, Borås, Sweden	March-May, 2010
MIKES, Espoo, Finland	August-September, 2010
SP, Borås, Sweden	October 2010 - May 2011

5 Measurement instructions and instruments used

5.1 Conditioning of the transfer standard

The transfer standard was kept in the laboratory before the measurements for at least 2 hours so that it reached stable temperature. The ambient temperature was (23 ± 2) °C during all measurements.

5.2 Energy comparison

The energy comparison the readings were obtained from the transfer reference according to the following guidance:

On the TPZ303 display go to “Funktioner” > “Ärvärden” to select the connection and measurement range

Mätartt > 4L-Aktiv or 4L-Reaktiv
U-Omr > 240, 120, or 60
I-Omr > 10,5,2,1,500m,200m,100m,50m,20m,10m or 5m

Use the frequency output fout = 60000 i/s

Calculate the right pulse constant, i/kWh, by using the formula:

$$\frac{1000 \times 3600 \times 60000}{U_{range} \times I_{range} \times 3} = \frac{\text{impulses}}{\text{kWh}}$$

5.3 Power comparison

The power readings were obtained from the transfer reference according to the following guidance:

On the TPZ303 display click on: “Funktioner” > “Ärvärden” to select the connection and measurement range;

Mätartt > 4L-Aktiv or 4L-Reaktiv
U-Omr > 240, 120, or 60
I-Omr > 10,5,2,1,500m,200m,100m,50m,20m,10m or 5m

To start the measurement first click on:
“Funktioner“ > “Kontrollmätning (U,I,P)“,

and then to get readings from the TPZ303 use the software “TPZ303 Reader”.

1) Use an RS232 cable to connect the COM port 1on the TPZ303 to the COM port on your computer.
2) Start the program “TPZ303 Reader”
3) In the program, select which of your computer’s COM ports you are using.
4) Choose an appropriate measuring time. (5000 ms)
5) Click on the button to start a measurement.

To copy the average values to Excel for instance, triple-click in the Average values text field to select the text. Then CTRL+C to copy and then, in Excel, CTRL+V to paste.

5.4 Measuring points

The agreed measuring points on active and reactive power and energy are listed in Tables 3 to 6.

Table 3 - Comparison points for positive active energy, Y-connected, 4L-Active

TPZ Range		Test point		
		Phase-voltage U	Current I	Power factor cos(φ)
60 V	1 A	60 V	1 A	1,00 0,87 ind 0,87 cap
120 V	5 A	120 V	5 A	1,00 0,87 ind 0,87 cap
240 V	5 A	240 V	5 A	1,00 0,87 ind 0,87 cap

Table 4 - Comparison points for positive active power, Y-connected, 4L-Active

TPZ Range		Test point		
		Phase-voltage U	Current I	Power factor cos(φ)
60 V	0,05 A	60 V	0,05 A	1,00
60 V	1 A	60 V	1 A	1,00 0,87 ind 0,50 ind 0,25 ind 0,87 cap 0,50 cap 0,25 cap
120 V	0,005 A 0,01 A 0,02 A 0,05 A 0,1 A 0,2 A 0,5 A 1 A 2 A	120 V	0,005 A 0,01 A 0,02 A 0,05 A 0,1 A 0,2 A 0,5 A 1 A 2 A	1,00
120 V	5 A	120 V	5 A	1,00 0,87 ind 0,50 ind 0,25 ind 0,87 cap 0,50 cap 0,25 cap 0 ind 0 cap
120 V	10 A	120 V	10 A	1,00
240 V	0,05 A	240 V	0,05 A	1,00
240 V	5 A	240 V	5 A	1,00 0,87 ind 0,50 ind 0,25 ind 0,87 cap 0,50 cap 0,25 cap
240 V	10 A	240 V	10 A	1,00

Table 5 - Comparison points for positive reactive energy, Y-connected, 4L-Reactive

TPZ Range		Test point			Nominal TPZ readings	
		Phase voltage U	Phase current I	Power factor sin(φ)	Reactive power Q [VAr]	Active power P [W]
60 V	1 A	60 V	1 A	0,50 ind	450	790
				0,50 cap	450	-790
120 V	5 A	120 V	5 A	0,50 ind	900	1570
				0,50 cap	900	-1570
				1,00	1800	0
240 V	5 A	240 V	5 A	0,50 ind	1800	3100
				0,50 cap	1800	-3100

Table 6 - Comparison points for positive reactive power, Y-connected, 4L-Reactive

TPZ Range		Test point			Nominal TPZ readings	
		Phase voltage U	Phase current I	Power factor sin(φ)	Reactive power Q [VAr]	Active power P [W]
60 V	1 A	60 V	1 A	0,50 ind	450	790
				0,87 ind	790	450
				1,00	900	0
				0,50 cap	450	-790
				0,87 cap	790	-450
120 V	5 A	120 V	5 A	0,50 ind	900	1570
				0,87 ind	1570	900
				1,00	1800	0
				0,50 cap	900	-1570
				0,87 cap	1570	-900
240 V	5 A	240 V	5 A	0,50 ind	1800	3100
				0,87 ind	3100	1800
				1,00	3600	0
				0,50 cap	1800	-3100
				0,87 cap	3100	-1800

6 Results

Both participants issued standard calibration certificate(s). The calibration certificates were kept by the issuing laboratory until all three certificates were prepared.

Comparison uncertainty shown in the following figures and tables is calculated from the calibration uncertainties by adding the calibration uncertainties quadratically.

The results of active power and energy measurement are shown in Figure 2 and Tables 7 and 8 and for reactive power and energy in Figure 3 and Tables 9 and 10.

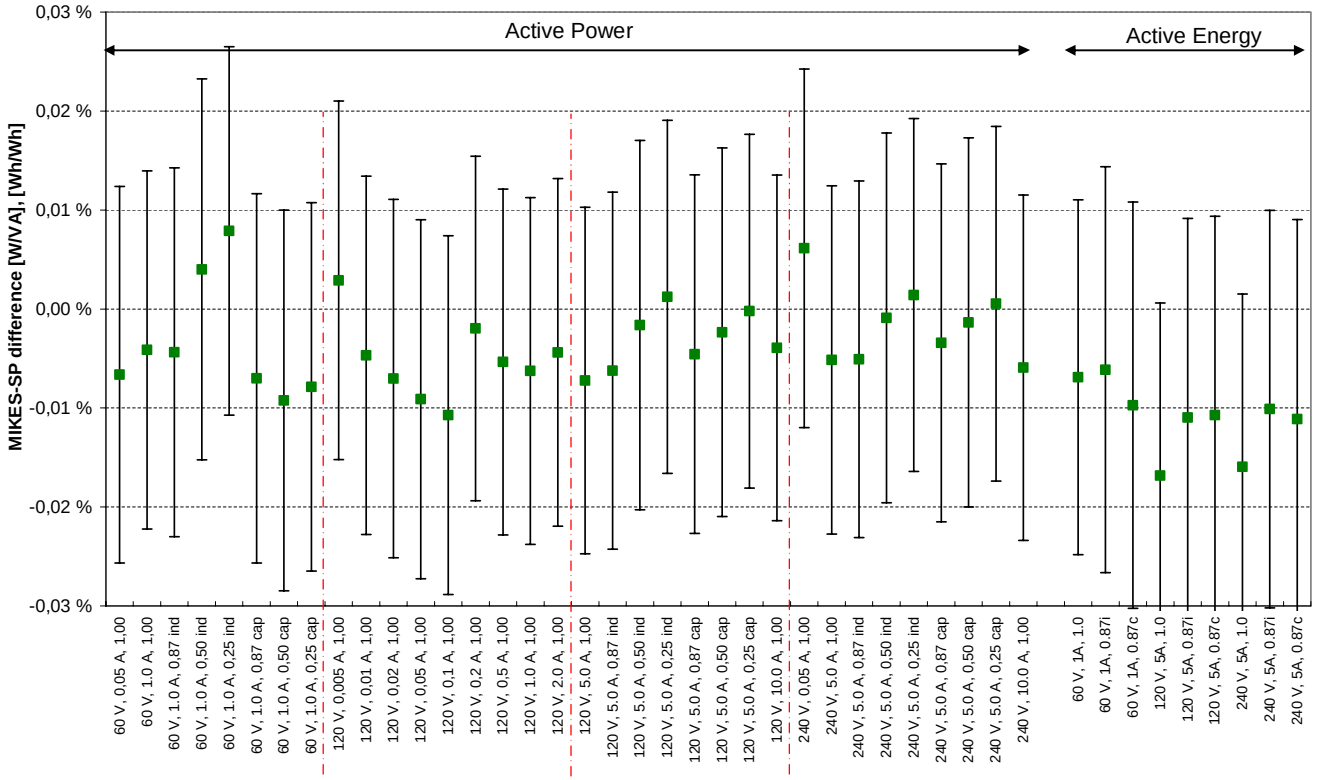

Figure 2. Overview of active power and energy comparison together with comparison uncertainty (k=2).

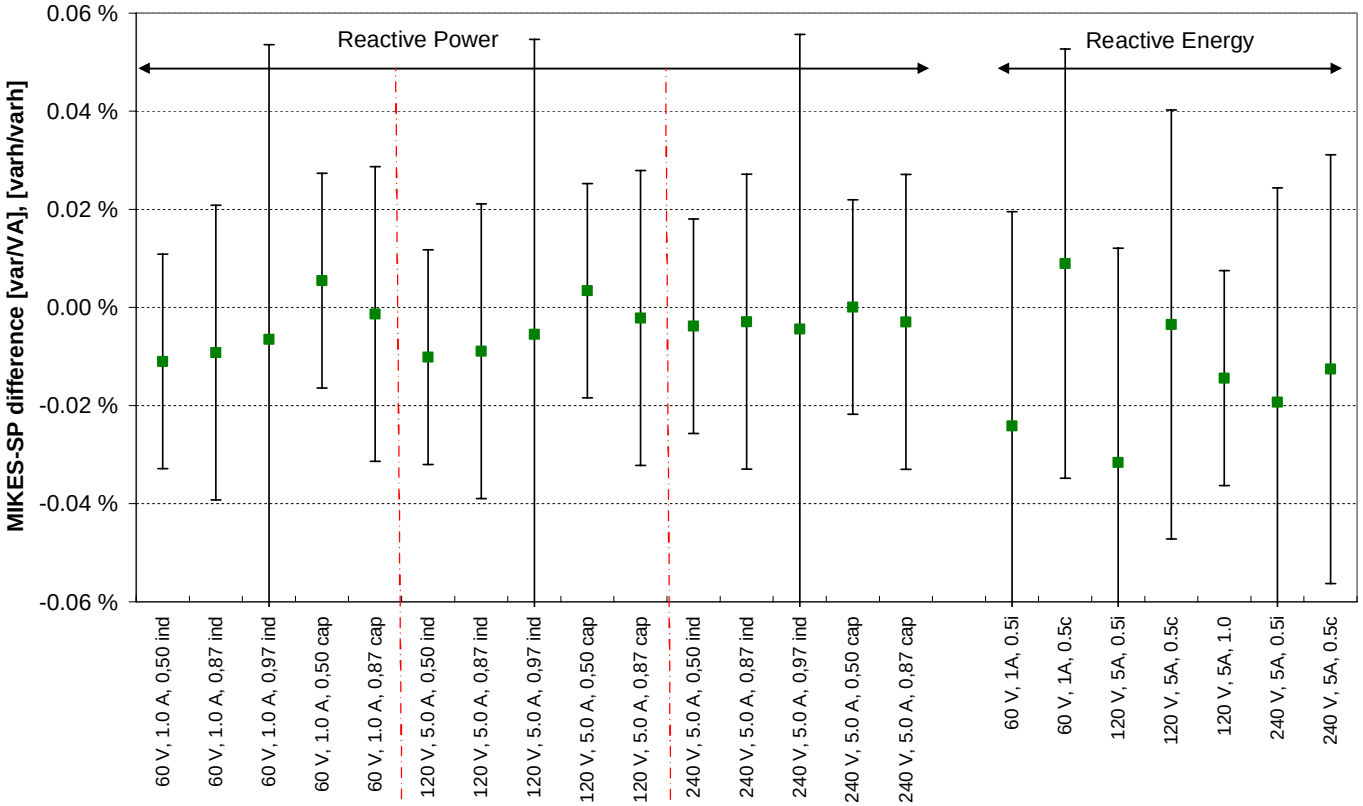

Figure 3. Overview of reactive power and energy comparison together with comparison uncertainty (k=2).

Table 7. Overview of active energy comparison results.

Setup					SP		MIKES		Result	
TPZ Range		Test point: Phase voltage	Test point: Current	Test point: Power factor	Error of TPZ	Combined Expanded Uncertainty (k=2)	Error of TPZ	Combined Expanded Uncertainty (k=2)	MIKES-SP	Comparison uncertainty (k=2)
[V]	[A]	[V]	[A]	cos(φ)		[Wh/Wh]		[Wh/Wh]		[Wh/Wh]
60	1	57.7	1	1	**-0.003 %**	**0.015 %**	**-0.010 %**	**0.010 %**	**-0.007 %**	**0.018 %**
				0.87 ind	**0.002 %**	**0.018 %**	**-0.004 %**	**0.010 %**	**-0.006 %**	**0.021 %**
				0.87 cap	**-0.007 %**	**0.018 %**	**-0.017 %**	**0.010 %**	**-0.010 %**	**0.021 %**
120	5	115.5	5	1	**-0.021 %**	**0.015 %**	**-0.038 %**	**0.009 %**	**-0.017 %**	**0.017 %**
				0.87 ind	**-0.020 %**	**0.018 %**	**-0.031 %**	**0.009 %**	**-0.011 %**	**0.020 %**
				0.87 cap	**-0.023 %**	**0.018 %**	**-0.034 %**	**0.009 %**	**-0.011 %**	**0.020 %**
240	5	230	5	1	**-0.019 %**	**0.015 %**	**-0.035 %**	**0.009 %**	**-0.016 %**	**0.017 %**
				0.87 ind	**-0.019 %**	**0.018 %**	**-0.029 %**	**0.009 %**	**-0.010 %**	**0.020 %**
				0.87 cap	**-0.019 %**	**0.018 %**	**-0.030 %**	**0.009 %**	**-0.011 %**	**0.020 %**

Table 8. Overview of active power comparison results.

Setup					SP		MIKES		Result	
TPZ Range [V]	[A]	Phase voltage [V]	Current [A]	Power factor cos(ϕ)	Error of TPZ	Combined expanded uncertainty (k=2) [W/VA]	Error of TPZ	Combined expanded uncertainty (k=2) [W/VA]	MIKES-SP	Comparison uncertainty (k=2) [W/VA]
60 V	0.05 A	60 V	0.05 A	1	**0.004 %**	**0.015 %**	**-0.003 %**	**0.012 %**	**-0.007 %**	**0.019 %**
60 V	1.0 A	60 V	1.0 A	1	**-0.008 %**	**0.015 %**	**-0.012 %**	**0.010 %**	**-0.004 %**	**0.018 %**
				0.87 ind	**-0.003 %**	**0.016 %**	**-0.007 %**	**0.010 %**	**-0.004 %**	**0.019 %**
				0.50 ind	**0.004 %**	**0.015 %**	**0.007 %**	**0.012 %**	**0.004 %**	**0.019 %**
				0.25 ind	**0.006 %**	**0.015 %**	**0.014 %**	**0.011 %**	**0.008 %**	**0.019 %**
				0.87 kap	**-0.011 %**	**0.016 %**	**-0.018 %**	**0.010 %**	**-0.007 %**	**0.019 %**
				0.50 kap	**-0.011 %**	**0.015 %**	**-0.020 %**	**0.012 %**	**-0.009 %**	**0.019 %**
				0.25 kap	**-0.009 %**	**0.015 %**	**-0.017 %**	**0.011 %**	**-0.008 %**	**0.019 %**
120 V	0.005 A	120 V	0.005 A	1	**-0.018 %**	**0.015 %**	**-0.015 %**	**0.010 %**	**0.003 %**	**0.018 %**
	0.01 A		0.01 A		**-0.012 %**	**0.015 %**	**-0.017 %**	**0.010 %**	**-0.005 %**	**0.018 %**
	0.02 A		0.02 A		**-0.015 %**	**0.015 %**	**-0.022 %**	**0.010 %**	**-0.007 %**	**0.018 %**
	0.05 A		0.05 A		**0.005 %**	**0.015 %**	**-0.004 %**	**0.010 %**	**-0.009 %**	**0.018 %**
	0.1 A		0.1 A		**0.006 %**	**0.015 %**	**-0.005 %**	**0.010 %**	**-0.011 %**	**0.018 %**
	0.2 A		0.2 A		**0.001 %**	**0.015 %**	**-0.001 %**	**0.009 %**	**-0.002 %**	**0.017 %**
	0.5 A		0.5 A		**-0.007 %**	**0.015 %**	**-0.012 %**	**0.009 %**	**-0.005 %**	**0.017 %**
	1.0 A		1.0 A		**-0.007 %**	**0.015 %**	**-0.013 %**	**0.009 %**	**-0.006 %**	**0.018 %**
	2.0 A		2.0 A		**-0.010 %**	**0.015 %**	**-0.014 %**	**0.009 %**	**-0.004 %**	**0.018 %**
120 V	5.0 A	120 V	5.0 A	1	**-0.034 %**	**0.015 %**	**-0.041 %**	**0.009 %**	**-0.007 %**	**0.018 %**
				0.87 ind	**-0.028 %**	**0.016 %**	**-0.034 %**	**0.009 %**	**-0.006 %**	**0.018 %**
				0.50 ind	**-0.015 %**	**0.015 %**	**-0.017 %**	**0.011 %**	**-0.002 %**	**0.019 %**
				0.25 ind	**-0.007 %**	**0.015 %**	**-0.005 %**	**0.010 %**	**0.001 %**	**0.018 %**
				0.87 kap	**-0.031 %**	**0.016 %**	**-0.036 %**	**0.009 %**	**-0.005 %**	**0.018 %**
				0.50 kap	**-0.018 %**	**0.015 %**	**-0.020 %**	**0.011 %**	**-0.002 %**	**0.019 %**
				0.25 kap	**-0.009 %**	**0.015 %**	**-0.009 %**	**0.010 %**	**0.000 %**	**0.018 %**
120 V	10.0 A	120 V	10.0 A	1	**-0.032 %**	**0.015 %**	**-0.036 %**	**0.009 %**	**-0.004 %**	**0.017 %**
240 V	0.05 A	240 V	0.05 A	1	**0.006 %**	**0.015 %**	**0.012 %**	**0.010 %**	**0.006 %**	**0.018 %**
240 V	5.0 A	240 V	5.0 A	1	**-0.033 %**	**0.015 %**	**-0.038 %**	**0.009 %**	**-0.005 %**	**0.018 %**
				0.87 ind	**-0.028 %**	**0.016 %**	**-0.033 %**	**0.009 %**	**-0.005 %**	**0.018 %**
				0.50 ind	**-0.017 %**	**0.015 %**	**-0.018 %**	**0.011 %**	**-0.001 %**	**0.019 %**
				0.25 ind	**-0.009 %**	**0.015 %**	**-0.007 %**	**0.010 %**	**0.001 %**	**0.018 %**
				0.87 kap	**-0.029 %**	**0.016 %**	**-0.032 %**	**0.009 %**	**-0.003 %**	**0.018 %**
				0.50 kap	**-0.016 %**	**0.015 %**	**-0.017 %**	**0.011 %**	**-0.001 %**	**0.019 %**
				0.25 kap	**-0.007 %**	**0.015 %**	**-0.006 %**	**0.010 %**	**0.001 %**	**0.018 %**
240 V	10.0 A	240 V	10.0 A	1	**-0.030 %**	**0.015 %**	**-0.036 %**	**0.009 %**	**-0.006 %**	**0.017 %**

Table 9. Overview of reactive energy comparison results.

Setup					SP		MIKES		Result	
TPZ Range		Test point								
		Phase voltage	Current	Power factor	Error of TPZ	Combined Expanded Uncertainty (k=2)	Error of TPZ	Combined Expanded Uncertainty (k=2)	MIKES-SP	Comparison uncertainty (k=2)
[V]	[A]	[V]	[A]	sin(φ)		[varh/varh]		[varh/varh]		[varh/varh]
60	1	57.7	1	0.50 cap	**0.011 %**	**0.032 %**	**0.020 %**	**0.030 %**	**0.009 %**	**0.044 %**
				0.50 ind	**-0.016 %**	**0.032 %**	**-0.040 %**	**0.030 %**	**-0.024 %**	**0.044 %**
120	5	115.5	5	0.50 cap	**-0.018 %**	**0.032 %**	**-0.021 %**	**0.030 %**	**-0.003 %**	**0.044 %**
				0.50 ind	**-0.023 %**	**0.032 %**	**-0.055 %**	**0.030 %**	**-0.032 %**	**0.044 %**
				1	**-0.021 %**	**0.016 %**	**-0.035 %**	**0.015 %**	**-0.014 %**	**0.022 %**
240	5	230	5	0.50 cap	**-0.020 %**	**0.032 %**	**-0.033 %**	**0.030 %**	**-0.013 %**	**0.044 %**
				0.50 ind	**-0.017 %**	**0.032 %**	**-0.036 %**	**0.030 %**	**-0.019 %**	**0.044 %**

Table 10. Overview of reactive power comparison results.

Setup					SP		MIKES		Result	
TPZ Range [V]	TPZ Range [A]	Phase voltage [V]	Current [A]	Power factor sin(ϕ)	Error of TPZ	Combined expanded uncertainty (k=2) [var/VA]	Error of TPZ	Combined expanded uncertainty (k=2) [var/VA]	MIKES-SP	Comparison uncertainty (k=2) [var/VA]
60 V	1.0 A	60 V	1.0 A	0.50 ind	**-0.011 %**	**0.016 %**	**0.008 %**	**0.015 %**	**-0.011 %**	**0.022 %**
				0.87 ind	**-0.012 %**	**0.026 %**	**-0.005 %**	**0.015 %**	**-0.009 %**	**0.030 %**
				0.97 ind	**-0.011 %**	**0.058 %**	**-0.015 %**	**0.015 %**	**-0.006 %**	**0.060 %**
				0.50 kap	**0.003 %**	**0.016 %**	**-0.022 %**	**0.015 %**	**0.005 %**	**0.022 %**
				0.87 kap	**-0.003 %**	**0.026 %**	**-0.021 %**	**0.015 %**	**-0.001 %**	**0.030 %**
				0.97 kap	**-0.006 %**	**0.058 %**				
120 V	5.0 A	120 V	5.0 A	0.50 ind	**-0.018 %**	**0.016 %**	**-0.012 %**	**0.015 %**	**-0.010 %**	**0.022 %**
				0.87 ind	**-0.030 %**	**0.026 %**	**-0.030 %**	**0.015 %**	**-0.009 %**	**0.030 %**
				0.97 ind	**-0.034 %**	**0.058 %**	**-0.038 %**	**0.015 %**	**-0.005 %**	**0.060 %**
				0.50 kap	**-0.015 %**	**0.016 %**	**-0.028 %**	**0.015 %**	**0.003 %**	**0.022 %**
				0.87 kap	**-0.028 %**	**0.026 %**	**-0.039 %**	**0.015 %**	**-0.002 %**	**0.030 %**
				0.97 kap	**-0.031 %**	**0.058 %**				
				1	**-0.034 %**	**0.016 %**				
240 V	5.0 A	240 V	5.0 A	0.50 ind	**-0.016 %**	**0.016 %**	**-0.017 %**	**0.015 %**	**-0.004 %**	**0.022 %**
				0.87 ind	**-0.029 %**	**0.026 %**	**-0.031 %**	**0.015 %**	**-0.003 %**	**0.030 %**
				0.97 ind	**-0.032 %**	**0.058 %**	**-0.036 %**	**0.015 %**	**-0.004 %**	**0.060 %**
				0.50 kap	**-0.017 %**	**0.016 %**	**-0.019 %**	**0.015 %**	**0.000 %**	**0.022 %**
				0.87 kap	**-0.028 %**	**0.026 %**	**-0.032 %**	**0.015 %**	**-0.003 %**	**0.030 %**

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