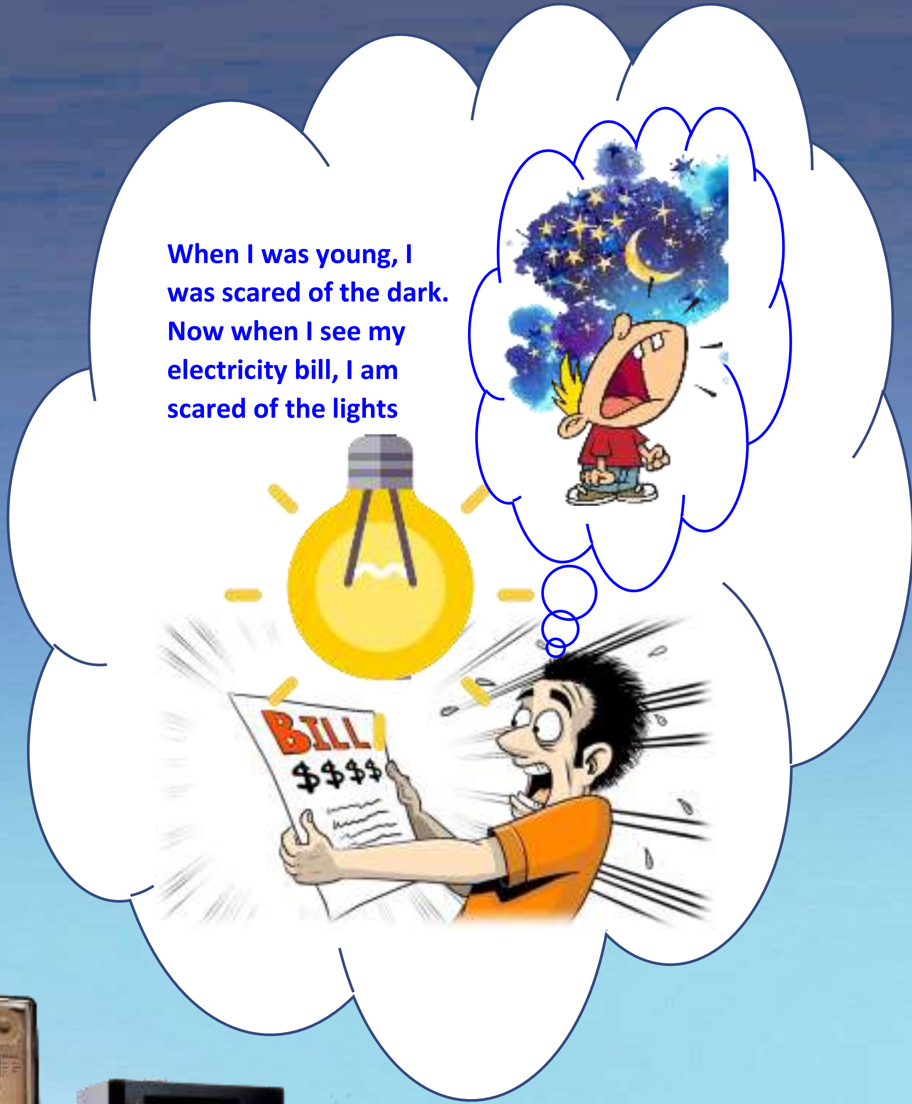
The art of meter testing on site



CALMET

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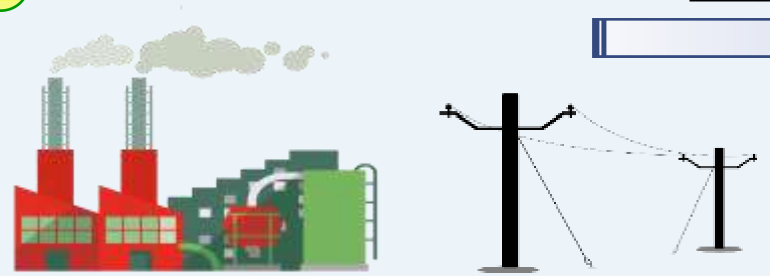
The art of energy meter testing on site

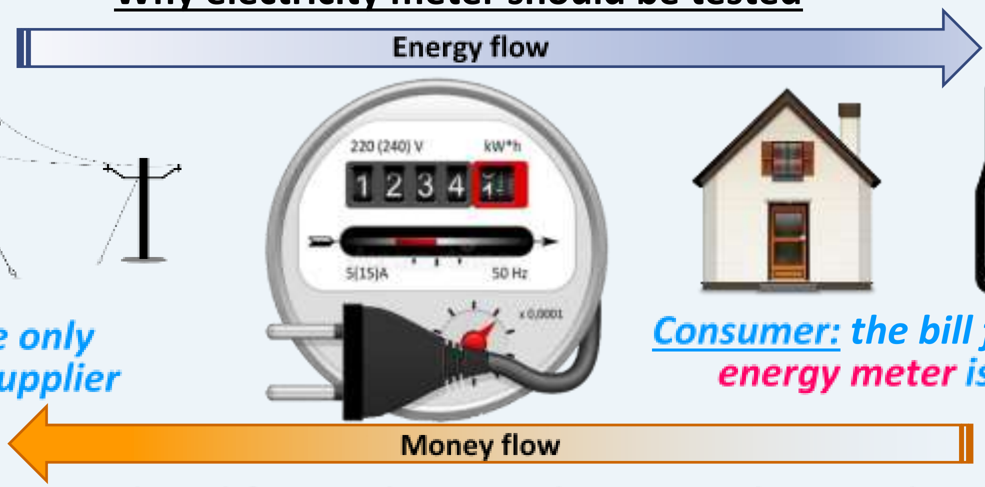
Why test on site? The utility wants to receive full payment for the services it provides. The customer wants to be billed fairly to get the lowest bill possible. This set of infographics is to facilitate the understanding of the need to test electricity meters and practically show how testing should be done. Intended for technicians, engineers, students, utilities staff and all interested in reliable energy measurement. Many definitions and examples are simplified to get clear way of reliable test results obtaining. Although the author tried to avoid errors, they can probably be found in the content, hence any comments are welcomed.

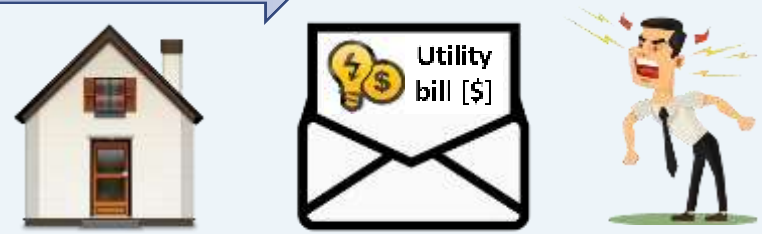
Contents:

CALMET

Why electricity meter should be tested







***Utility**: the energy meter is the only way to get **revenue** by energy supplier*

***Consumer:** the bill for electricity measured by energy meter is always **too high** (🙂)*

energy meter is a legally agreed tool for settlements between the supplier and the consumer warranted by law and international standards

Conclusion: energy meter must be **checked** for compliance with applicable standards to ensure **reliable energy measurements**

Who, where, why, when and how often should test the energy meters?*)

Who	Where	Why	When	How often
Manufacturer	Production line	Manufacturing quality	During production	As often as manufacturing process requires
	Manufacturer lab	Accuracy compliance with standards	Before delivery	At least one time
Electric Utility or Laboratory or legitimate company	Utility Lab	Prove accuracy and functionality	Before installation	At least one time
	On site	Prove proper installation and measurements	During installation	Every time
	On site / Lab	Prove accuracy and functionality	Consumer complaint	Every time
	On site / Lab	Prove accuracy and functionality	Suspected theft of energy	Every time
	On site	Maintenance to ensure proper functioning	Periodic *)	- electromechanical (Ferraris) meters every 8, 16, 20 years - electronic meters every 8 years - large load consumers every 1, 2, 8 years, depends on power flow

**) time period can vary because of country law regulations*

Recommendation & Standards: OIML R46-1/-2, ANSI C12.1, IEC62052-11, IEC62053-xx, IEC50470-1/-2/-3, IEC62057-1/-2 draft

Electricity meter types

SINGLE PHASE

Electromechanical / Ferraris / Analog


Ordinary meter


Two tariffs meter

Electronic / Static


Ordinary meter


Rail mounted meter


Prepaid meter

THREE PHASE

Electromechanical / Ferraris / Analog


Ordinary meter


Two tariffs meter

Electronic / Static


4-quadrant meter


P & Q maximum demand meter

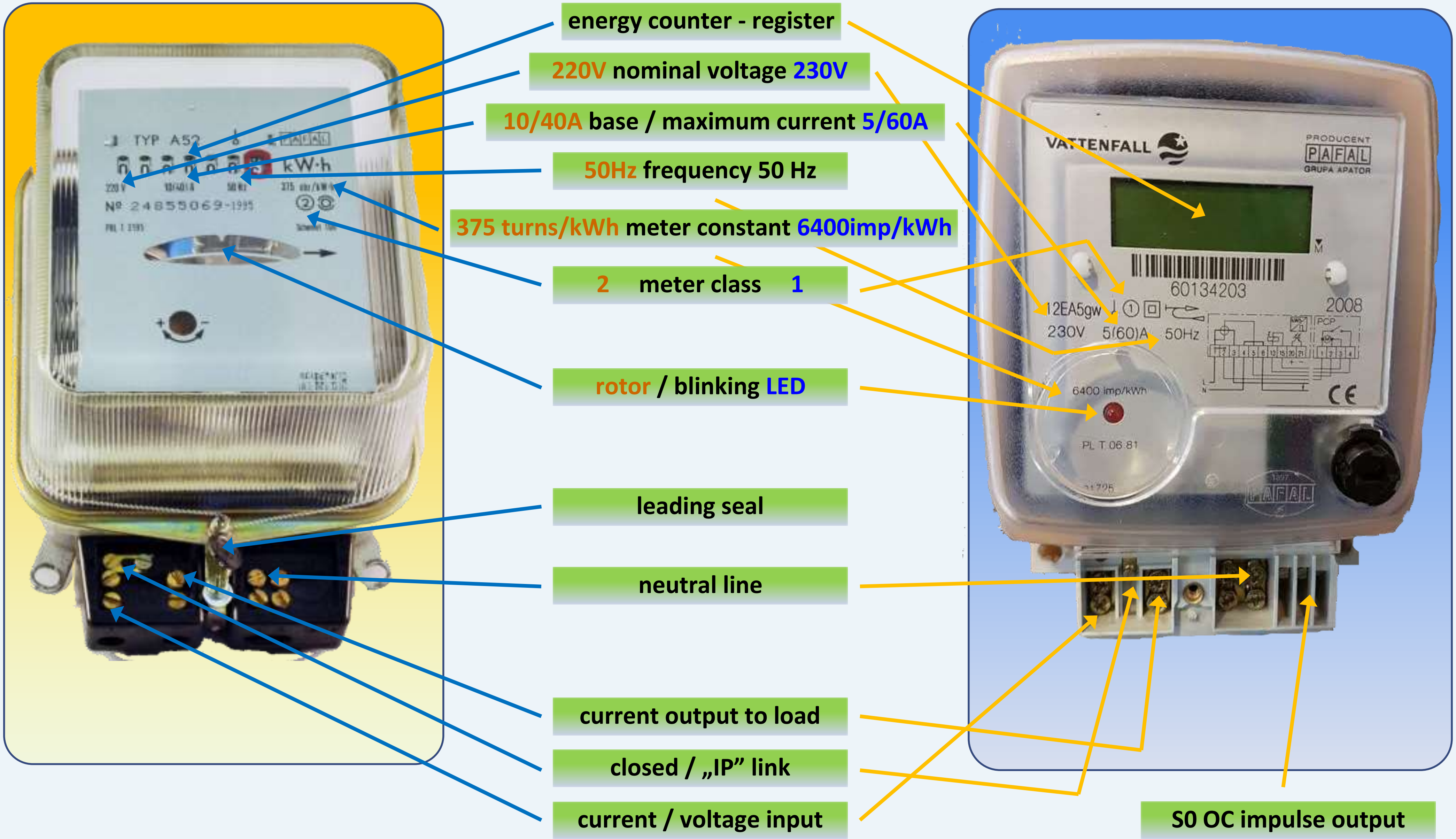

Smart 4-quadrant meter


Rail mounted meter


Prepaid meter

Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

Electricity meter parts and parameters



Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

04

Electricity meter constant – how to calculate time of revolution or pulse frequency

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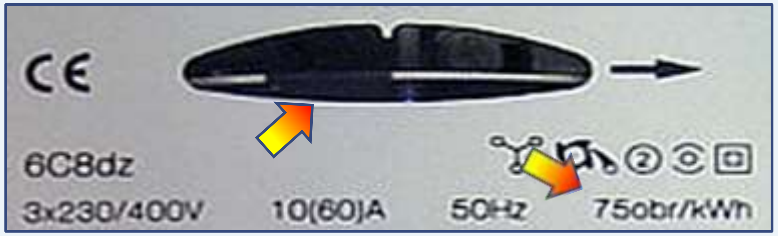
Energy meter constant: value expressing the relation between the energy registered by the meter and the corresponding value of the test output: number of revolutions (rev) of rotor (disk) for electromechanical, number of pulses (imp) (LED blinks) for static meters or pulses on electric output.

Can be expressed as:

rev/kWh (rev/kvarh, rev/kVAh) or rev/Wh or Wh/rev for electromechanical meters (rev=revolution, turn)

imp/kWh (imp/kvarh, imp/kVAh) or imp/Wh or Wh/imp for static meters (imp=pulse)



What is the time of revolution for? At known power, we can visually check **correct operation** of the electricity meter

Dependencies between constants expressed in different units, pulse frequency and revolution (pulse) time *)

Constant, time and frequency calculation		OUTPUT VALUE				
		C [imp/kWh]	C [imp/Wh]	C [Wh/imp]	Freq.[Hz]@power[kW]	Time[s]@power[kW]
INPUT VALUE	C [imp/kWh]	=	$\frac{C}{1000}$	$\frac{1000}{C}$	$\frac{P \times C}{3600}$	$\frac{3600}{P \times C}$
	375	375	0.375	2.6667	0.2396Hz	4.1739s
	C [imp/Wh]	$C \times 1000$	=	$\frac{1}{C}$	$\frac{P \times C \times 1000}{3600}$	$\frac{3600}{P \times C \times 1000}$
	0.375	375	0.375	2.6667	0.2396Hz	4.1739s
	C [Wh/imp]	$\frac{1000}{C}$	$\frac{1}{C}$	=	$\frac{P \times 1000}{C \times 3600}$	$\frac{C \times 3600}{P \times 1000}$
	2.6667	375	0.375	2.6667	0.2396Hz	4.1739s
	Freq.[Hz]@power[kW]	$\frac{f \times 3600}{P}$	$\frac{f \times 3600}{P \times 1000}$	$\frac{P \times 1000}{f \times 3600}$	=	$\frac{1}{f}$
	0.2396Hz	375	0.375	2.6667	0.2396Hz	4.1739s
	Time[s]@power[kW]	$\frac{3600}{P \times T}$	$\frac{3600}{P \times T \times 1000}$	$\frac{P \times T \times 1000}{3600}$	$\frac{1}{T}$	=
	4.1739s	375	0.375	2.6667	0.2396Hz	4.1739s

*) example values are calculated for:
- meter constant C=375 imp/kWh;
- power flow: $P = U \times I \times PF$ for U=230V, I=10A, PF=1 $\rightarrow P = 230V \times 10A \times 1 = 2300W = 2.3kW$

Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

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Electricity meter constant – CT & PT transformer connected (single & three phase)

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All examples are calculated for:
- Meter constant C[imp/kWh]=375imp/kWh
- CT ratio K_I=1000A/5A=200
- PT ratio K_U=15000V/100V=150
- Secondary current I_S=3.5A
- Secondary voltage U_S= 99.5V
- Power factor PF=0.8

Secondary side power P_S

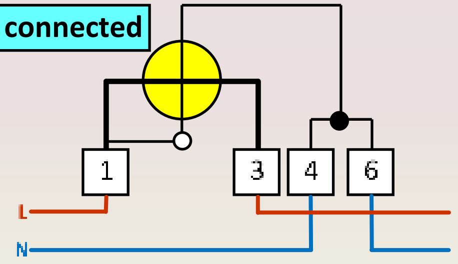
$$P_S = U_S \times I_S \times PF$$

EXAMPLE: SECONDARY SIDE

P_S=99.5V·3.5A·0.8=278.6W

METER CONSTANT C=375IPM/KWH

Direct connected



Primary side power P_P

$$P_P = U_S \times I_S \times PF \times K_I$$

and primary meter constant C_P

$$C_P = \frac{C}{K_I}$$

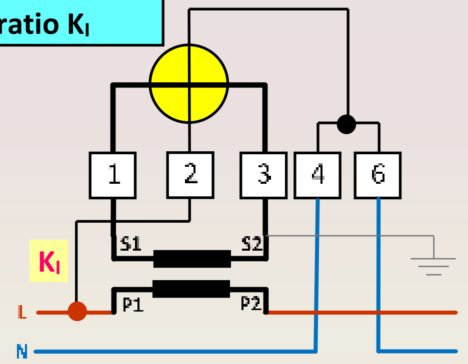
EXAMPLE: PRIMARY SIDE

P_P=99.5V·3.5A·0.8·200=55.72KW

PRIMARY METER CONSTANT :

C_P=375IMP/KWH / 200=1.875IMP/KWH

CT connected ratio K_I



Primary side power P_P

$$P_P = U_S \times I_S \times PF \times K_I \times K_U$$

and primary meter constant C_P

$$C_P = \frac{C}{K_I \times K_U}$$

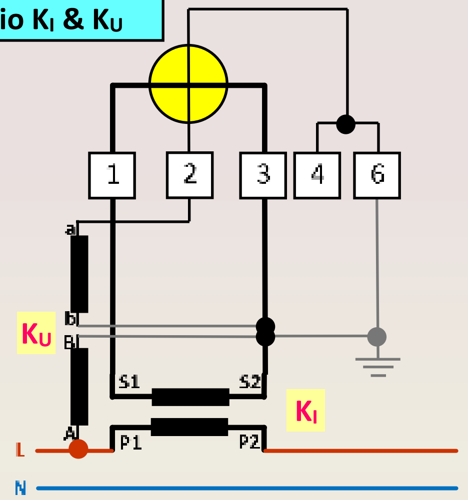
EXAMPLE: PRIMARY SIDE

P_P=99.5V·3.5A·0.8·200·150=8358KW

PRIMARY METER CONSTANT :

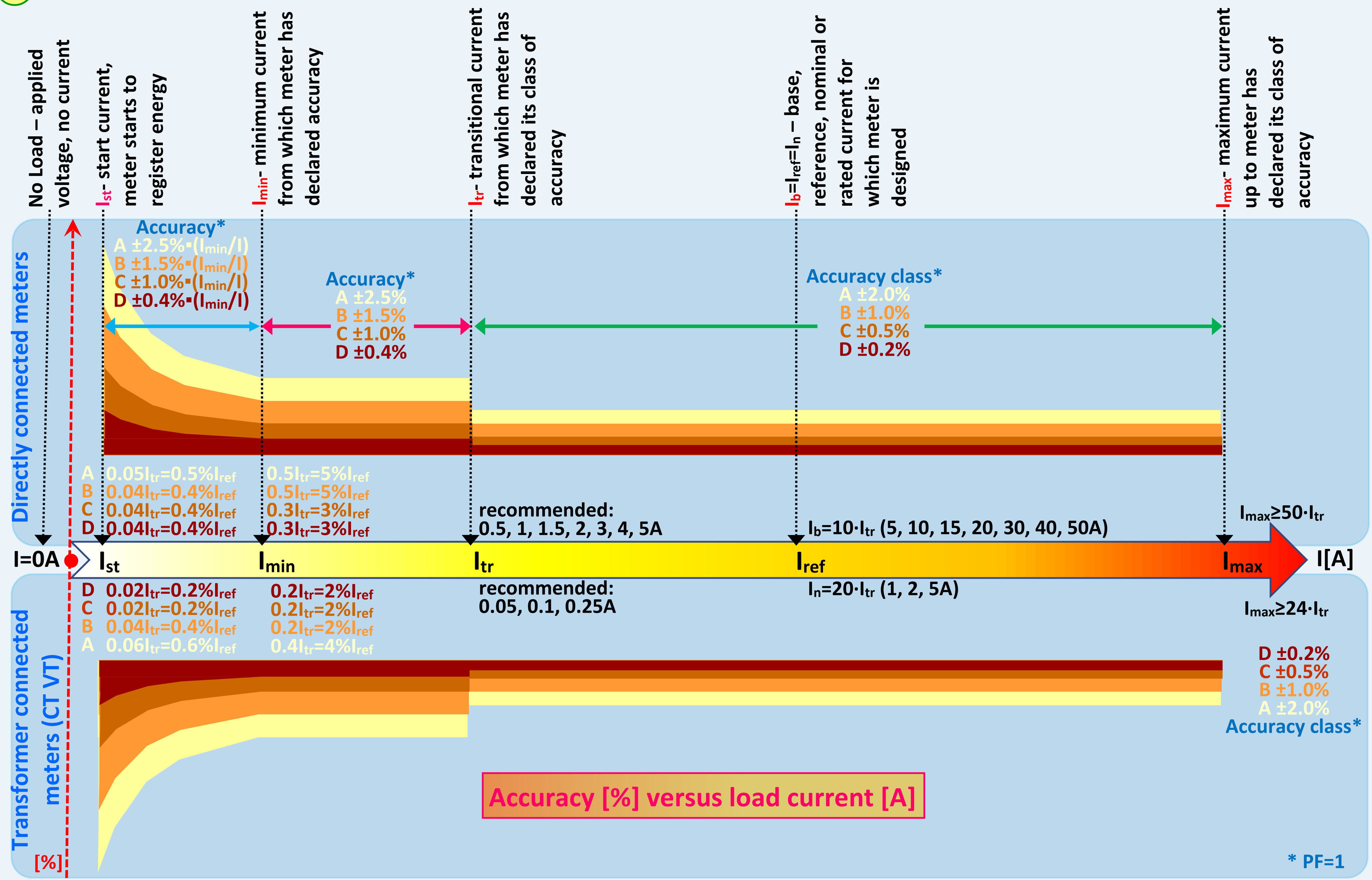
C_P=375IMP/KWH / (200·150)=0.0125IMP/KWH

CT / PT connected ratio K_I & K_U



Conclusion: pay attention to the **primary** and **secondary** meter constant and voltage K_U and current K_I transformers ratio; very big error result during calibration, can be caused by taking wrong meter constant into account!

Energy meter accuracy and load range



Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

07

Reference conditions for testing energy meters - how to calculate the acceptable error limit

Definition: **reference conditions** are used, when determining all errors, including the initial intrinsic error. **Reference conditions** allow to compare results of tests by elimination of **influence quantities**, which can change the meter accuracy.

Additional error caused by influence quantities out of reference range

Quantity	Reference value	Reference tolerance	Influence range	Influence limit *)
Ambient temperature	23°C	± 2°C	5°C to 30°C	~ 0.5 of class
Voltage	Nominal (eg. 230V)	± 1% (227.7V to 232.3VV	± 10% (207V to 253V)	~ 0.5 of class
Frequency	50Hz or 60Hz	± 0.3% (49.85…50.15Hz)	± 2% (49…52Hz)	~ 0.5 of class
Phase sequence	L1-L2-L3	L1-L2-L3	L1-L3-L2	~ 1.0 of class
Waveform	Pure sinus	THD < 2%	10%	~ 0.5 of class
Phase angle U&I	According to PF	± 2°	- - -	- - -
Voltage unbalance	For symmetric load	± 2%	- - -	- - -
Current unbalance	For symmetric load	± 1% or ± 2%	- - -	- - -

*) limit is simplified value of accuracy for meter class at load point

Maximum permissible error (MPE) for testing energy meter on site

Reference conditions usually are in Laboratory and very seldom during measurements performed **on site.** To get acceptable meter error limit on site, we can assume, that influence quantities are in their range so the composite error is a square root of squared influence limits sum:

$$e_{MPE} = \sqrt{e_{class}^2 + e_{temp}^2 + e_{volt}^2 + e_{freq}^2 + e_{wave}^2} = \sqrt{1^2 + 0.5^2 + 0.5^2 + 0.5^2 + 0.5^2 +} = \sqrt{2} = 1.41 \approx 1.5 \ldots 2$$

Conclusion: there is no reference conditions during measurements on site! To get error limit for result evaluation, we can take as a "rule of thumb", the **doubled** accuracy of meter for tested load point and we can assume, that the meter is working correctly if result is lower than this value.

Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

Is my meter measur energy in proper way? - How to test electricity meter error

Simply methods to check meter, however not very accurate. Checking means **meter error** evaluation

Energy meter error: value expressing the relation between the energy registered by the meter and true value of energy - expressed in [%]:

$$\varepsilon = \frac{E_m - E_{ref}}{E_{ref}} \times 100\% \text{ where:}$$

ε – meter under test error
E_m – energy registered by meter under test
E_{ref} – true (reference) value of energy

Testing methods

time & known load	time & known power	time & ammeter / voltmeter	Specialized tester - reference meter
			
- disconnect all electrical equipment in your home - connect one device with known power from nameplate eg. electric heater 2000W=2kW - switch the device ON		- connect ammeter if you have access to the cable close to energy meter - connect voltmeter to any socket in home - in the absence of a voltmeter, use the nominal voltage value eg. 230V	- connect current clamp to the cable close to energy meter - connect voltage cables to the voltage - use push button or scanning head to count turns or pulses
- use nominal power in calculations P=2kW	- readout the power consumption from meter P=3470W=3.47kW	- calculate the power as: P=U*I P=5.1A * 227V = 1157.7W=1.158kW	- power, voltage and current are shown on display
- by stopwatch (or mobile phone) measure time (T[s]) of N (eg.10) rotor turns (or LED blinks); eg. T=241.2s	- by stopwatch (or mobile phone) measure time (T[s]) of N (eg.100) LED blinks; eg. T=10.3s	- by stopwatch (or mobile phone) measure time (T[s]) of N (eg.10) rotor turns (or LED blinks); eg/T=84s	- set the measurement time eg. 10s
- readout meter constant C[imp/kWh]; eg. 75turns/kWh or 6400imp/kWh	- readout meter constant C[imp/kWh]; eg. 10000imp/kWh	- readout meter constant C[imp/kWh]; eg. 375turns/kWh	- set the meter constant in the tester
- calculate the nominal time of N turns (blinks) at power P: $T_N = \frac{3600}{C \times P} \times N$; eg. $T_N = \frac{3600}{75 \times 2} \times 10 = 240s$	- calculate the nominal time of N turns (blinks) at power P: $T_N = \frac{3600}{C \times P} \times N$; eg. $T_N = \frac{3600}{10000 \times 3.47} \times 100 = 10.4s$	- calculate the nominal time of N turns (blinks) at power P: $T_N = \frac{3600}{C \times P} \times N$; eg. $T_N = \frac{3600}{375 \times 1.158} \times 10 = 82.9s$	- all calculations are made automatically
- calculate error as: $\varepsilon = \frac{T - T_N}{T_N} \times 100\%$ $\varepsilon = \frac{241.2 - 240}{240} \times 100\% = 0.5\%$	- calculate error as: $\varepsilon = \frac{T - T_N}{T_N} \times 100\%$ $\varepsilon = \frac{10.3 - 10.4}{10.4} \times 100\% = -0.96\%$	- calculate error as: $\varepsilon = \frac{T - T_N}{T_N} \times 100\%$ $\varepsilon = \frac{84 - 82.9}{24082.9} \times 100\% = 1.33\%$	- the error is calculated automatically ε = -0.780%

- compare ε with meter class: if ε ≤ class → meter is OK'; if 2*class > ε > class → meter seems to be OK' (method is not accurate); if ε > 2*class → meter should be tested in professional way

Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

Energy meters testing method - ON LINE

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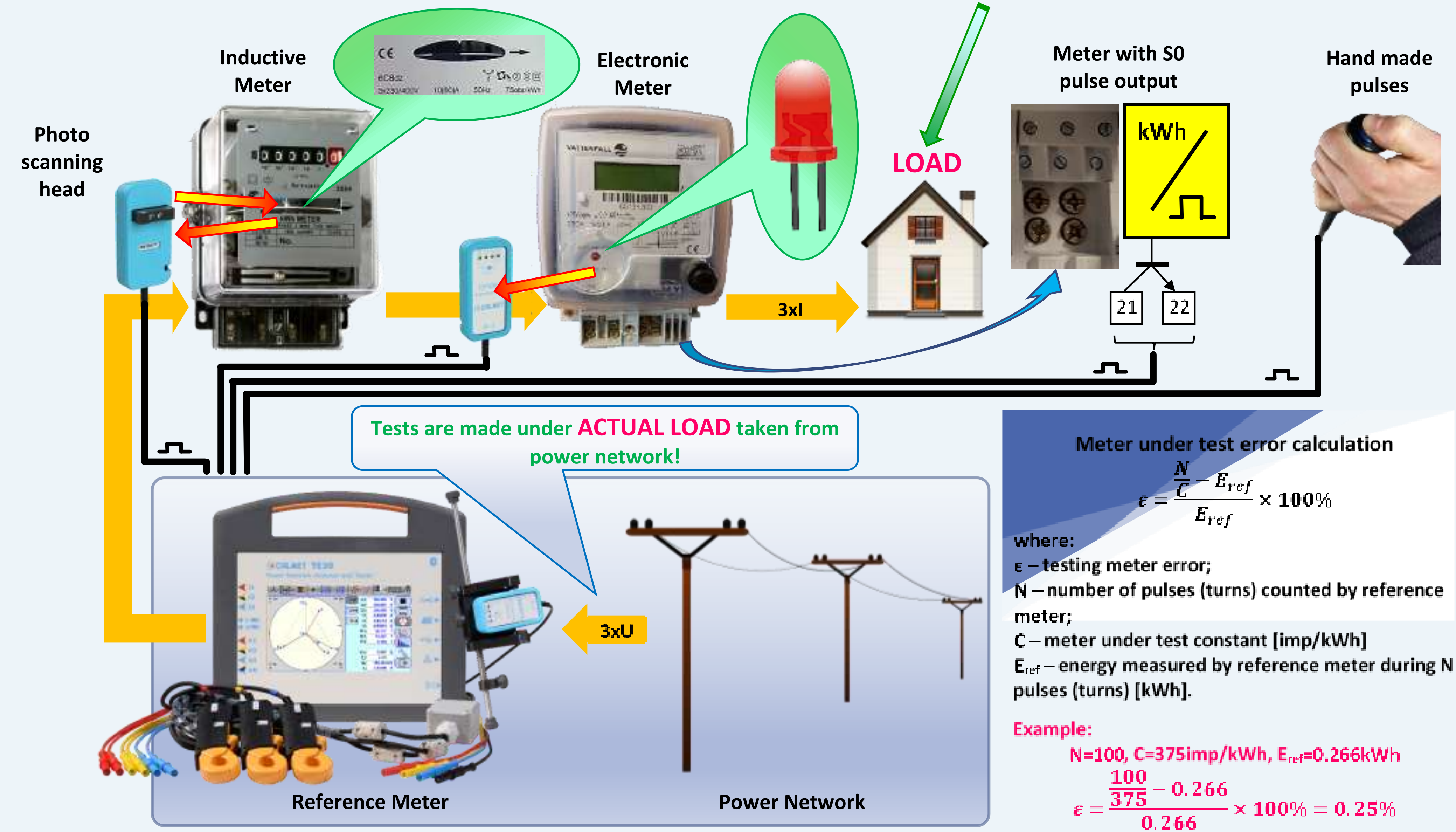
Electricity meters are tested by direct comparison method with higher accuracy Reference Meter

On Line **means, that electricity meter is in normal operation during test, connected to the power network, at the current load**



Meter under test error calculation

$$\varepsilon = \frac{\frac{N}{C} - E_{ref}}{E_{ref}} \times 100\%$$

where:

ε – testing meter error;

N – number of pulses (turns) counted by reference meter;

C – meter under test constant [imp/kWh]

E_{ref} – energy measured by reference meter during N pulses (turns) [kWh].

Example:

N=100, C=375imp/kWh, E_{ref}=0.266kWh

$$\varepsilon = \frac{\frac{100}{375} - 0.266}{0.266} \times 100\% = 0.25\%$$

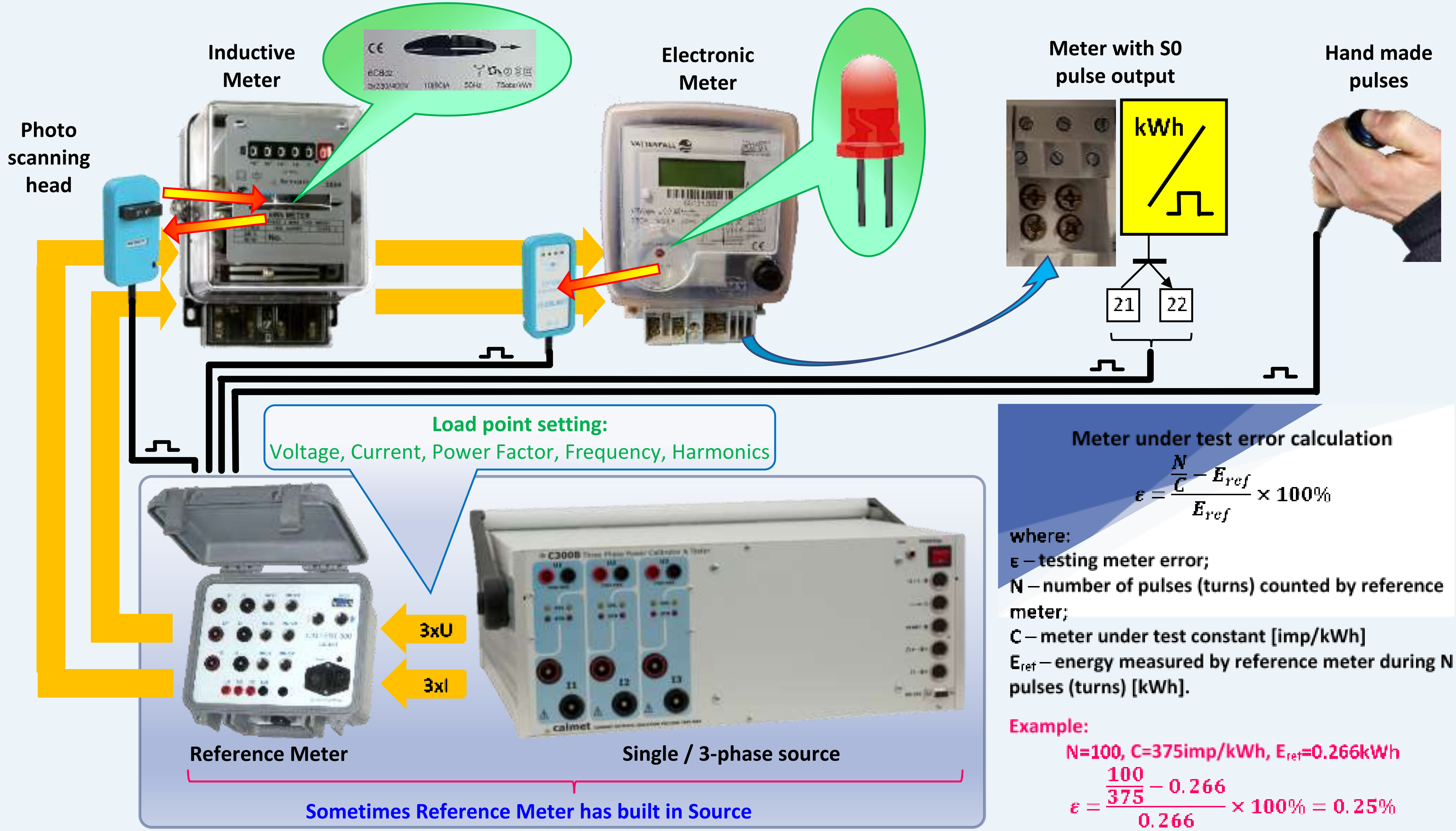
<u>Recommendation & Standards:</u> OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

Energy meters testing method - OFF LINE

CALMET

Electricity meters are tested by direct comparison method with higher accuracy Reference Meter

Off Line **means, that electricity meter is unconnected from power network and is powered by single or 3-phase source → calibrator**



Meter under test error calculation

$$\varepsilon = \frac{\frac{N}{C} - E_{ref}}{E_{ref}} \times 100\%$$

where:

ε – testing meter error;

N – number of pulses (turns) counted by reference meter;

C – meter under test constant [imp/kWh]

E_{ref} – energy measured by reference meter during N pulses (turns) [kWh].

Example:

N=100, C=375imp/kWh, E_{ref}=0.266kWh

$$\varepsilon = \frac{\frac{100}{375} - 0.266}{0.266} \times 100\% = 0.25\%$$

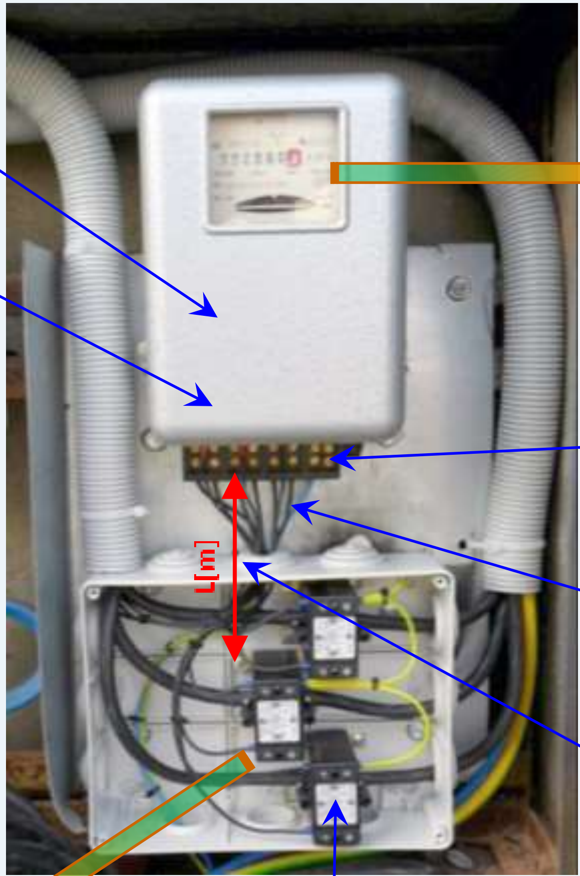
Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

Metering installation – source of errors

Meter error greater than class requirement in whole or part range of load

Internal break in voltage or current circuit

- missed or wrong CT / PT label;
- not readable ratio factor;
- too small or too high power [VA] (for 25% to 120% of rated load);
- CT (PT) is out of accuracy class (ratio and phase shift error);
- too long or too thin wires (burden problem);
- too high or to low primary current against typical load in the network.



Damaged register or wrong gear

Rotor friction

Wrong or not readable meter constant

- lack of contact, unscrewed screw;
- opened “IP link”, “close link”.

- interchanged voltage cables;
- changed beginning with the end for current;
- current phase connected to wrong voltage phase (transformer meters);
- lack of neutral cable);

Too long or to thin cables for current from CT (burden problem)

CT assembled in opposite way to current flow

Conclusion: whole installation must be tested to ensure reliable energy measurements

Energy meter. What to test? Testing sequence

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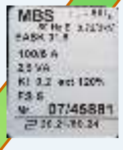
Installation checking

1. Meter as found(value of register, photo)
   Is it working?(rotor moving, LED flashing)

2. Meter name plate (meter type, accuracy class, I_{TR}(I_B), I_{MAX}, meter constant)

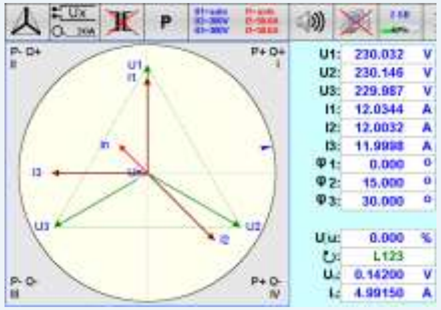
3. Leading seals condition (certification and installation)

4. Current & voltage transformers ratio (CT / PT ratio)



5. Wiring condition (isolation, breaks)

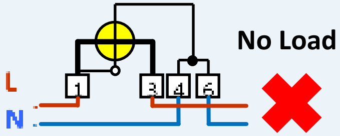
6. Connection verification:
   - phase association
   - phase sequence L1L2L3 <-> L1L3L2
   - CT / PT polarity
   - vector diagram
   - values of U, I, φ, Freq.,P, Q, S in each phase



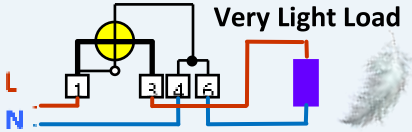
Conclusion: installation and electricity meter must be tested in proper queue to enable **reliable energy measurements**

Testing

7. No load test (creep test) (applied voltage, load disconnected eg. by circuit breaker, no current flow)

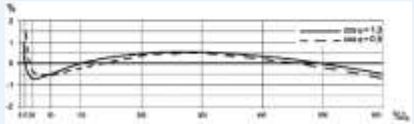


8. Startup current (minimal current at which rotor starts moving or LED blinking)



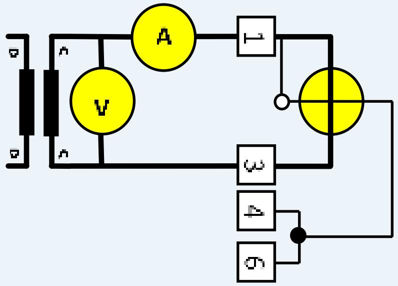
9. Meter constant test (register or dial test) to prove that rotor turns or LED blink corresponds with register

10. Accuracy test – meter error (at customer load – ON LINE or at load by PHANTOM LOAD)



11. CT/PT burden test (to check wiring and CT/PT power [VA])

12. CT/PT ratio and phase shift error test (to check correct labeling and operation)



Results

13. Meter as left (value of register, photo)
    Is it working? (rotor moving, LED flashing)

14. Report (customer data, meter data, results, conclusion)

Recommended load points for testing energy meter error

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Two ways of testing meter on site:

On Line **means, that electricity meter is in normal operation during test, connected to the power network, at the current load existing on site**

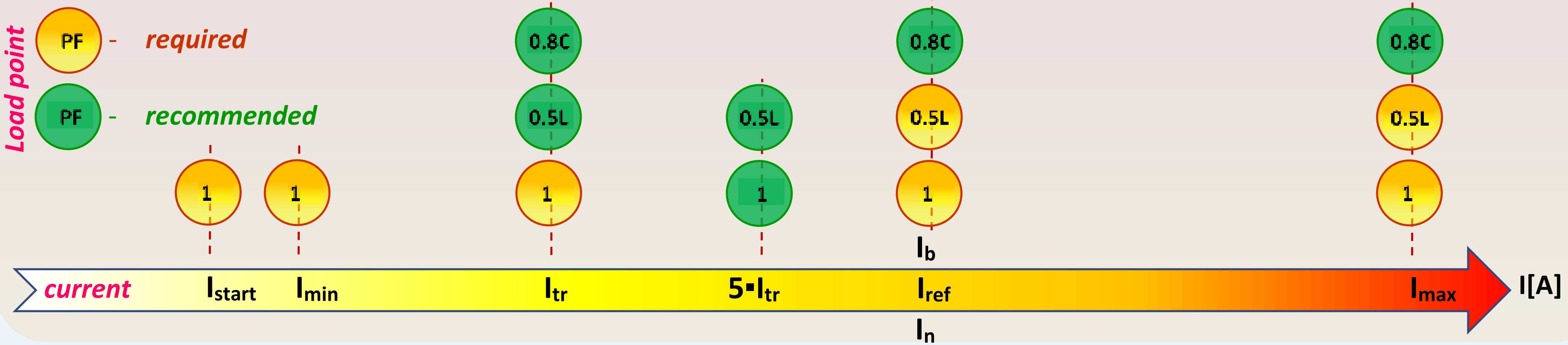
No load test (creep test) **-** *can be performed by moving circuit breakers to the OFF position*

Accuracy test **-** *can be performed only for the load, which is at the moment in power network; the load can be changed by switching ON / OFF electrical devices:*

400 – 2000W | *100 – 400W* | *800 – 2000W* | *100 – 4000W* | *25 – 200W* | *70 (unheated) – 1800W* | *20 – 100W*

Off Line **means, that electricity meter is unconnected from power network and it is powered by single or 3-phase source → with load set by calibrator or phantom load**

Accuracy test **–** *load points and power factor PF required and additionally recommended during testing*



Conclusion: only by means of phantom load or calibrator, we can test energy meter in **whole range of loads** during measurements on site!

Which tester to which meter?

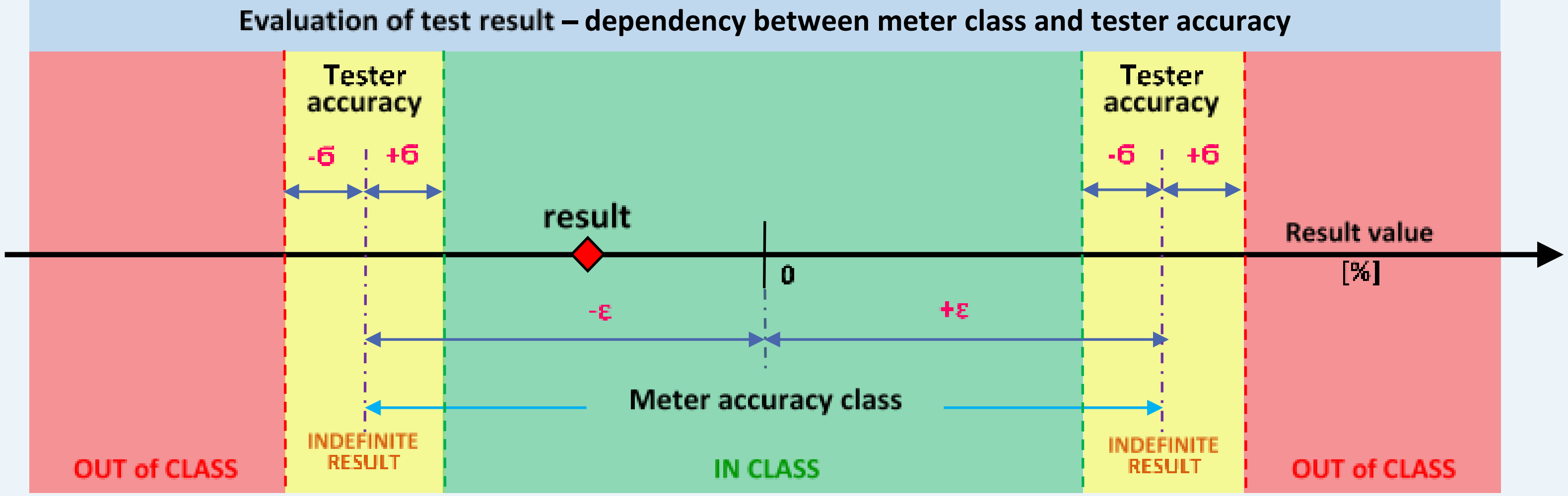
(accuracy of tester)

Only tester with proper accuracy can give valuable result of electricity meter calibration

Definitions:

***Electricity meter** accuracy class: an index, which corresponds to meter accuracy in reference conditions; usually value in [%] – ε*

***Portable working standard** – energy meter tester accuracy: accuracy in % - б*



EXAMPLE: FOR METER CLASS 0.5S AND TESTER ACCURACY 0.1 THE RESULT OF MEASUREMENT IS:

- -0.25% - METER IN CLASS
- +0.7% - METER OUT OF CLASS
- -0.45% - INDEFINITE RESULT

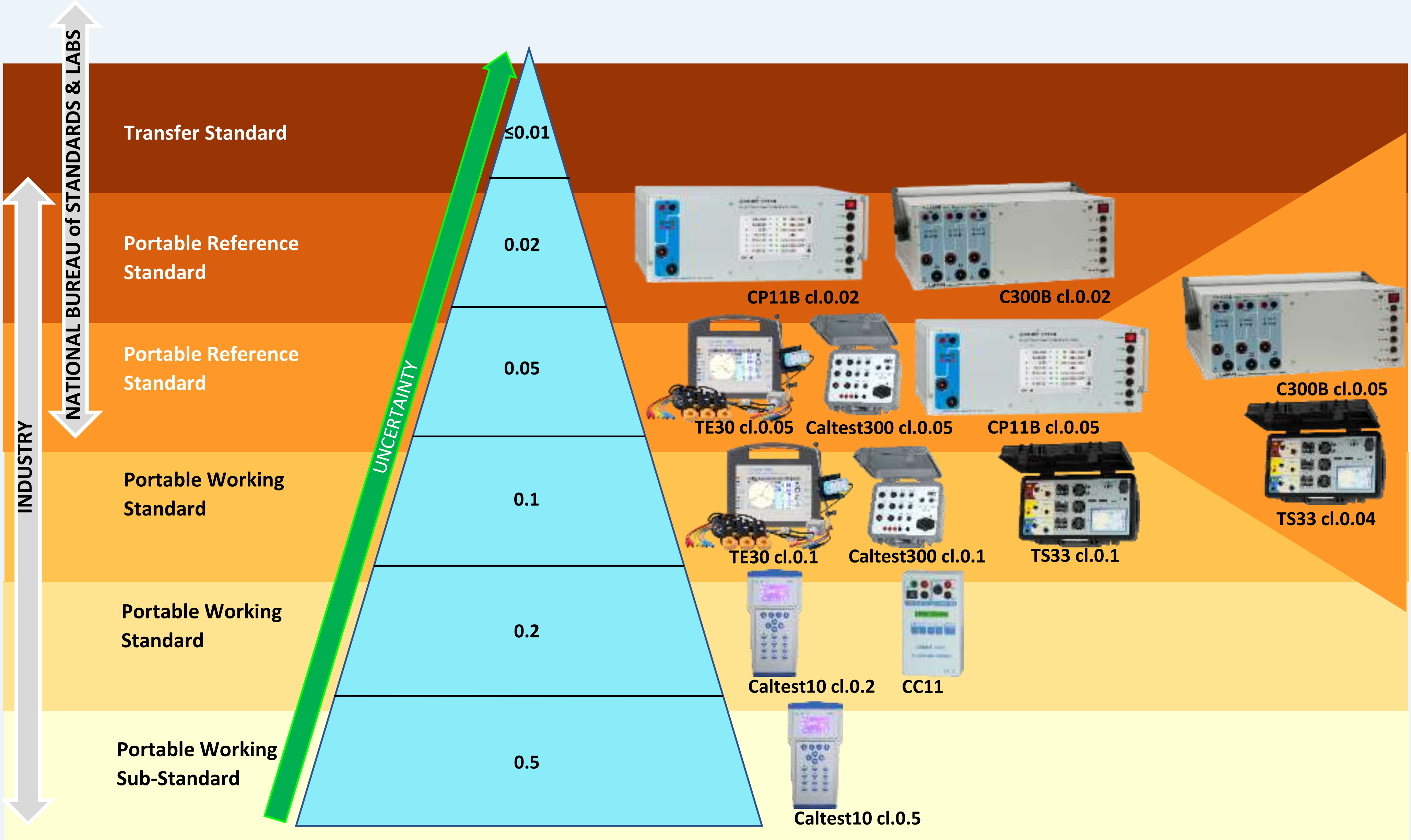
Conclusion: tester should have a few times greater accuracy than meter; if tester accuracy is 10 to 5 times better, all results can be treated as defined

Electricity meter installation configuration and meter requirements

Voltage level	Configuration description and power flow	Minimum meter accuracy class	Recommended tester accuracy
Low voltage	Direct measurement	2 / A	0.2% ...0.4%
Low voltage	CT measurement	1 / B	0.1%...0.2%
High voltage	CT & PT measurement for power < 2MW	1 / B	0.05%...0.1%
High voltage	CT & PT measurement for power 2MW – 10MW	0.5S / C	0.05%...0.1%
High voltage	CT & PT measurement for power > 10MW	0.2S / D	0.02%...0.04%

Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

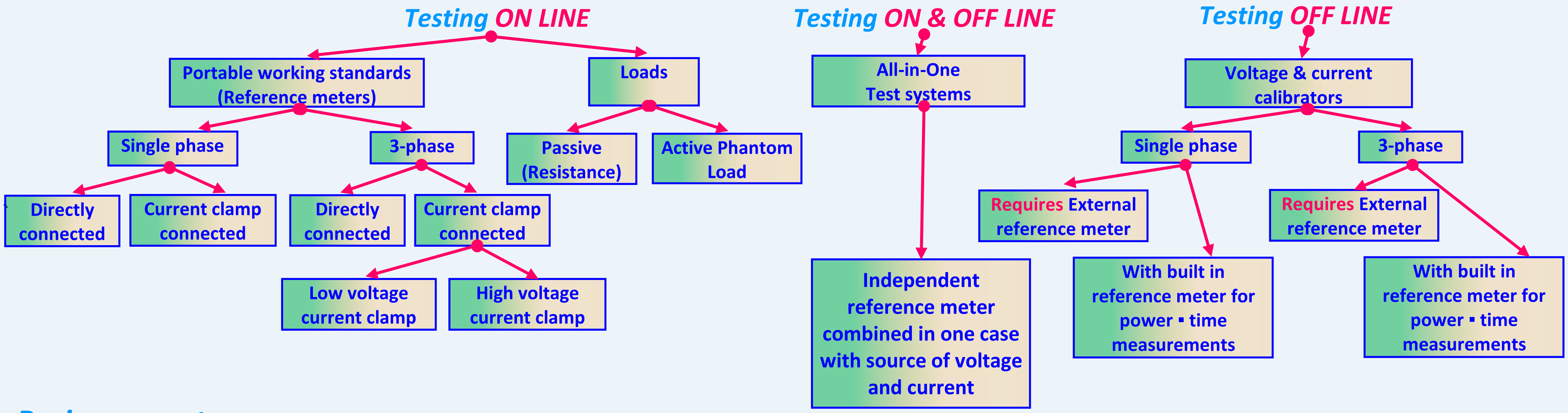
Accuracy pyramid of Portable Working Standards for Electricity Meter Testing



Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft www.calmet.com.pl

Energy meter test equipment - types and properties of testers

Energy meter test equipment

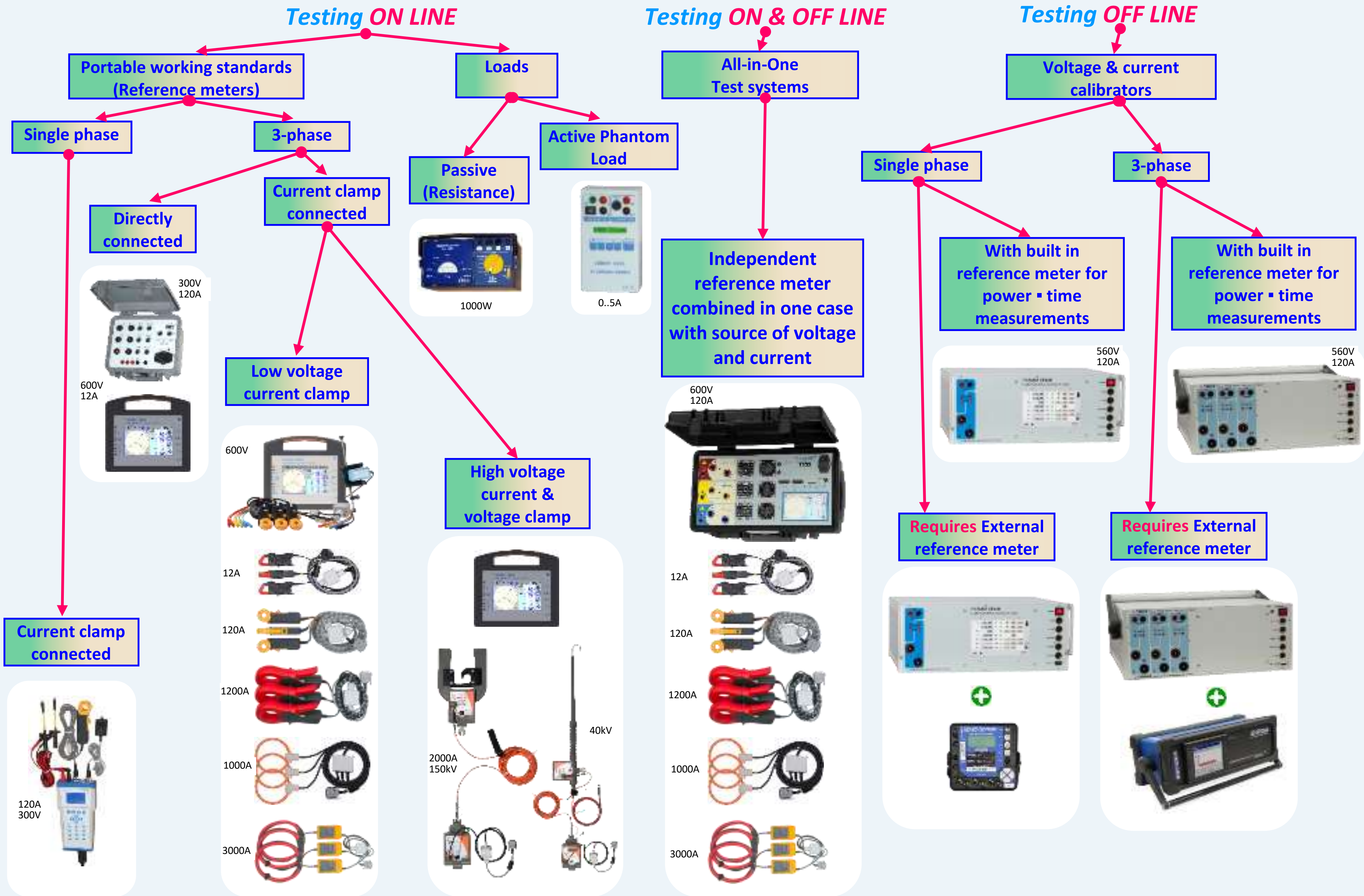


Basic parameters

Reference meter		Voltage & current source	
Input voltage	50mV … 400V (Line – Neutral)	Output voltage range	40V … 400V
Voltage accuracy	0.02% … 0.2%	Voltage output power	>15VA per phase
Input current: / Accuracy:	-	Voltage setting accuracy	< 0.5%
- direct connection	1mA … 12A / 0.02% … 0.2%	Output current range	1mA … 120A
- current clamp connection	10mA … 3000A / 0.2% … 1%	Current output power	>30VA per phase
Power / energy accuracy:	-	Current setting accuracy	< 0.5%
- direct connection	0.02% … 0.2%	Frequency range	45Hz … 65Hz
- current clamp connection	0.2% … 1%	Frequency resolution	0.01Hz
Frequency	45Hz … 65Hz	Waveform	Pure sinus, THD<0.5%
Measured parameters	U, I, φ, Frq, PF, P, Q, S, E	Phase shift setting / resolution	0° … ±360° / 0.1°
Operating temperature	-10°C … +50°C	Phase shift between voltages	0° … ±360°
Storage temperature	-20°C … +60°C	Operating temperature	-10°C … +50°C
Protection class	Min. IP30	Storage temperature	-20°C … +60°C

Recommendation & Standards: OIML R46-1/-2, ANSI C12.1, IEC62052-11, IEC62053-xx, IEC50470-1/-2/-3, IEC62057-1/-2 draft

Energy meter test equipment - examples of testers

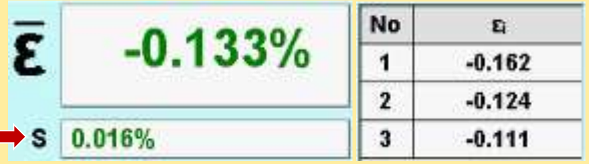


Recommendation & Standards: OIML R46-1/-2, ANSI C12.1, IEC62052-11, IEC62053-xx, IEC50470-1/-2/-3, IEC62057-1/-2 draft

Energy meter test equipment – additional functionality. What is this functionality for?

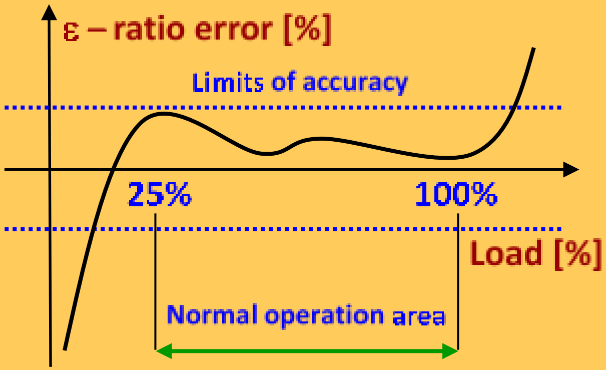
CALMET

Standard deviation (s) – shows dispersion of a set of results from average value calculated by formula: $s = \sqrt{\frac{\sum_{i=1}^{N}(\varepsilon_i - \bar{\varepsilon})^2}{N-1}}$ *where:* ε_i*-individual result,* $\bar{\varepsilon}$ *– average value of results:* $\bar{\varepsilon} = (\sum_{i=1}^{N} \varepsilon_i)/N$*, N – number of results.*



Practical meaning: let's analyse example of 3 results: 1.0%, 4.0%, -5.0%. The average is $\bar{\varepsilon} = 0\%$, so it seems, that meter has very small error. But standard deviation is s=2.65%, so results have big dispersion and meter doesn't work correctly.
Conclusion: the standard deviation for at least 3 measurements, should be lower than class of tester to achieve reliable result. Analysis of only average value of result can lead to wrong conclusions.

CT/PT burden test – each current (CT) or voltage transformer (PT) has limited output power [VA] and accuracy in specified load range (25% - 100%) of secondary side. Overload or underload can lead to increased measurement error. Testing consists in power consumption measurement on secondary side of transformer. Because usually measurements are made close to meter, the length of connection wires between CT/PT and fuse resistance for PT should be taken into account.

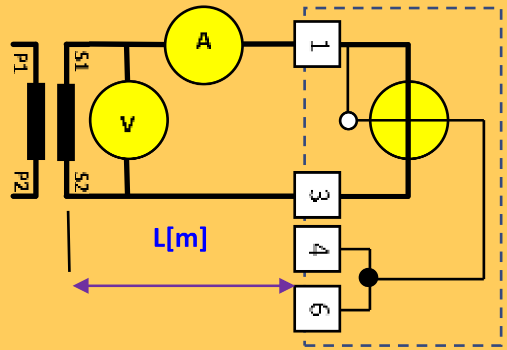


Wires resistance calculation if the CT/PT burden is out of nominal range, there is additional measurement error. Resistance R_w and power loss S_l can be calculated by formula:

$$R_w[\Omega] = \frac{\rho_{cu}[\Omega\times mm^2/m]\times l[m]}{S[mm^2]} \quad \rho_{cu} = \frac{0175\Omega\times mm^2}{m} \text{ and } S_l[VA] = I^2[A]\times R_w[\Omega]$$

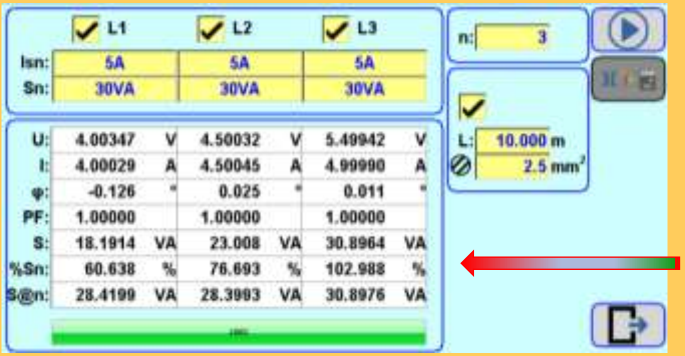
Practical example: let's analyse example of CT connected by 2 copper wires length 20m (total 2 x 20m=40m) with cross-section 2.5mm², at nominal current 5A.

$$R_w = \frac{0.0175\times 40}{2.5} = 0.28\Omega \text{ and } S_l = 5^2\times 0.28 = 7VA$$



Practical example: *– screen shot shows burden test result for CT 600/5A and nominal power Sn=30VA:*

- *U – secondary side voltage*
- *I – secondary current*
- *φ – phase shift primary / secondary*
- *PF – power factor*
- *S – apparent power at secondary side*
- *%Sn – percent of used nominal CT power*
- *S@n - power that would be at nominal current*



	L1		L2		L3	
Isn:	5A		5A		5A	
Sn:	30VA		30VA		30VA	
U:	4.00347	V	4.50032	V	5.49942	V
I:	4.00029	A	4.50045	A	4.99990	A
φ:	-0.126	°	0.025	°	0.011	°
PF:	1.00000		1.00000		1.00000	
S:	18.1914	VA	23.008	VA	30.8964	VA
%Sn:	60.638	%	76.693	%	102.988	%
S@n:	28.4199	VA	28.3993	VA	30.8976	VA

In L3, the nominal power of the transformer is exceeded. In L1 & L2 power is in limits.

Conclusion: improper system installation with CT/PT can cause unpredicted decreasing of accuracy in electricity measurement.

Power calibrator – what is this? Principle of operation

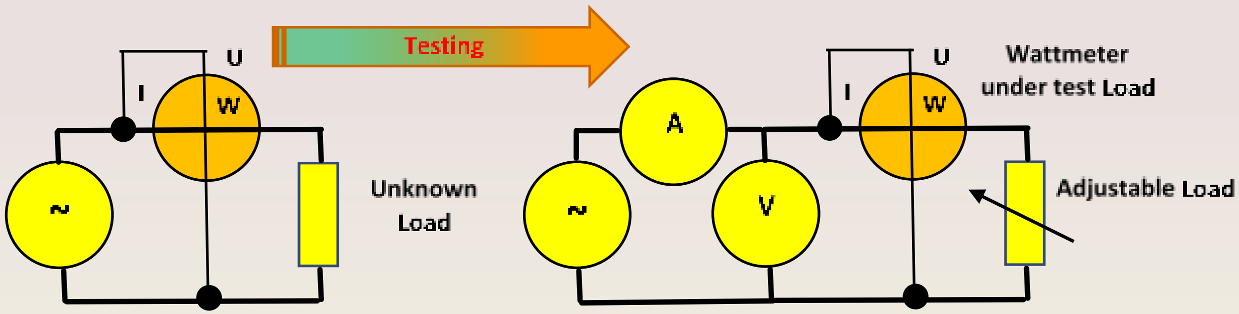
CALMET

Wattmeter (Electricity meter) calibration requires high power load in traditional method

Typical wattmeter application. In this circuit we can measure unknown load.

For wattmeter calibration we need voltmeter, ammeter and adjustable or exactly known high power load.

By changing the Load, we can compare calculated Power $P=U \cdot I \cdot \cos(\varphi)$ (U=voltmeter readout, I=ammeter readout, for resistive load $\cos(\varphi)=1$) with result shown by Wattmeter and then calculate the error.



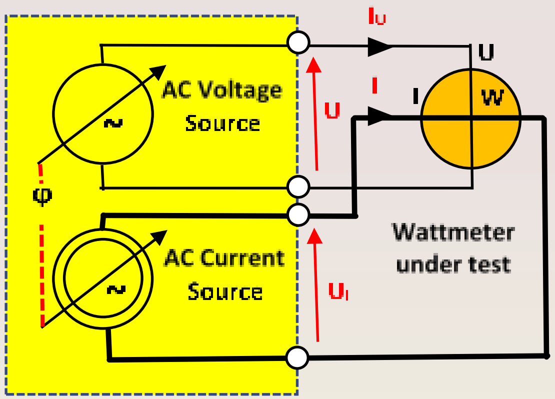
EXAMPLE: REQUIRED LOAD POWER CALIBRATION POINT:

U=230V, I=10A, cos(φ)=1

P=230·10·1=2300W=**2.3kW!!!**

SOLUION

Power calibrator consists of separate, programmable voltage source and current source with adjustable phase shift between them



The voltage input of Wattmeter is connected to the programmable AC Voltage Source. The input resistance of the Wattmeter is relatively high (hundreds of kΩ to MΩ), so only a few mA is required and voltage source power is: $P_U=U \cdot I_U$ (few tenths of VA).

We can also apply the phase shift φ between voltage and current and we can test Wattmeter for all values of cosφ or power factor.

The current input of Wattmeter is connected to the programmable AC Current Source. The resistance of this input is relatively low (a few mΩ), so the voltage drop is very low (parts of volt). The power required from current source is: $P_I=U_I \cdot I$ (few tenths of VA).

EXAMPLE: REQUIRED CALIBRATOR POWER

WATTMETER UNDER TEST:

UP TO 3kW, VOLTAGE RANGE 300V

R_U - INPUT RESISTANCE 100kΩ

CURRENT RANGE 10A

R_I - INPUT RESISTANCE 0.1Ω

TESTING LOAD POINT:

U=230V, I=10A, cos(φ)=1 → P=2.3kW

POWER REQUIRED FROM CALIBRATOR:

$P_U=U \cdot I_U=U \cdot (U/R_U)=230V \cdot (230V/100k\Omega)=0.53VA$

$P_I=U_I \cdot I=I \cdot R_I \cdot I=10A \cdot 0.1\Omega \cdot 10A=10VA$

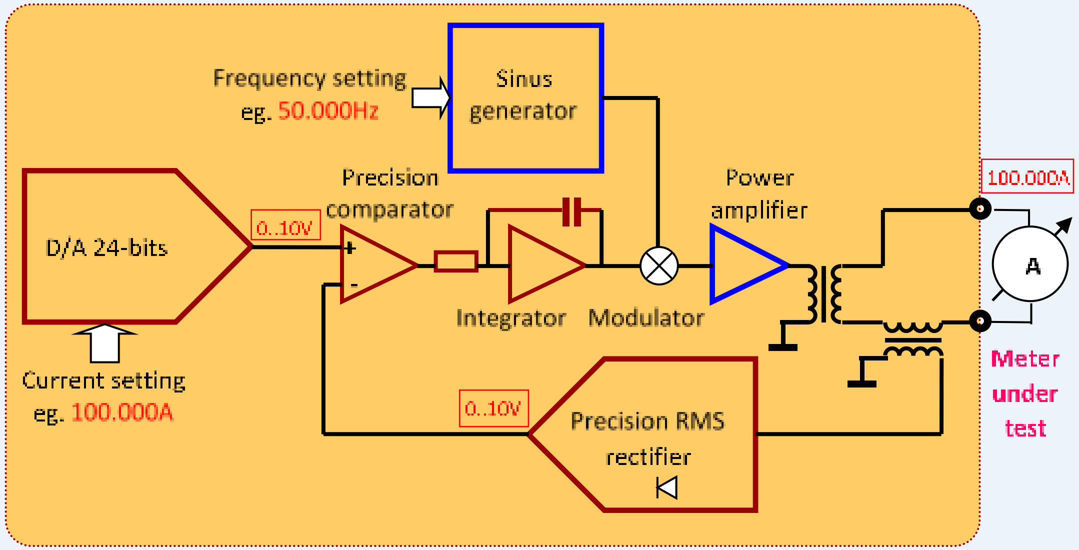
CALIBRATOR CAN SIMULATE 2.3kW BY USING ONLY 0.53VA FOR VOLTAGE AND 10VA FOR CURRENT !!!

Conclusion: Power Calibrator **simulate** the power and doesn't require high power delivery from network

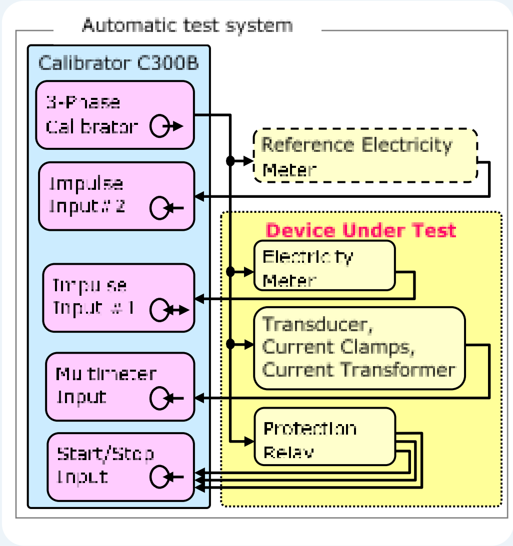
Power calibrator – example solution

3-phase power calibrator – general principle of operation

Energy meter test set



Simplified diagram of power calibrator – one current channel



Calibrator as automatic test system

The C300B 3-phase power calibrator is controlled via RS232/USB interface by means of dedicated Calpro300 PC software. All settings are transferred to the C300B to get required output signal values.

The idea of calibrator is presented on base of one current channel of C300B. The set value of frequency is transferred to the sinus generator, and set value of current (eg. 100.000A) is transferred from computer to calibrator, and then to precision, 24 bits, digital to analog converter D/A, which converts it to the voltage in range 0...10V. At the same time, the sinusoidal signal from generator, through modulator is delivered to the power amplifier and then current transformer, which delivers output current to the calibrator terminals. The output current is controlled by second, precision current transformer. Signal from this transformer is rectified (RMS - root mean square) to the DC on level 0..10V. This DC voltage is compared with set value of voltage from D/A and result of comparison - drives integrator, which control modulator of sinusoidal signal. In this way is realised feedback for precision control of calibrator output value and output value doesn't depend on load change or time or temperature and is stable in defined as accuracy limits. So the meter under test see exactly set value.

For example the set value of 100.000A is converted by D/A and then it is stabilized at the output with accuracy ±0.02%, what means 100.000A ± 0.020A. So the user, who set and see on display 100.000A, get for sure, the output signal between 99.980A .... 100.020A, which fits into accuracy class of calibrator.

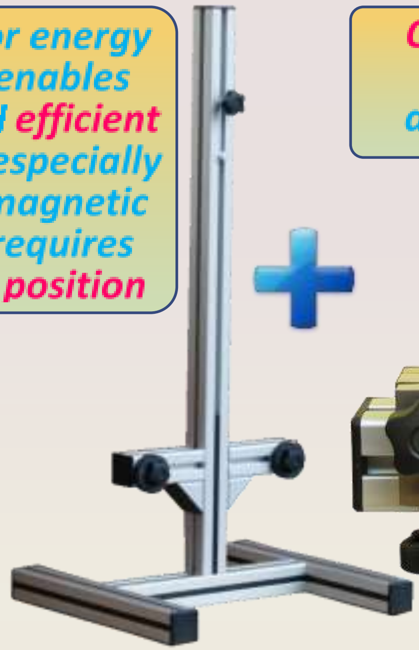
The value of internal signals (0..10V) from D/A or RMS does not any matter for user, because the adjustment of calibrator, during process of it calibration, is made by measure the output value by higher level reference standard against set value in calibrator by PC software.

Conclusion: Power Calibrator **is a precision source** of AC voltage and current, **set value** is at the output

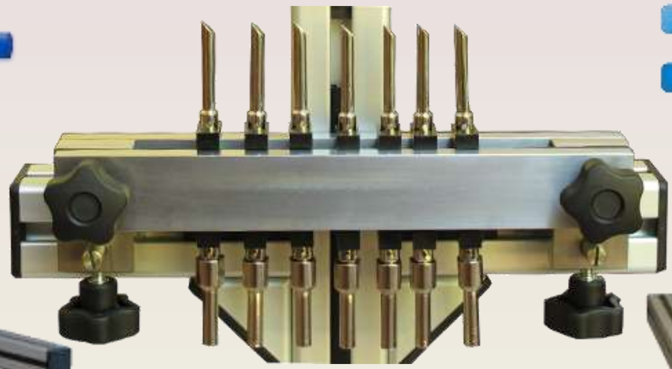
Meter test equipment – accessories - stand and quick connector

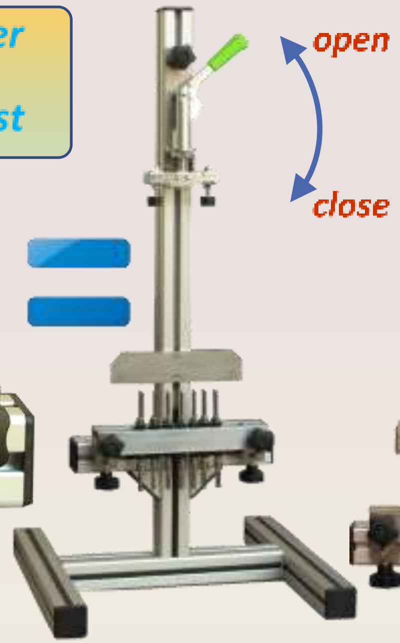
CALMET

Stand for energy meter enables easy and efficient testing, especially electromagnetic meter requires vertical position



Quick connector for energy meter enables fast connection / disconnection of meter under test





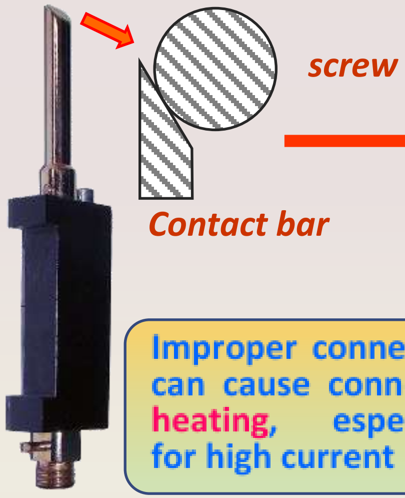
Meter ready for testing

Energy meter have to be prepared for quick connector. ALL screws must be tightened to the end

Properly tightened screws

Bolts tightened in half

Unscrewed screws



Improper connection can cause connector heating, especially for high current

Conclusion: stand with quick connector speeds up the testing process, however requires proper meter under test terminals preparation!

Meter test equipment – accessories - cables

Warning! Use only safe and undamaged wires with 4 mm safety plugs!
The recommended length is 2m – 3m and thickness (cross section) 1mm^2 for voltage cables up to 10A and 2.5mm^2 for current cables to 30A

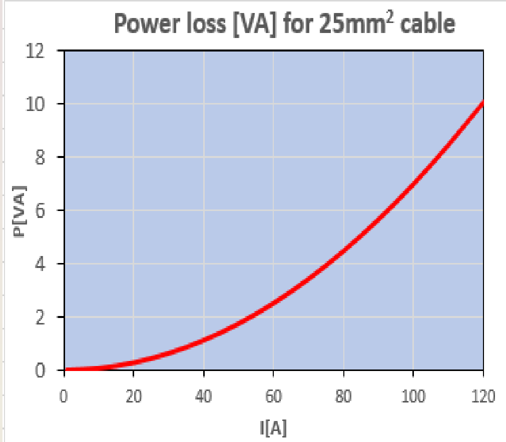
Why is the cable resistance important?
The current flowing through cable makes voltage drop, power loss and cable heating

How to calculate resistance

$$R[\Omega] = \frac{\rho_{Cu}[\frac{\Omega \cdot mm^2}{m}] \cdot l[m]}{S[mm^2]}$$

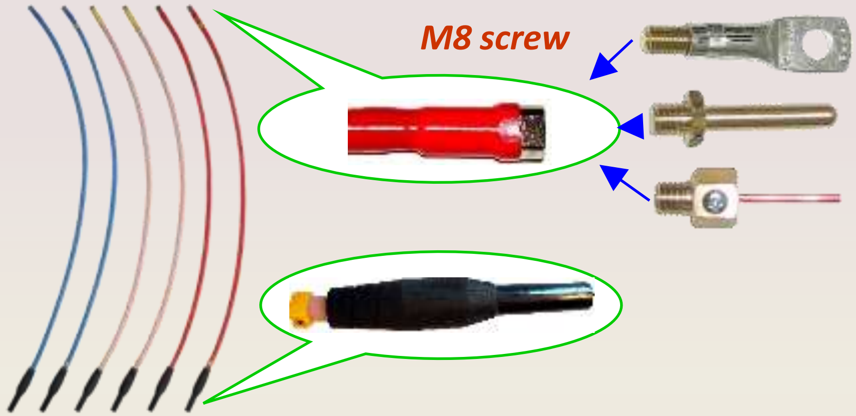
$$\rho_{Cu} = 0.0175 \frac{\Omega \cdot mm^2}{m}$$

1m cable resistance and power loss in dependency on cable cross section and maximum current



Cross section [mm^2]	1m resistance [mΩ]	Maximum current [A]	Power loss [VA] at max current
1	17.50	19	6.32
1.5	11.67	24	6.72
2.5	7.00	32	7.17
4	4.38	43	9.09
6	2.92	54	8.51
10	1.75	73	9.33
16	1.09	98	10.50
25	0.70	128	11.47

High current 120A cables, length 1m, S=25mm^2



Typical safety current cables length 2m, cross section 2.5mm^2 resistance 15mΩ

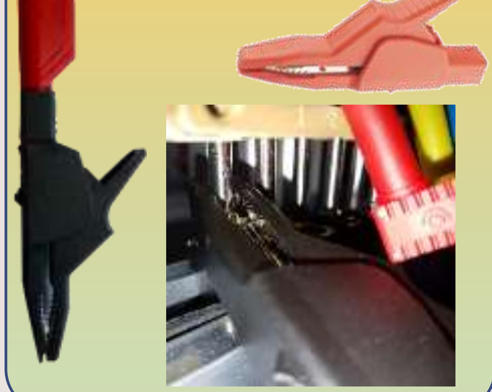
Typical safety voltage cables length 2m, cross section 1mm^2 resistance 35mΩ. For voltage stackable plugs are recommended

Conclusion: The length of cables should be minimized and cross section maximized, especially for high currents

Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

Accessories for laboratory cables with 4 mm safety plugs allows easy and fast meter connection

Wide crocodile terminal
- max wire diameter – ∅ 30mm
- working voltage 1000V
- working current 34A
- contact resistance 10mΩ



Banana plug - terminal
- working voltage 1000V
- working current 20A
- contact resistance 2mΩ

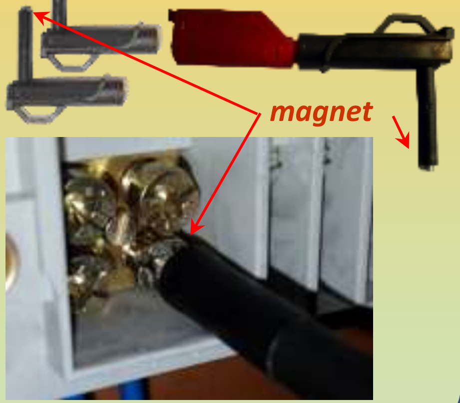
Fork terminal
- working voltage 1000V
- working current 20A
- contact resistance 2mΩ

Thin needle terminal
- pin diameter ∅ 2.0mm, length 25mm
- working voltage 600V
- working current 19A
- contact resistance 5mΩ

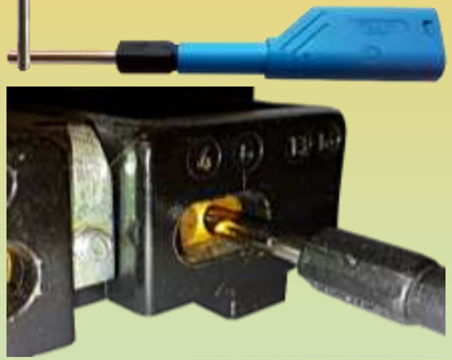
Long crocodile terminal
- length – 157mm
- working voltage 1000V
- working current 20A
- contact resistance 50mΩ

Long copper wire terminal
- length – 130mm, ∅ 1.8mm
- working voltage 1000V
- working current 32A
- contact resistance 10mΩ

Magnetic terminal
- working voltage 1000V
- working current 10A
- contact resistance 10mΩ



Thick needle terminal
- pin diameter ∅ 3.5mm, length 25mm
- working voltage 600V
- working current 30A
- contact resistance 2mΩ



Conclusion: only professional accessories allow for safe and secure connection to the electricity meter and thus a reliable measurement

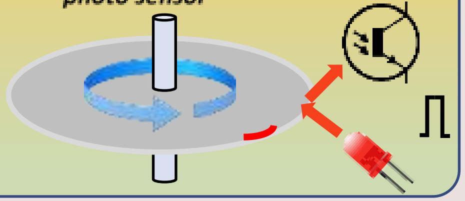
Meter test equipment – accessories - scanning head – getting pulses

CALMET

Getting proper pulses is essential for automatic electricity meter testing

Inductive energy meter

- disk with red or black mark
- photo head with LED lamp and photo sensor



Electronic energy meter

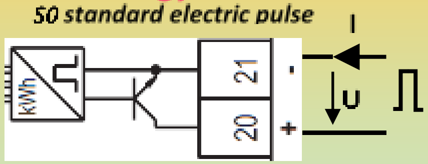
- red, green or infrared LED blinking or LCD segment flashing
- photo head with photo sensor

Electronic and Inductive energy meter

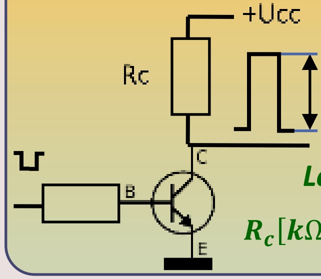
manual push – button and pulse generation

Electronic and Inductive energy meter

S0 standard electric pulse



Open collector pulse output + external Rc



$U_{cc}max \leq 27V$

$I_c max \leq 100mA$

TTL logic example:
Level "0" 0..0.8V "1" 2.4..5V

$$R_c[k\Omega] = \frac{U_{cc}[V]}{I_c} = \frac{5V}{1.8mA} \sim 2.7k\Omega$$

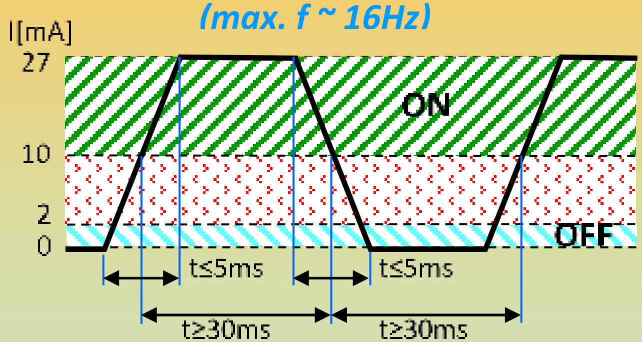
Frequency of pulse output

$$f_{imp}[Hz] = \frac{P_{3-phase}[W] \cdot C[imp/kWh]}{3600 \cdot 1000}$$

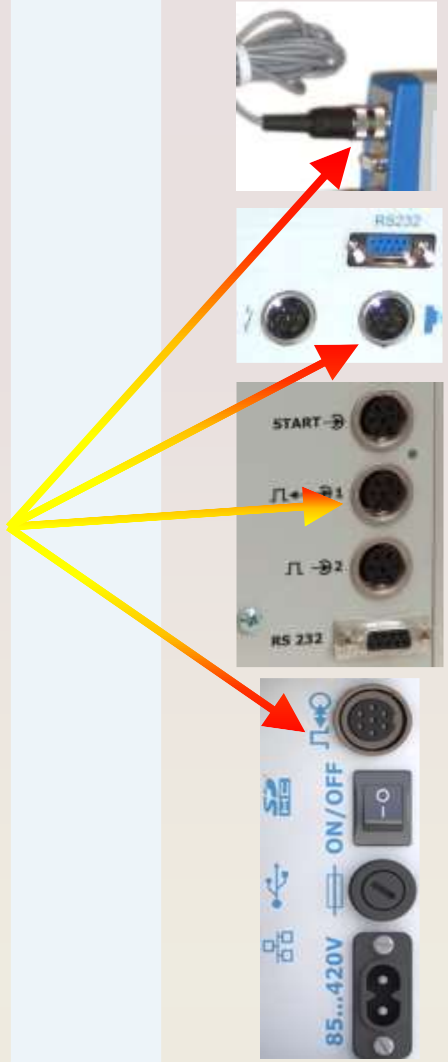
EXAMPLE: PULSE FREQUENCY
P=230V•10A•3=6900W
METER CONSTANT C=375IMP/KWH

$$f = \frac{6900 \cdot 375}{3600 \cdot 1000} = 0.72Hz$$

Timing and levels for S0 standard (max. f ~ 16Hz)



Example pulse inputs



Conclusion: proper setting of scanning head to get pulses of appropriate level for tester, allows reliable error measurement

Meter test equipment – accessories – current clamps

CALMET

Current clamps and Rogowski coils enables easy current measurement without breaking electrical circuit

120A current clamps

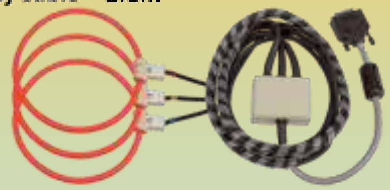
- max. wire diameter – ∅ 15mm
- typical accuracy 0.2% of measured value in range 0.1A..120A
- length of cable 2m

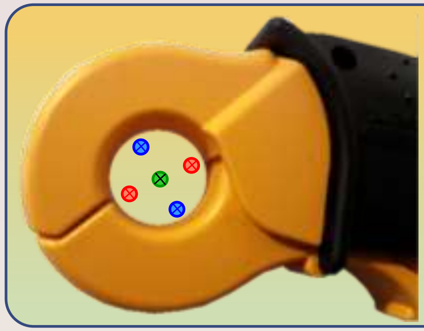
1200A current clamps

- max. wire diameter – ∅ 52mm
- typical accuracy 0.2% of measured value in range 0.3A..1200A
- length of cable 2m

30/300/3000A current clamps

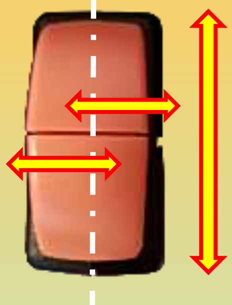
- max. wire diameter – ∅ ~150mm
- typical accuracy 1% of measured value in range 0.3A..30A / 3A..300A / 30A..3000A
- length of cable – 2.8m





Influence of cable position on current clamps accuracy

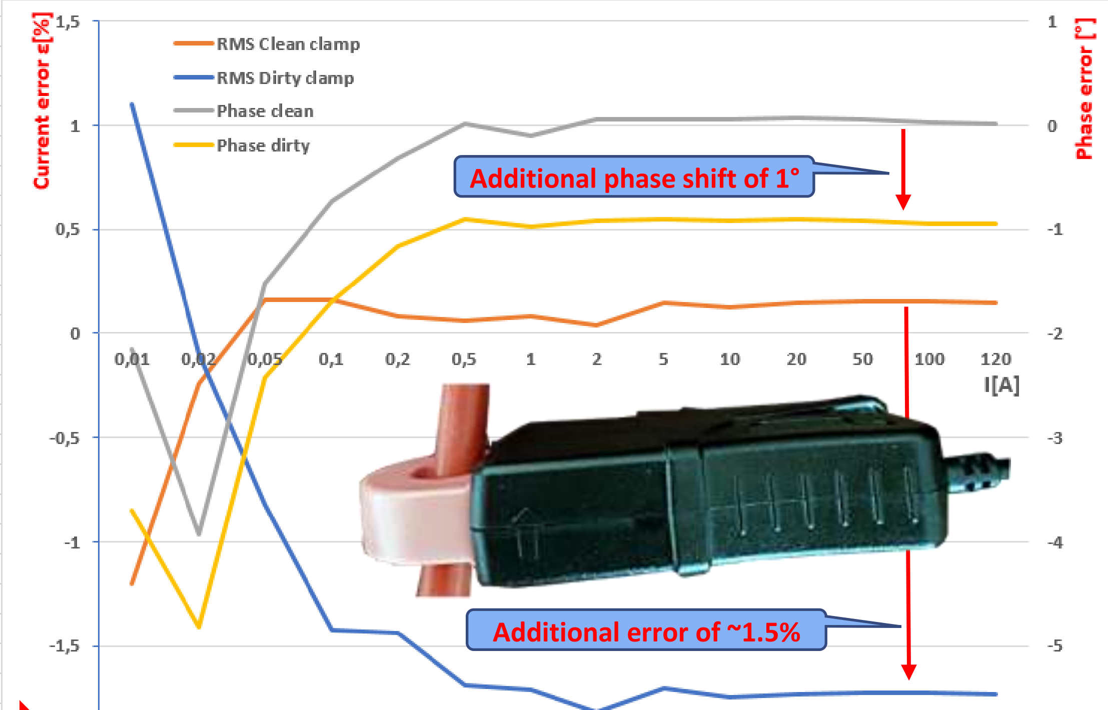
- ⊗ - the best position (green)
- ⊗ - acceptable position (blue)
- ⊗ - avoid this position (red)



Keep clamps exactly and symmetrical closed

Keep clamps jaws surface clean of dust and grease, protect from scratches

Example of cleanliness influence on clamps accuracy. The dust (dirty surface) is simulated as a small piece of foil 40µm thick.



Changing the precision of the current clamps as a result of incomplete closing of the jaws (40µm piece of foil in jaws)

Conclusion: take care about current clamps because the proper use has influence on final error of measurements

Meter testing – How to make creep test – no load test. Time calculation and result interpretation

No one wants to pay for unused electricity

Definition: the disk of a electromechanical meter may move, either forward or backward, when all load is disconnected. In the same way, LED can flash without any load. According to the standards, in meter with only test voltage applied, disk can't make more than 1 full turn or LED can't blink more than 1 time in defined or calculated period of time. Such test is called creep or no load test.

Testing time calculation

$$\tau|min| \geq \frac{a \cdot 10^6}{C|\frac{imp}{kWh}| \cdot m \cdot U_n|V| \cdot I_{max}|A|}$$

where:

τ[min]- minimum waiting time for pulse or disk rotation

a – coefficient dependent on accuracy class – see table

C[imp/kWh] – meter constant

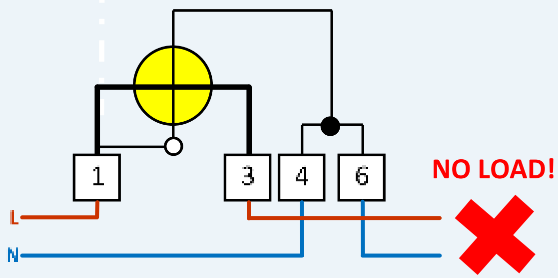
m – number of metering elements:

- 1 -> single phase,
- 2 -> 3 phase, 3 wires,
- 3 -> 3 phase, 4 wires

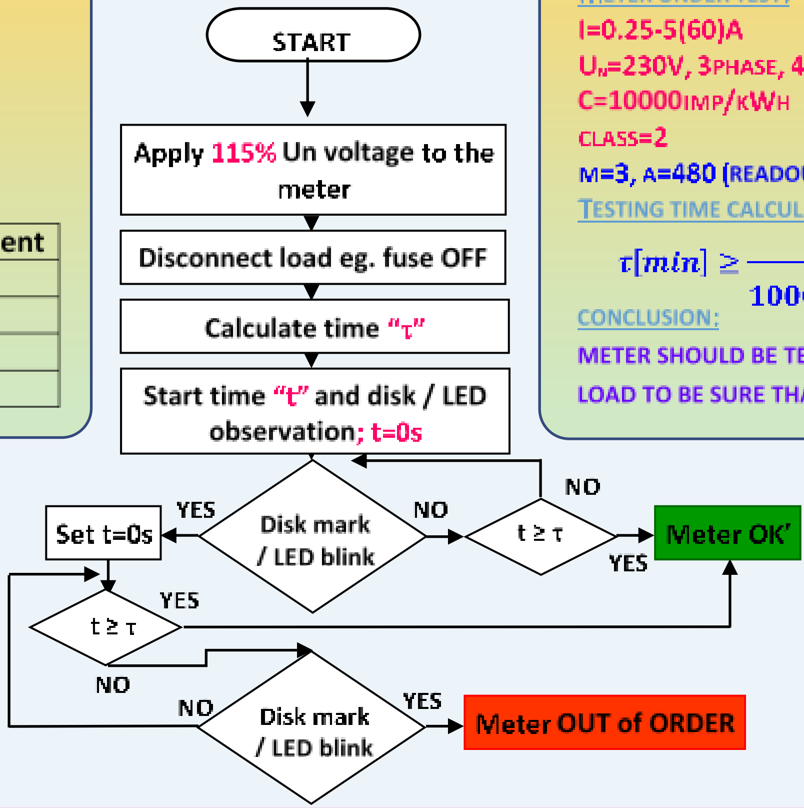
U_n – nominal voltage

I_{max} – maximum current

Meter class	„a" coefficient
0.2S	900
0.5S , 1	600
2	480
3	300



How to test



Example

EXAMPLE: REQUIRED NO LOAD TIME TESTING

METER UNDER TEST:

I=0.25-5(60)A

U_n=230V, 3PHASE, 4WIRES

C=10000IMP/KWH

CLASS=2

M=3, A=480 (READOUT FROM TABLE)

TESTING TIME CALCULATION

$$\tau[min] \geq \frac{480 \cdot 10^6}{10000\frac{imp}{kWh} \cdot 3 \cdot 230V \cdot 60A} = 1.16min$$

CONCLUSION:

METER SHOULD BE TESTED AT LEAST 1.16MIN (~70S) AT NO LOAD TO BE SURE THAT IT WORKS CORRECTLY

Conclusion: stopped meter under **no load** conditions is **essential** for reliable energy settlement

Meter testing – *How to make starting current test*. Time calculation and result interpretation

CALMET

Electricity distributor wants to count every piece (even very small) of used energy!

Definition: the starting current (I_{st}) is the lowest value of current, specified by the manufacturer, at which the meter should register electrical energy at unity power factor and, for poly-phase meters, with balanced load. It is allowed, that below I_{st} meter stops to measure energy.

$$\tau[s] = \frac{3.6 \cdot 10^6}{C\left[\frac{imp}{kWh}\right] \cdot m \cdot U_n[V] \cdot I_{st}[A]}$$

where:

τ[s] - expecting time between pulses or disk one turn time at I_{st} current

C[imp/kWh] – meter constant

m – number of metering elements:

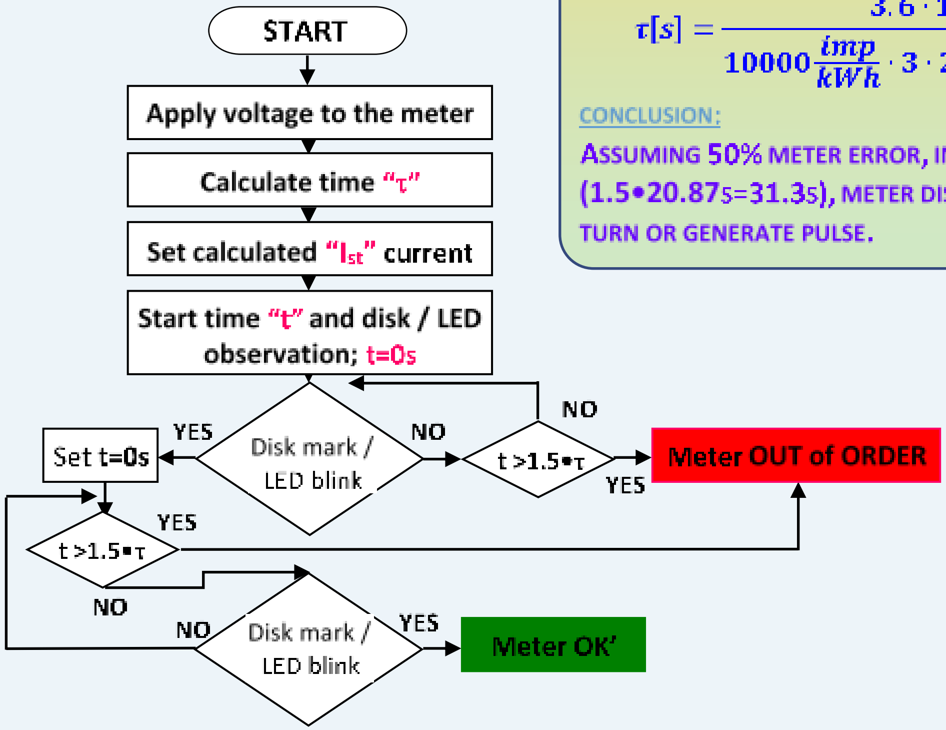
- 1 -> single phase,
- 2 -> 3 phase, 3 wires,
- 3 -> 3 phase, 4 wires

U_n – nominal voltage

I_{st} – starting current – as % of I_b or I_n – see table:

Meter class	Directly connected	CT connected
0.2S	-	0.1%
0.5S	-	0.1% (0.2%)
1	0.4%	0.2%
2	0.5%	0.3%
3	1%	0.5%
A	0.5%	0.6%
B	0.4%	0.4%
C	0.4%	0.2%

The test consists in calculation expecting time between 2 pulses or 1 disk turn τ[s] and then checking if in extended by 50% time, meter generates pulse or disk make 1 turn.



Example: Estimated time for pulse in starting current test

Meter under test:

I=0.25-5(60)A

U_n=230V, 3phase, 4wires

C=10000imp/kWh

class=2

m=3, I_{st}=0.5%•5A=0.025A

One pulse (disk turn) time calculation

$$\tau[s] = \frac{3.6 \cdot 10^6}{10000\frac{imp}{kWh} \cdot 3 \cdot 230V \cdot 0.025A} = 20.87s$$

Conclusion:

Assuming 50% meter error, in maximum 1.5•τ time (1.5•20.87s=31.3s), meter disk should make 1 full turn or generate pulse.

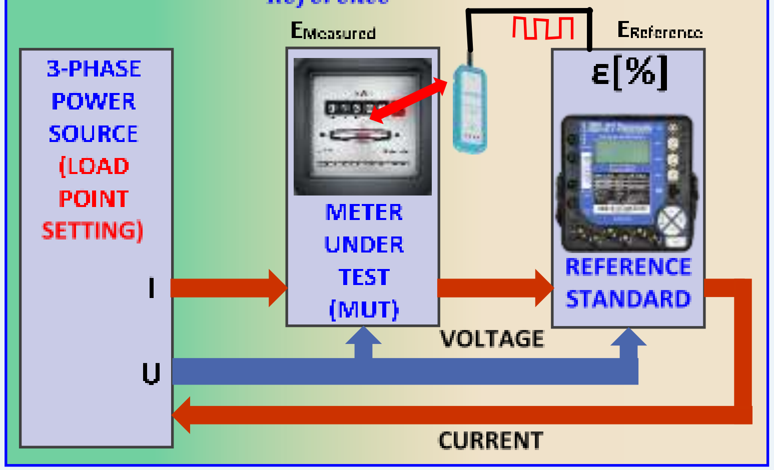
Conclusion: testing **starting current** of meter is obligatory test point to get reliable energy measurement

Meter testing – How the electricity meter error is measured and calculated?

CALMET

Principle of electricity meter testing

$$\varepsilon|\%| = \frac{E_{Measured} - E_{Reference}}{E_{Reference}} \cdot 100\%$$



Definition: energy meter testing (MUT) by energy comparison method consists in counting pulses from MUT and calculation of measured energy as:

$$E_{Measured}[kWh] = \frac{N[pulses\ or\ turns\ number]}{C[imp/kWh](meter\ constant)}$$

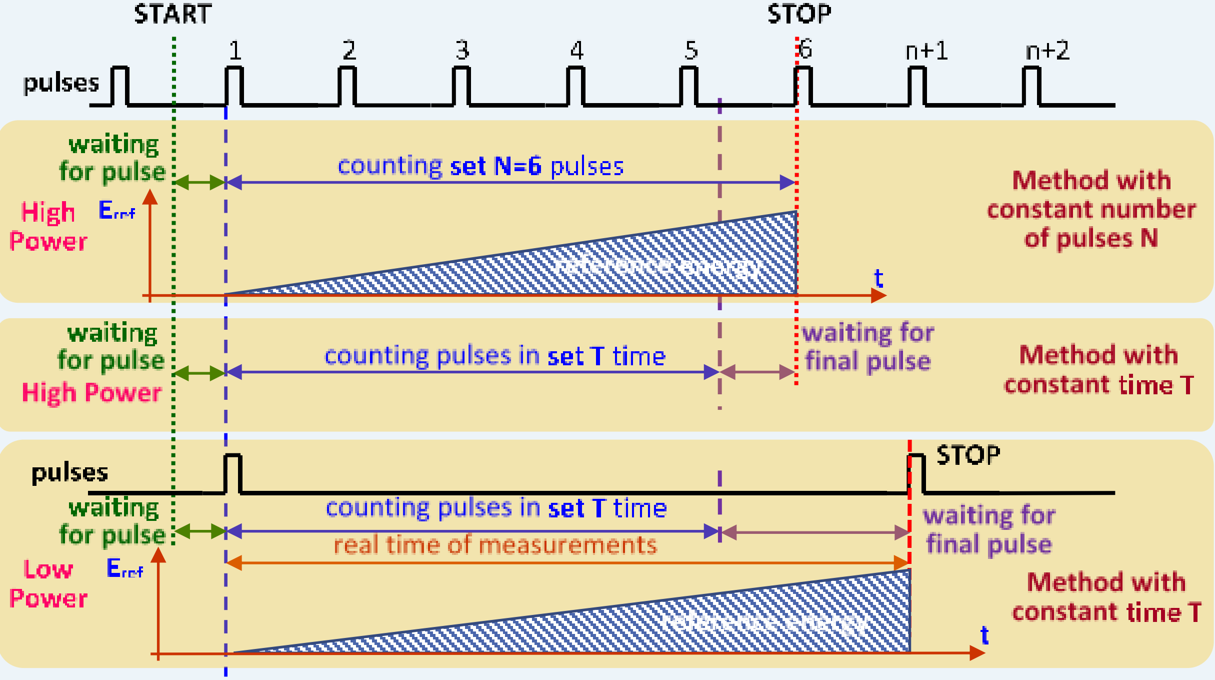
and then compare it with, reference value measured by special, at least 5 times more accurate standard meter ($E_{Reference}$).

Example: counted were 500 pulses by meter with constant 375 turns/kWh.

The measured energy is:

$$E_{Measured} = \frac{500}{375} kWh = 1.333 kWh$$

The test consists in: waiting for the first pulse, counting N number of pulses or waiting set T time and then waiting for final pulse. By the time of counting is measured reference energy and then compared with meter under test



pro:
- exactly known number of pulses

con:
- different number of pulses for different load to keep reasonable low time of test
- decision how many pulses to enter

pro:
- time can be independent from load and can be constant for all loads
- system have to automatically wait for at least two pulses
- setting eg. 20s covers almost all typical cases of testing

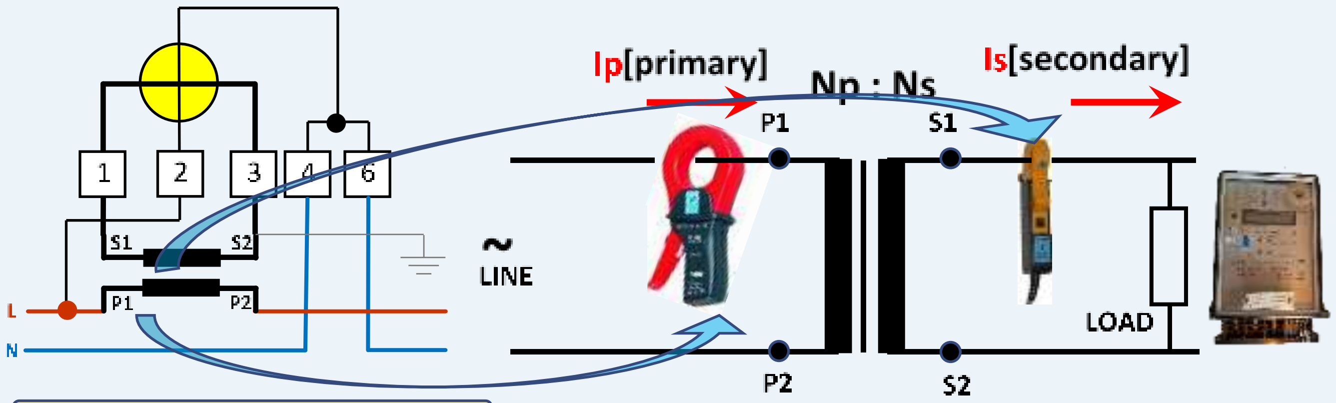
con:
- unknown number of counted pulses

Conclusion: all methods of electricity meter error testing consist of counting pulses and time they occurred

Meter testing – How to test CT ratio and phase shift error?

CALMET

CT/PT ratio test idea; small ratio and phase shift error are essential for reliable measurement

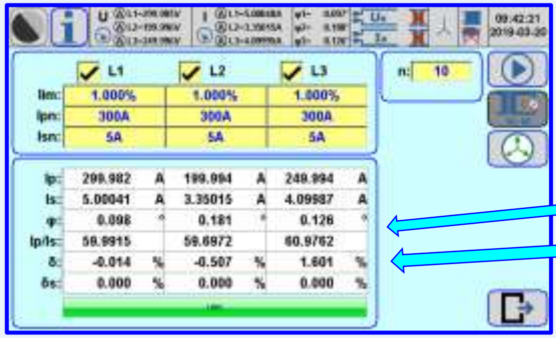


The test method is based on primary current measurement by means of current clamps from 0.1A to 3000A and secondary current measurement directly or also by means of clamps in 10mA to 10A range.

$$\delta I = \frac{\frac{N_P}{N_S} \cdot I_S - I_P}{I_P}$$

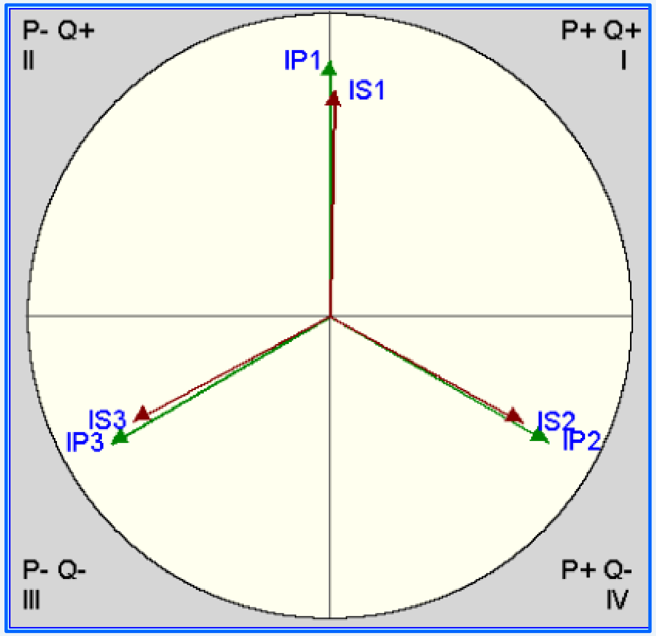
The ratio error is given by equation, where:

δI – current transformer error [%]
N_P - number of primary turns
N_S - number of secondary turns
N_P / N_S – nominal CT ratio
I_P - primary current
I_S - secondary current



Example results of CT 300/5A test:

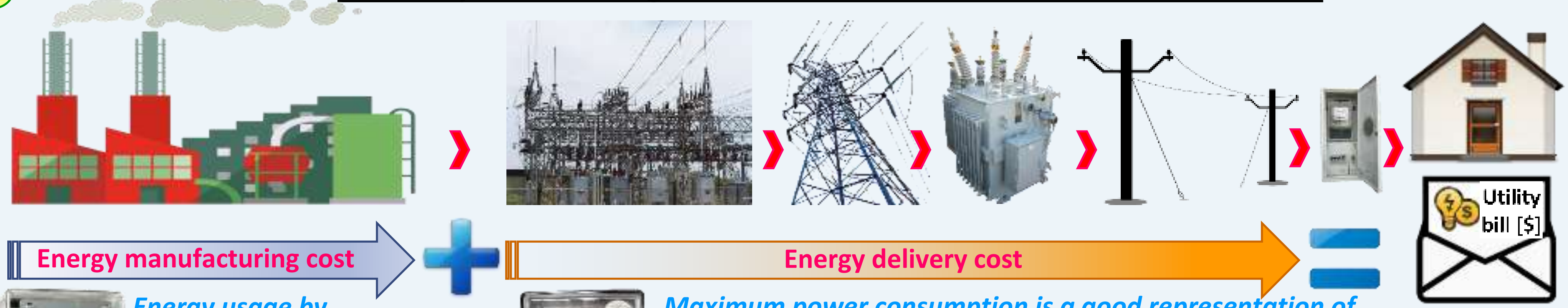
- **phase shift error [°]**
- **ratio error in [%]**



Vector diagram shows proper connection and phasing of CT

Expected value of ratio error is δI=0% and phase shift error φ=0°

Electricity meter testing. What is the maximum demand meter used for?



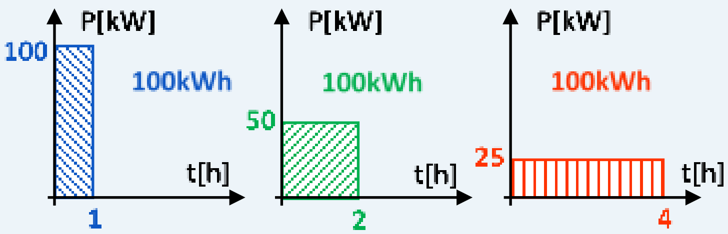
Energy usage by consumer is a good representation of energy manufacturing cost

Maximum power consumption is a good representation of energy delivery cost to the consumer. It determines capacity of transformers, switch gears, transmission lines and substations.

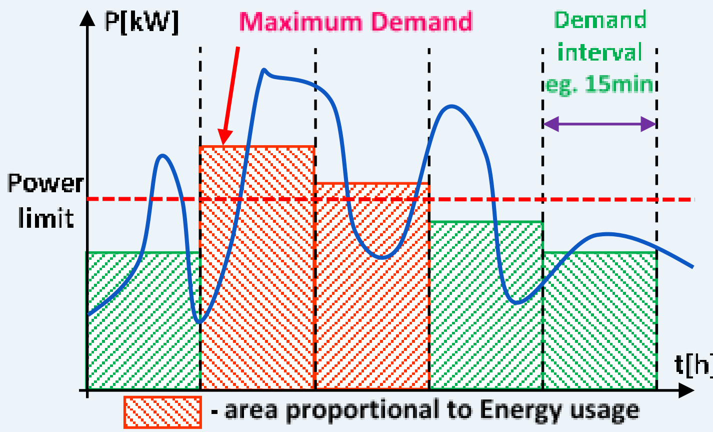
Energy [kWh]=Power [kW] x Time [h]

Power [kW]=Energy [kWh] / Time [h]

Demand definition: maximum rate of energy transfer demanded by the consumer equal to the maximum power averaged in certain time, usually 15min. Calculated as **energy** used in defined period of time **divided** by this **time**.



Example: three of customers have the same energy usage 100kWh but the first has the highest power demand 100kW, compare with the third customer, which has 25kW only. Energy usage is settled by typical energy meter and readiness of power delivery by demand meter.



Demand is measured by interval of time, usually 15min (5, 10, 30, 60min). The highest value of averaged through time power is the maximum demand, which can be compared with the power limit set in contract between utility and consumer. The typical billing period is 1 month and crossing the limits cause penalties paid by consumer.

Smart meter has usually function of maximum demand metering built in

Conclusion: maximum demand influences on installation cost and can be a major component in electricity bill

Recommendation & Standards: OIML R46-1/-2, ANSI C12.1, IEC62052-11, IEC62053-xx, IEC50470-1/-2/-3, IEC62057-1/-2 draft

Electricity mater testing. “IP-link”& “closed link” What are they for?

IP-link definition: permanent or disconnectable connection between phase voltage and current input in electricity meter, used during adjustment and calibration. Almost all of older meters and all CT operated meters have possibility to open link. Increased number of new electronic meters has **permanent connection between U & I** inputs because of:

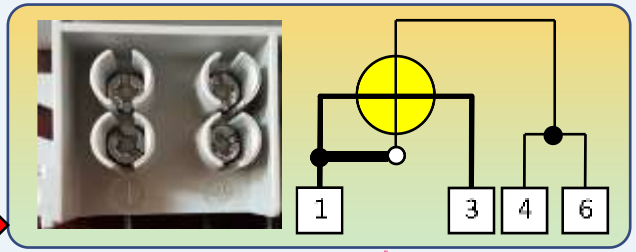
- lower production cost of meter using resistive shunts for current measurements in whole current meters;
- additional protection against electricity thieves.

CT operated meter - no link | Opened link - calibration | Closed link - normal operation

switchable link

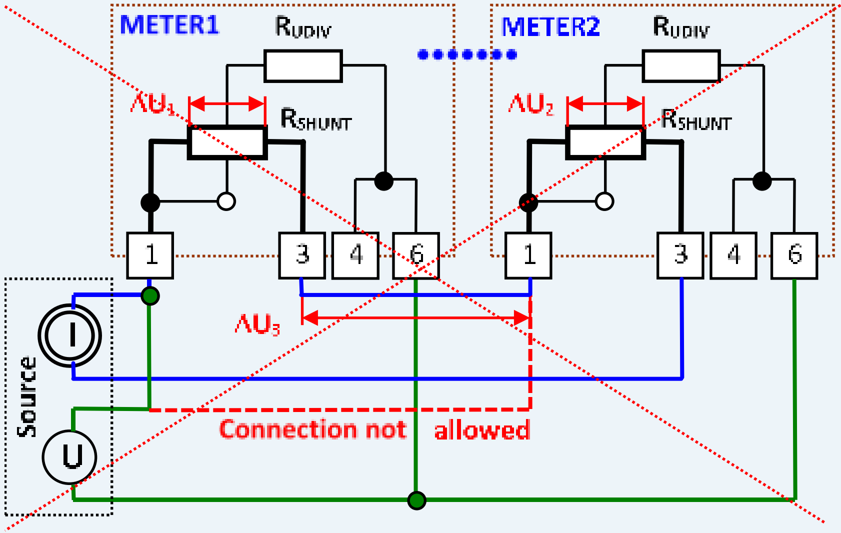
Energy meter with permanent U&I link has usually less screw terminals

permanent link



Permanent link for normal operation and calibration

Permanent IP-link has a great influence on accuracy, when we test more than one meter simultaneously

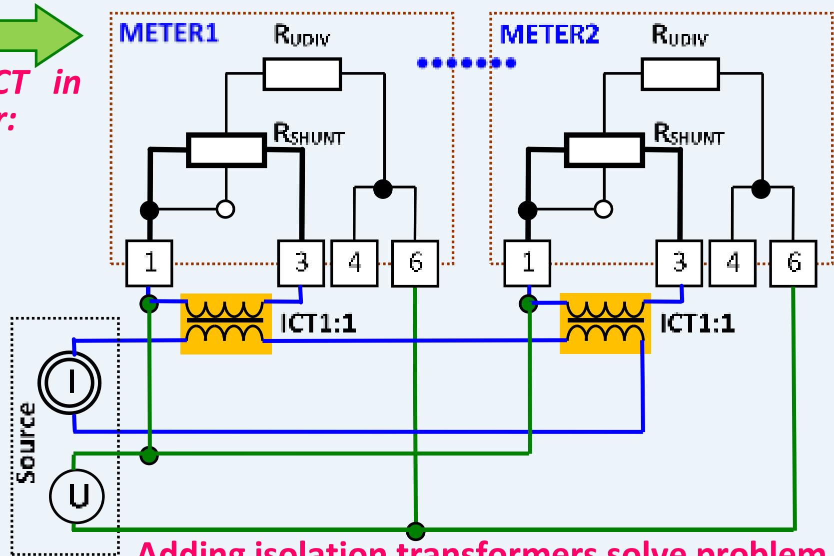


Additional voltage drops cause unpredictable current flow

SOLUTION

Isolation transformer ICT in each phase of each meter:

- *current range: 10mA... 120A*
- *ratio: 1:1 (±0.01%)*
- *phase error: ±0.05min*



Adding isolation transformers solve problem

Conclusion: special **isolation transformers** ICT(1:1) should be used for testing **more that one** meter with permanent IP - link

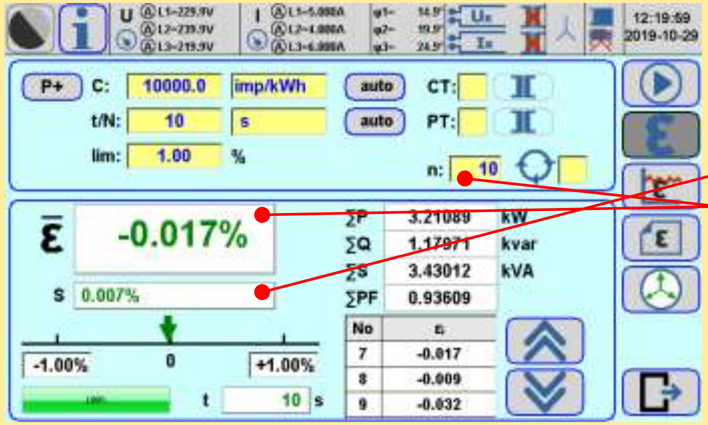
Recommendation & Standards: OIML R46-1/-2, ANSI C12.1, IEC62052-11, IEC62053-xx, IEC50470-1/-2/-3, IEC62057-1/-2 draft

Energy meter test equipment – how to calculate meter error uncertainty during testing

CALMET

Meter parameters:
Un=230V In=5A
C=10000imp/kWh
class 1

Testing results: average error ε=-0.017%, standard deviation s=0.007%



Partial results [%]	
ε_1=	-0,018
ε_2=	-0,009
ε_3=	-0,024
ε_4=	-0,003
ε_5=	-0,014
ε_6=	-0,021
ε_7=	-0,017
ε_8=	-0,009
ε_9=	-0,032
ε_{10}=	-0,023

***Standard deviation (s)** – shows dispersion of a set of results from average value calculated by formula:* $s = \sqrt{\frac{\sum_{i=1}^{N}(\varepsilon_i - \bar{\varepsilon})^2}{N-1}}$ *where:*

ε_i - individual result

$\bar{\varepsilon}$ – average value of results: $\bar{\varepsilon} = \frac{\sum_{i=1}^{N}\varepsilon_i}{N}$

N – number of results.

Number of measurements N should be between 3 to 10, the more the better, however achieving more results takes more time

Remark: some Reference Meters have built in average error and standard deviation calculation, in other case, they should be calculated manually

Reference Meter:
Accuracy: δ = ±0.04%
(taken from manufacturer data sheet)
[absolute extended uncertainty under confidence level of 95%]

Uncertainty of measurement is the doubt that exists about the result of any measurement. There are two types of uncertainty: Type A (statistical - u_A) and Type B - u_B (eg. taken from device data sheet or calibration certificate). The uncertainty can be calculated by formulas: $u_A = \frac{s}{\sqrt{N}}$ $u_B = \frac{\delta}{\sqrt{3}}$. Combined standard uncertainty is given by: $u_C = \sqrt{u_A^2 + u_B^2}$ *and expanded uncertainty* $U = k \times u_C$ *where* k *is coverage factor, which tell us (**k=2**), that 95% of results are in spread* $\pm 2 \times s$

Practical example (see above):

$\bar{\varepsilon}$=-0.017%, s=0.007%, N=10 so

$$u_A = \frac{0.007}{\sqrt{10}} = 0.0022 \text{ and } u_B = \frac{0.04}{\sqrt{3}} = 0.0231$$

what gives:

$$U = 2 \times \sqrt{0.0022^2 + 0.0231^2} = 0.046$$

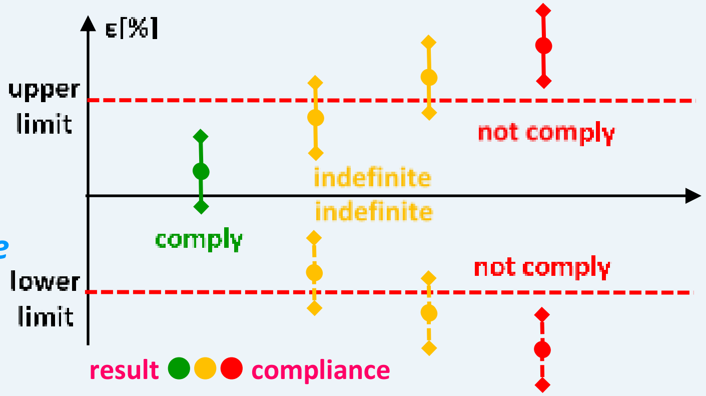
The meter error can be expressed as:

ε = -0.017% ±0.046%

[extended uncertainty under confidence level of 95%]

Steps to uncertainty evaluation:

1. carry out the error measurements (3 to 10 results)
2. readout or calculate average value of error and standard deviation
3. get Reference Meter accuracy from its data sheet or calibration certificate
4. calculate expanded uncertainty
5. check compliance of result with specification



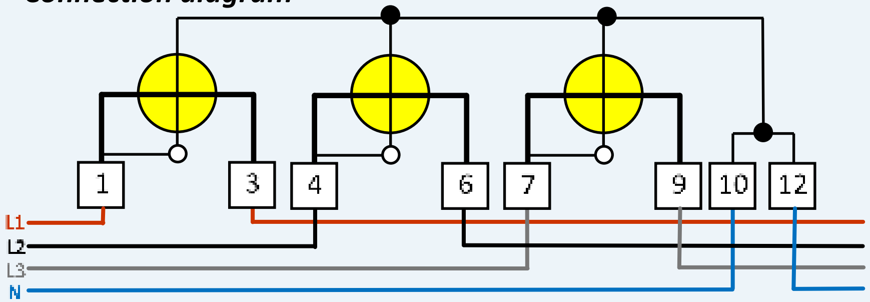
Conclusion: uncertainty evaluation is easy task aided by modern measuring instruments

Recommendation & Standards: OIML R46-1/-2, ANSI C12.1, IEC62052-11, IEC62053-xx, IEC50470-1/-2/-3, IEC62057-1/-2 draft

Meter testing – typical meter installation errors recognizing

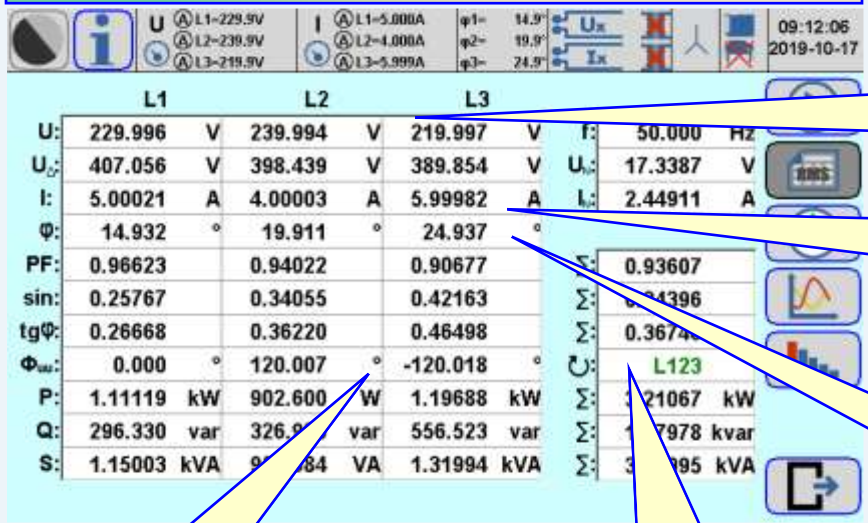
Reference connection and testing results of three phase, active energy meter

Connection diagram



Load

Current load point for Energy Meter test



	L1		L2		L3				
U:	229.996	V	239.994	V	219.997	V	f:	50.000	Hz
U_{Δ}:	407.056	V	398.439	V	389.854	V	U_0:	17.3387	V
I:	5.00021	A	4.00003	A	5.99982	A	I_0:	2.44911	A
φ:	14.932	°	19.911	°	24.937	°			
PF:	0.96623		0.94022		0.90677		Σ:	0.93607	
sin:	0.25767		0.34055		0.42163		Σ:	[illegible]4396	
tgφ:	0.26668		0.36220		0.46498		Σ:	0.3674[illegible]	
Φ_{uu}:	0.000	°	120.007	°	-120.018	°	↻:	L123	
P:	1.11119	kW	902.600	W	1.19688	kW	Σ:	[illegible]21067	kW
Q:	296.330	var	326.9[illegible]	var	556.523	var	Σ:	[illegible]7978	kvar
S:	1.15003	kVA	[illegible]84	VA	1.31994	kVA	Σ:	3[illegible]95	kVA

Voltage:
U1~230V
U2~240V
U3~220V

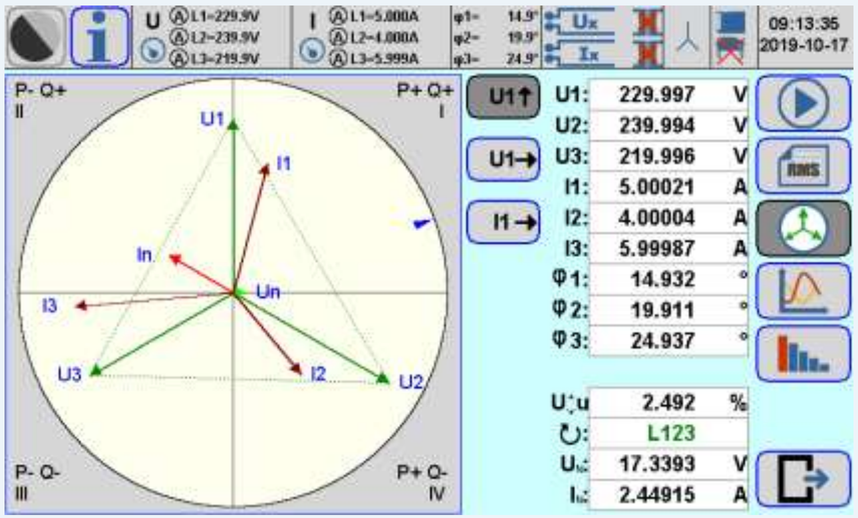
Current:
I1~5A
I2~4A
I3~6A

Phase shift:
φ1~15°
φ2~20°
φ3~25°

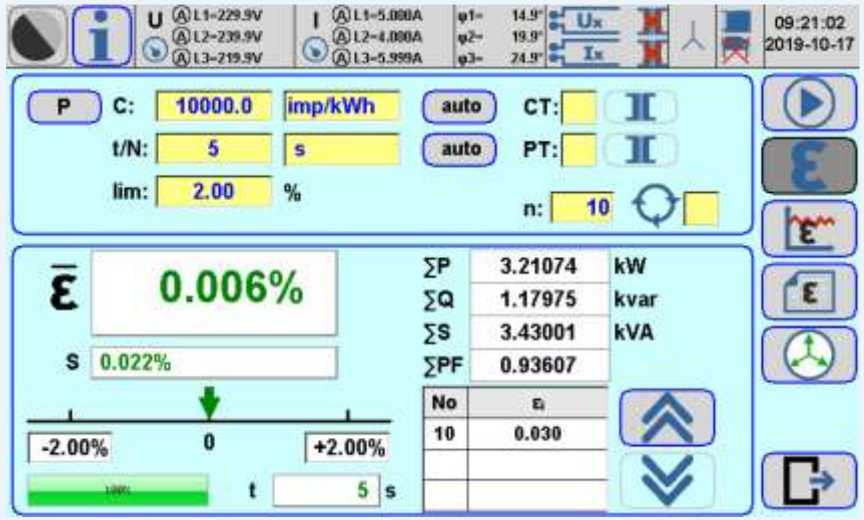
Phase shift U-U:
U1-2~120° U1-3~-120°

Vector rotation:
Correct L123

Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3



Error test result at load point



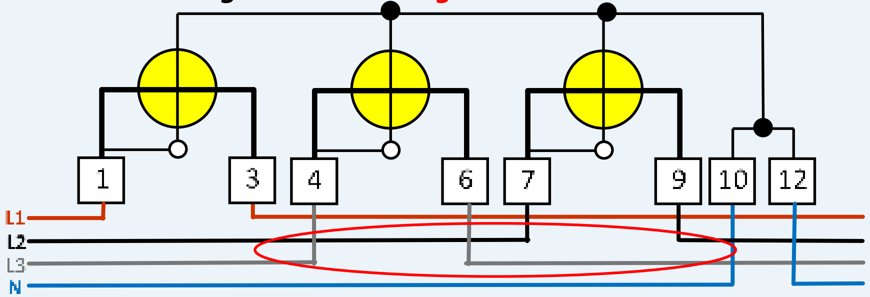
*The **initial assessment** of the installation, consists in checking whether the basic parameters are within the **typical** limits:*
Voltage: $U_{nominal}$ ±20%, Current: $I_{min}<I<I_{max}$, φ: 0…±60°, ∠U-U: 120° or -120° ±10°, Rotation: L123, meter Error: ±5%

Conclusion: knowledge of expected results makes troubleshooting more easy

Meter testing – typical meter installation errors recognizing

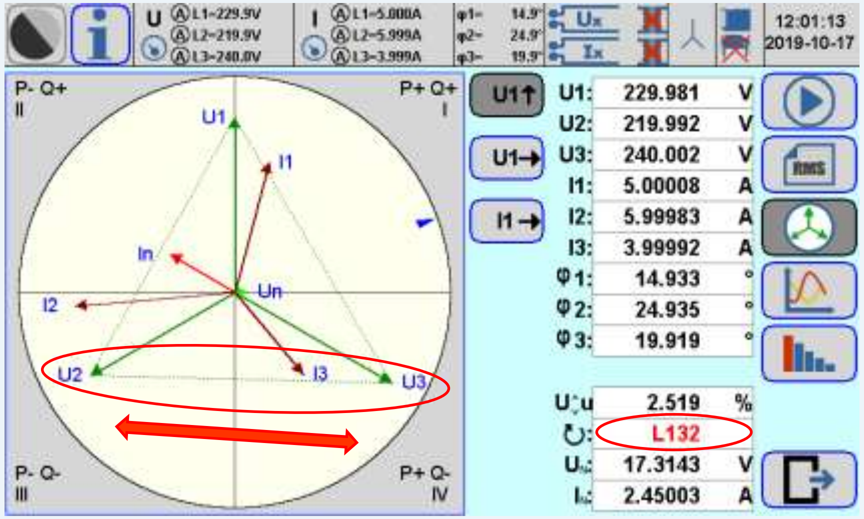
Phase L3 exchanged with phase L2 – negative vector rotation

Connection diagram: ***L3 exchanged with L2***

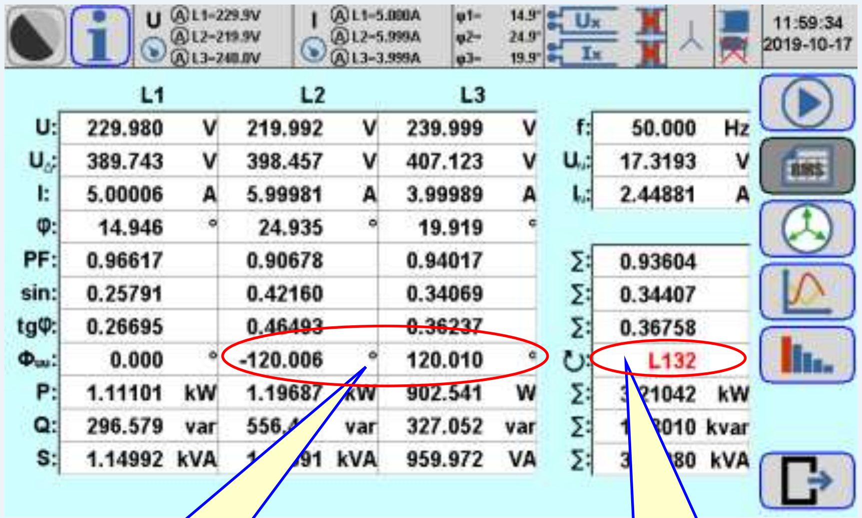


Load

Vector diagram: positive sequence U1 ⇨ U3 ⇨ U2



Current load point for Energy Meter test

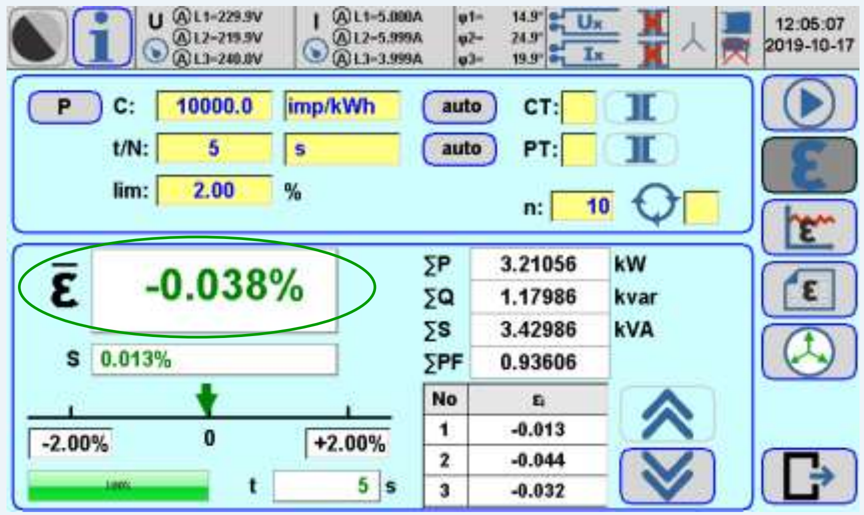


	L1		L2		L3				
U:	229.980	V	219.992	V	239.999	V	f:	50.000	Hz
U:	389.743	V	398.457	V	407.123	V	U:	17.3193	V
I:	5.00006	A	5.99981	A	3.99989	A	I:	2.44881	A
φ:	14.946	°	24.935	°	19.919	°			
PF:	0.96617		0.90678		0.94017		Σ:	0.93604	
sin:	0.25791		0.42160		0.34069		Σ:	0.34407	
tgφ:	0.26695		0.46493		0.36237		Σ:	0.36758	
Φ:	0.000	°	-120.006	°	120.010	°	↻:	L132	
P:	1.11101	kW	1.19687	kW	902.541	W	Σ:	3 21042	kW
Q:	296.579	var	556.4	var	327.052	var	Σ:	1 3010	kvar
S:	1.14992	kVA	1 91	kVA	959.972	VA	Σ:	3 80	kVA

Phase shift U-U:
U1-2~-120° U1-3~120°

Vector rotation:
Negative L132

Error test result at load point



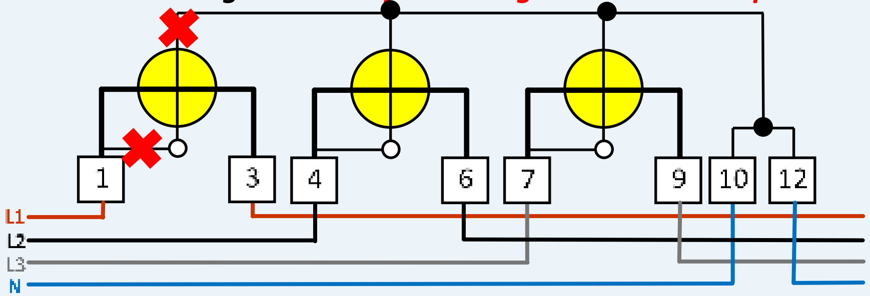
The phase exchange does not have a big influence for the energy meter error, however it can introduce additional error value on accuracy class level. It also makes problems with result interpretation and can be source of mistakes in the future.

Conclusion: it is recommended to reset the connection to positive L123 phase sequence

Meter testing – typical meter installation errors recognizing

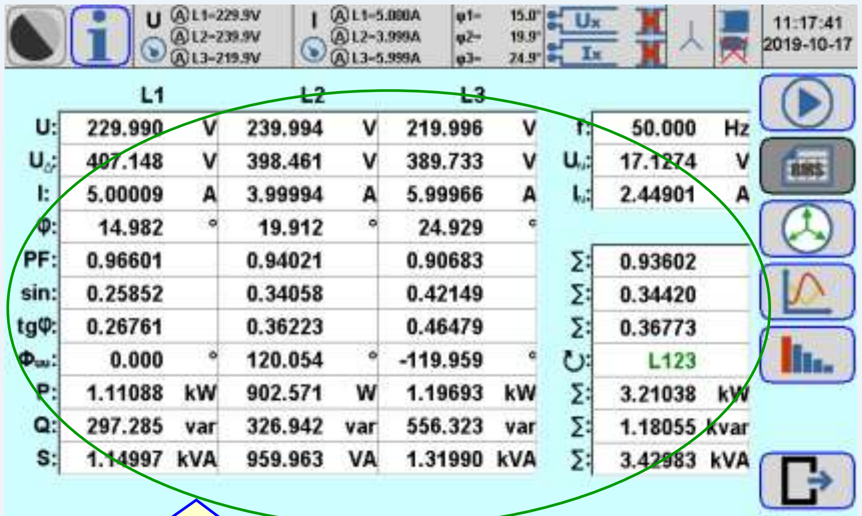
Lack of one voltage at the meter input

Connection diagram: *lack of U1 voltage at the meter input*



Load

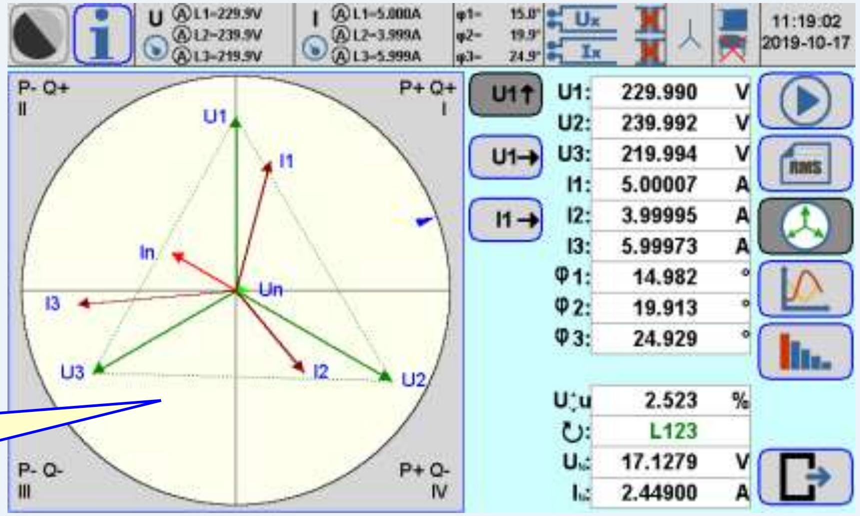
Current load point for Energy Meter test



	L1		L2		L3				
U:	229.990	V	239.994	V	219.996	V	f:	50.000	Hz
U_Δ:	407.148	V	398.461	V	389.733	V	U_N:	17.1274	V
I:	5.00009	A	3.99994	A	5.99966	A	I_N:	2.44901	A
φ:	14.982	°	19.912	°	24.929	°			
PF:	0.96601		0.94021		0.90683		Σ:	0.93602	
sin:	0.25852		0.34058		0.42149		Σ:	0.34420	
tgφ:	0.26761		0.36223		0.46479		Σ:	0.36773	
Φ_{UU}:	0.000	°	120.054	°	-119.959	°	↻:	L123	
P:	1.11088	kW	902.571	W	1.19693	kW	Σ:	3.21038	kW
Q:	297.285	var	326.942	var	556.323	var	Σ:	1.18055	kvar
S:	1.14997	kVA	959.963	VA	1.31990	kVA	Σ:	3.42983	kVA

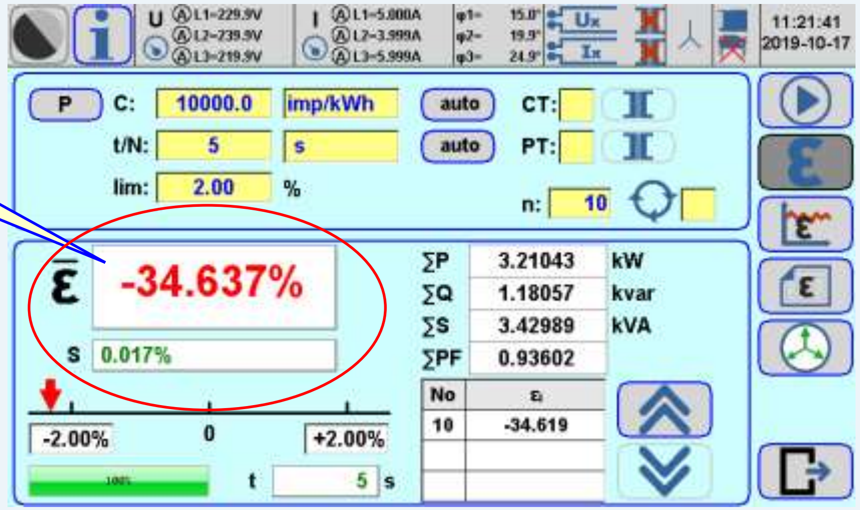
All values, measured at available meter inputs are correct

Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3



Vector and phase sequence are correct

Error test result at load point



There is high value of error

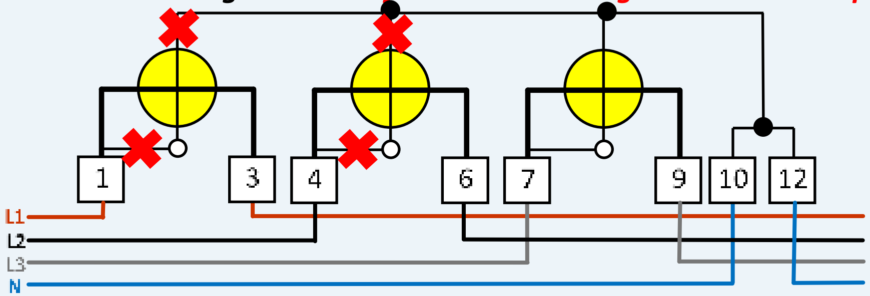
The lack of voltage can be caused by: wrong or improper connection, opened close link, internal connection break inside the meter, internal voltage divider failure. As a power is P=U(=0) x I x cos(φ), it causes lack (- sign) of about 1/3 of power for symmetrical load.

Conclusion: if the value of error is on -33% ±10% level, it is possible, that one of the voltages is not applied to the meter properly

Meter testing – typical meter installation errors recognizing

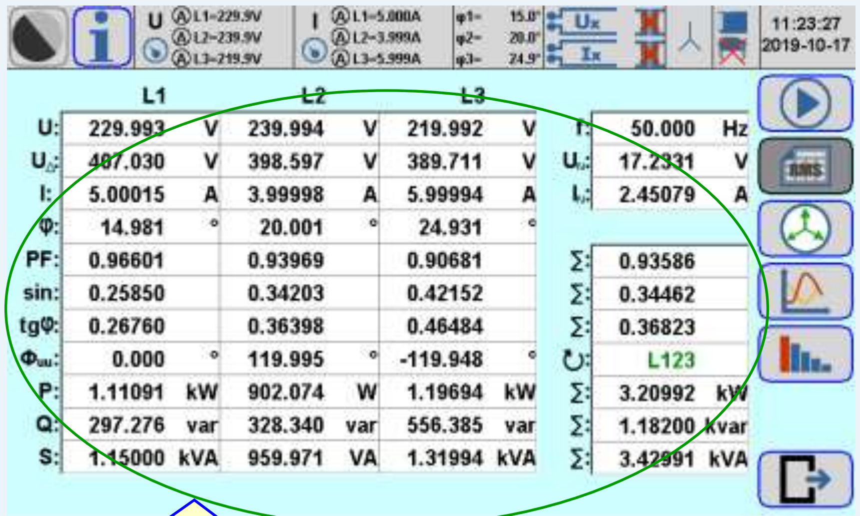
Lack of two voltages at the meter input

Connection diagram: *lack of U1 and U2 voltage at the meter input*



Load

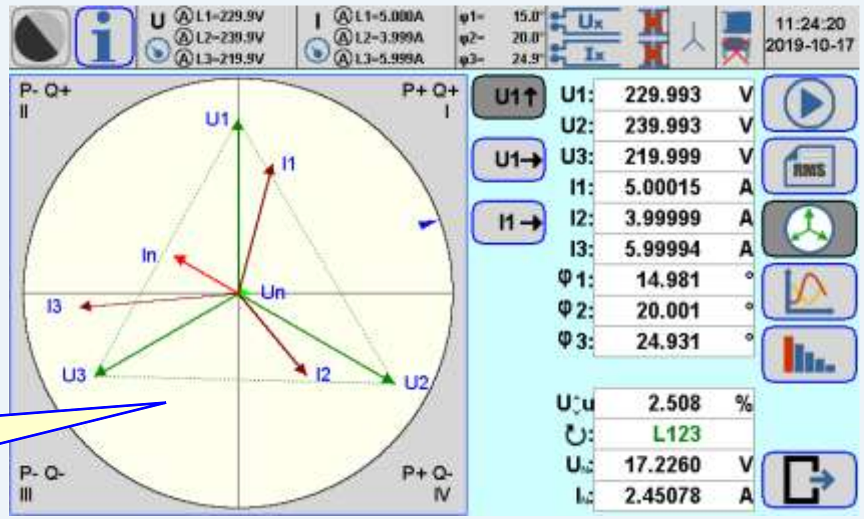
Current load point for Energy Meter test



	L1		L2		L3				
U:	229.993	V	239.994	V	219.992	V	f:	50.000	Hz
U△:	407.030	V	398.597	V	389.711	V	U₀:	17.2331	V
I:	5.00015	A	3.99998	A	5.99994	A	I₀:	2.45079	A
Φ:	14.981	°	20.001	°	24.931	°			
PF:	0.96601		0.93969		0.90681		Σ:	0.93586	
sin:	0.25850		0.34203		0.42152		Σ:	0.34462	
tgΦ:	0.26760		0.36398		0.46484		Σ:	0.36823	
Φuu:	0.000	°	119.995	°	-119.948	°	↻:	L123	
P:	1.11091	kW	902.074	W	1.19694	kW	Σ:	3.20992	kW
Q:	297.276	var	328.340	var	556.385	var	Σ:	1.18200	kvar
S:	1.15000	kVA	959.971	VA	1.31994	kVA	Σ:	3.42991	kVA

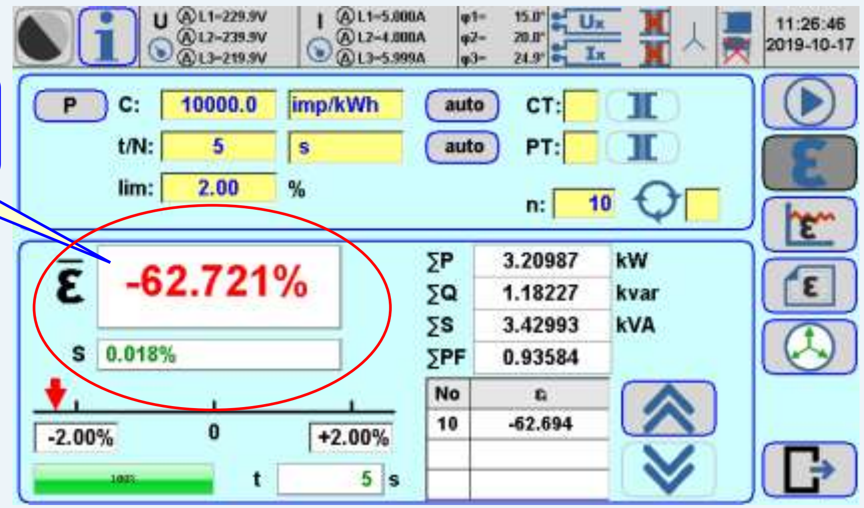
All values, measured at available meter inputs are correct

Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3



Vector and phase sequence are correct

Error test result at load point



There is high value of error

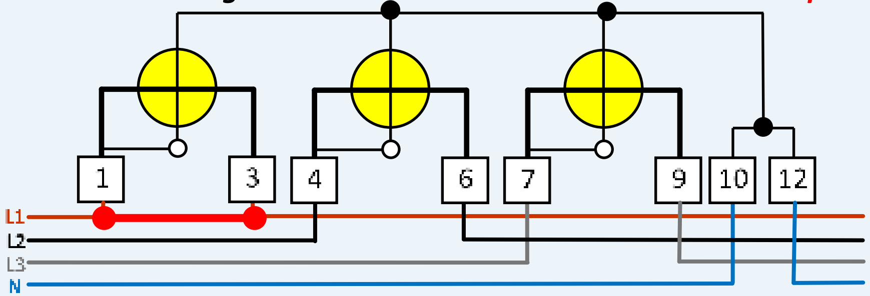
The lack of voltages can be caused by: wrong or improper connection, opened close link, internal connection break inside the meter, internal voltage divider failure. As a power is P=U(=0) x I x cos(φ), it causes lack (- sign) of about 2/3 of power for symmetrical load.

Conclusion: if the value of error is on -66% ±20% level, it is possible, that two of the voltages are not applied to the meter properly

Meter testing – typical meter installation errors recognizing

One current shorted at the meter input

Connection diagram: *one current I1 shorted at the meter input*



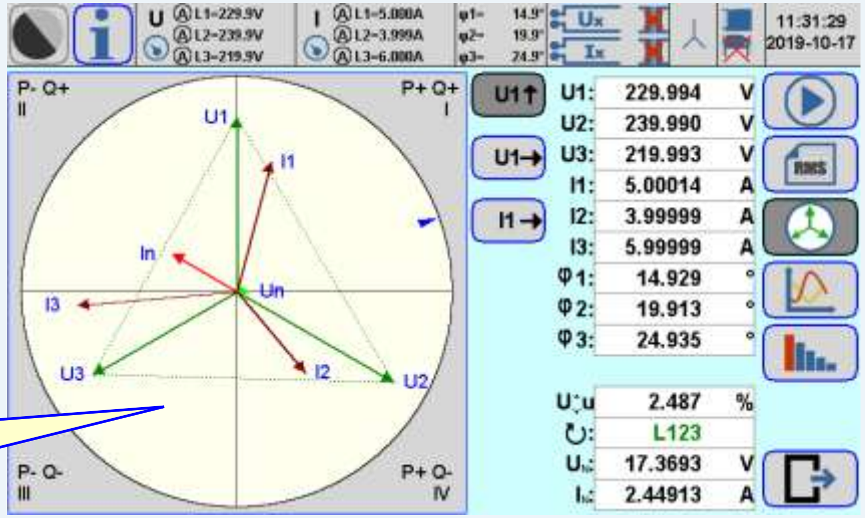
Load

Current load point for Energy Meter test

	L1		L2		L3				
U:	229.993	V	239.989	V	219.993	V	f:	50.000	Hz
U_{Δ}:	407.017	V	398.462	V	389.849	V	U_o:	17.3685	V
I:	5.00013	A	3.99998	A	6.00002	A	I_o:	2.44917	A
Φ:	14.929	°	19.914	°	24.935	°			
PF:	0.96625		0.94020		0.90678		Σ:	0.93607	
sin:	0.25762		0.34062		0.42159		Σ:	0.34395	
tgΦ:	0.26662		0.36228		0.46493		Σ:	0.36744	
$Φ_{uu}$:	0.000	°	119.991	°	-120.018	°	↻:	L123	
P:	1.11118	kW	902.546	W	1.19692	kW	Σ:	3.21064	kW
Q:	296.258	var	326.974	var	556.488	var	Σ:	1.17972	kvar
S:	1.14999	kVA	959.950	VA	1.31996	kVA	Σ:	3.42991	kVA

All values, measured at available meter inputs are correct

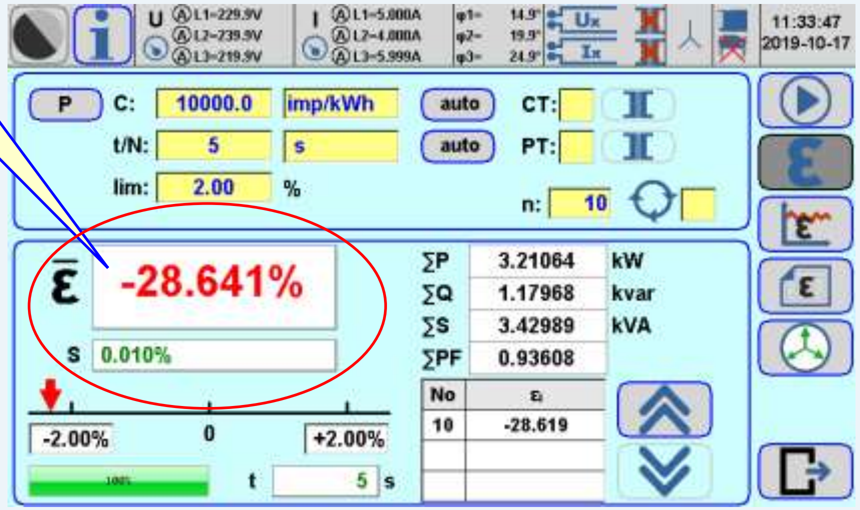
Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3



Vector and phase sequence are correct

There is high value of error

Error test result at load point



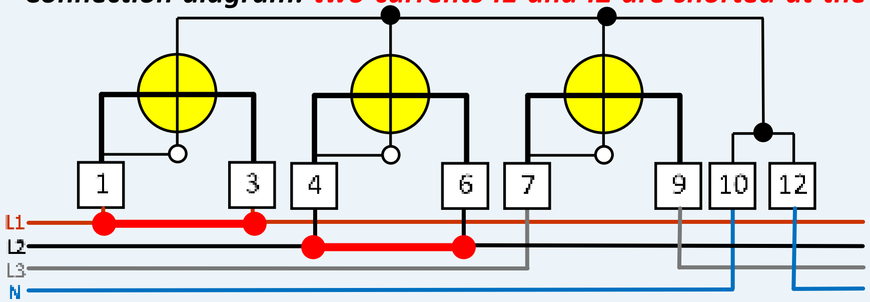
The current can be shorted by energy thieves, wrong connection, internal current transformer or shunt failure. As a power is P=U x I(=0) x cos(φ), it causes lack (- sign) of about 1/3 of power for symmetrical load.

Conclusion: if the value of error is on **-33%** ±10% level, it is possible, that one of the currents is not flowing through the meter properly

Meter testing – typical meter installation errors recognizing

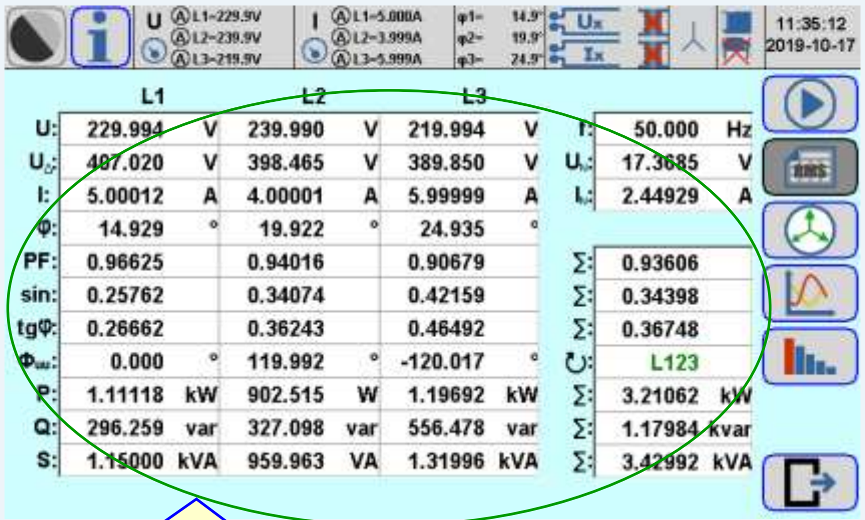
Two currents shorted at the meter input

Connection diagram: *two currents I1 and I2 are shorted at the meter*



Load

Current load point for Energy Meter test

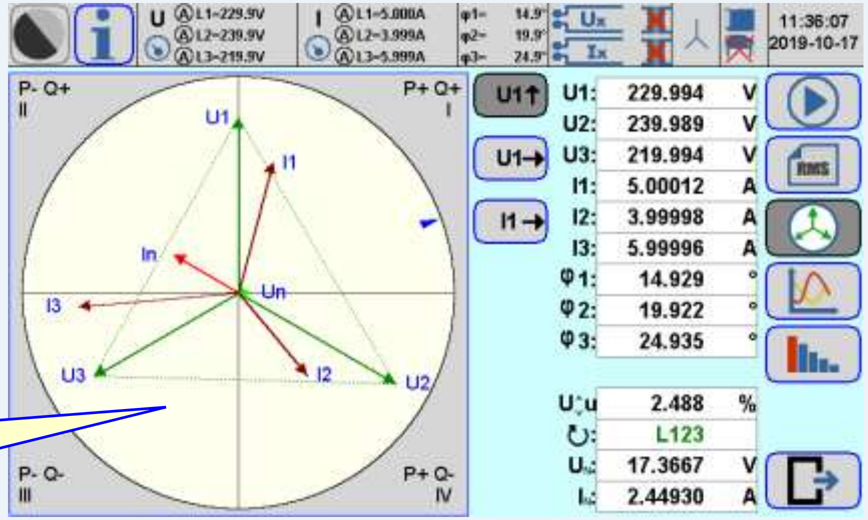


	L1		L2		L3				
U:	229.994	V	239.990	V	219.994	V	f:	50.000	Hz
U_Δ:	407.020	V	398.465	V	389.850	V	U_0:	17.3685	V
I:	5.00012	A	4.00001	A	5.99999	A	I_0:	2.44929	A
φ:	14.929	°	19.922	°	24.935	°			
PF:	0.96625		0.94016		0.90679		Σ:	0.93606	
sin:	0.25762		0.34074		0.42159		Σ:	0.34398	
tgφ:	0.26662		0.36243		0.46492		Σ:	0.36748	
Φ_{uu}:	0.000	°	119.992	°	-120.017	°	↻:	L123	
P:	1.11118	kW	902.515	W	1.19692	kW	Σ:	3.21062	kW
Q:	296.259	var	327.098	var	556.478	var	Σ:	1.17984	kvar
S:	1.15000	kVA	959.963	VA	1.31996	kVA	Σ:	3.42992	kVA

All values, measured at available meter inputs are correct

The current can be shorted by energy thieves, wrong connection, internal current transformer or shunt failure. As a power is P=U x I(=0) x cos(φ), it causes lack (- sign) of about 2/3 of power for symmetrical load.

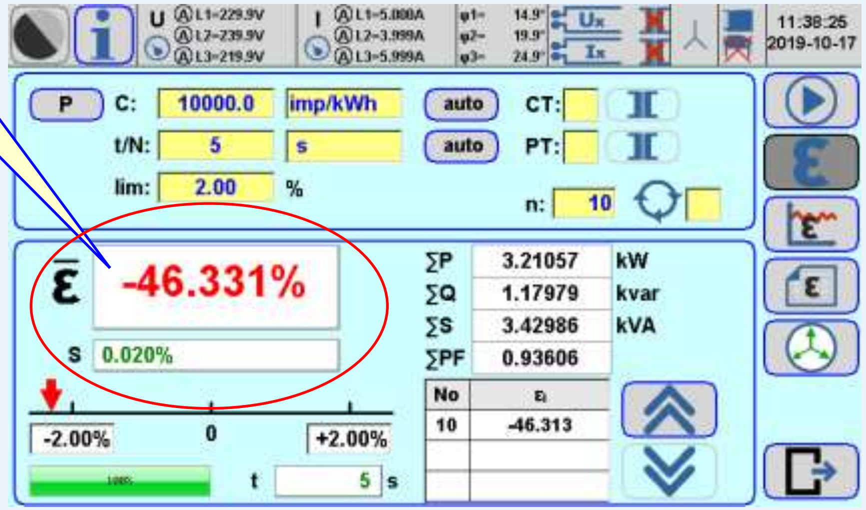
Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3



Vector and phase sequence are correct

There is high value of error

Error test result at load point

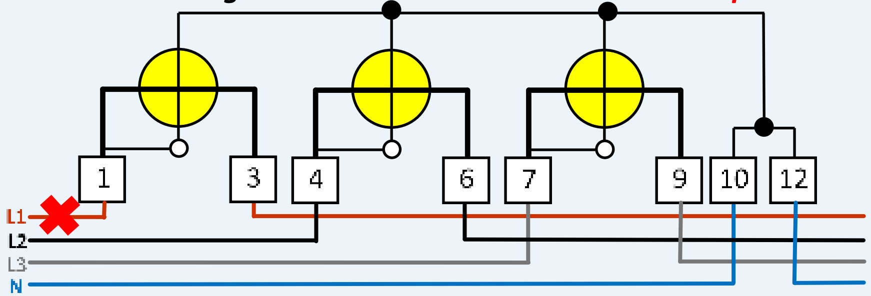


Conclusion: if the value of error is on -66% ±20% level, it is possible, that two of the currents are not flowing through the meter properly

Meter testing – typical meter installation errors recognizing

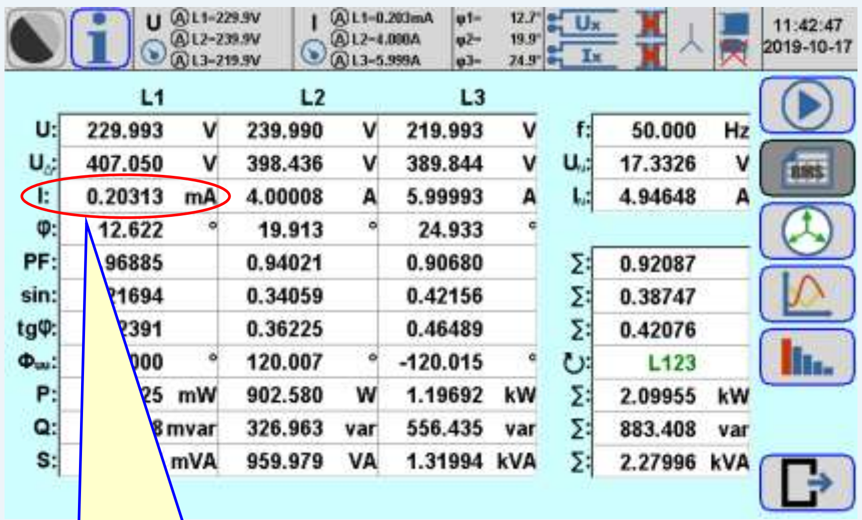
One current is not flowing through the meter input

Connection diagram: *one current I1=0 at the meter input*



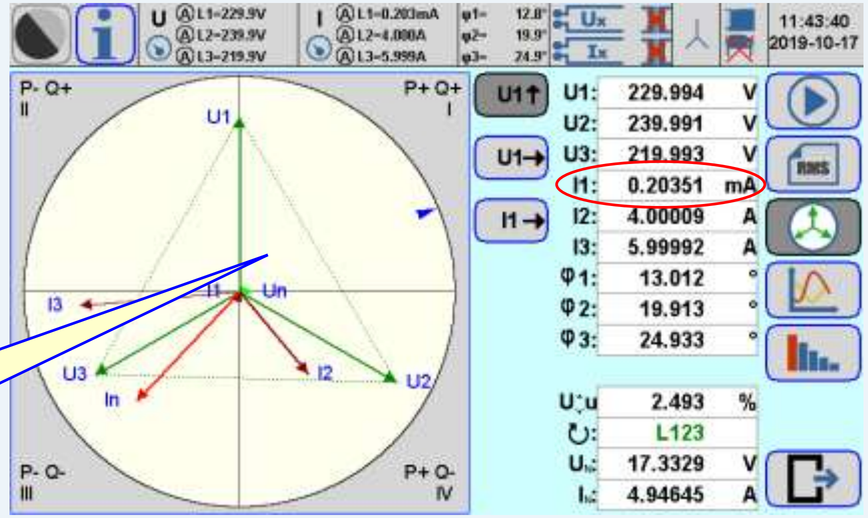
Load

Current load point for Energy Meter test



The current I1 in phase L1 is very small

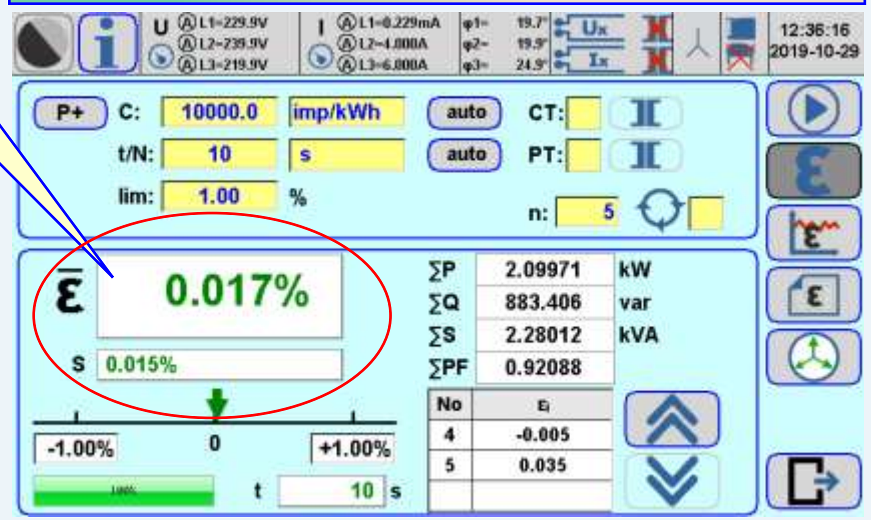
Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3

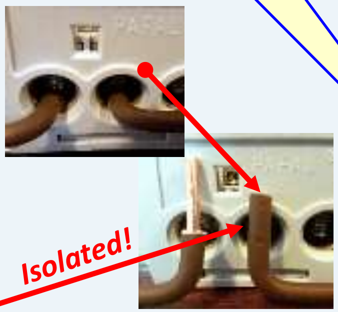


Vector and phase sequence is incomplete, lack of I1

The value of meter error is OK'

Error test result at load point





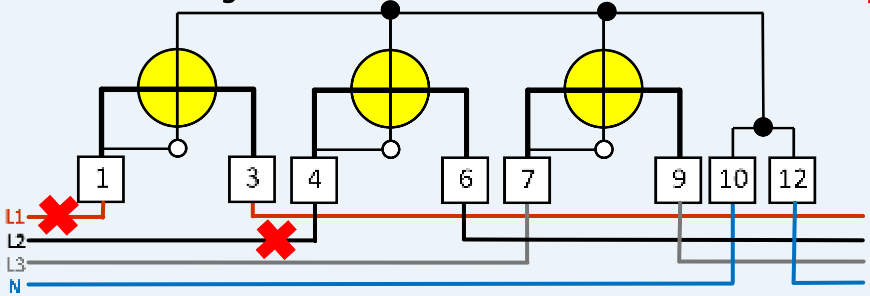
The current can be low because of lack of load, break in connection or wrong installation. As a power is P=U x I(=0) x cos(φ), it causes lack of about 1/3 of power for symmetrical load, however power is measured correctly.

Conclusion: if the value of one of currents is extremely low, it is possible, that there is break in current connection. Low value of error do not guarantee, that measurement system works correctly.

Meter testing – typical meter installation errors recognizing

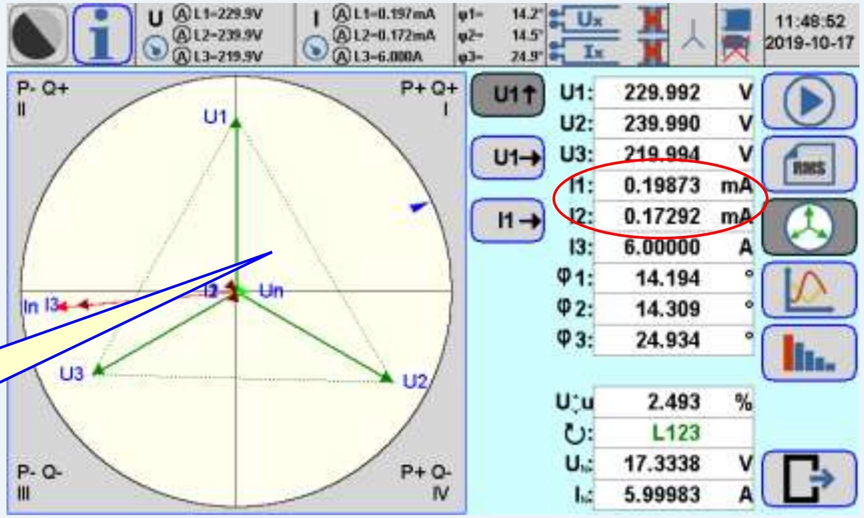
Two currents are not flowing through the meter input

Connection diagram: *two currents I1~0 and I2~0 at the meter input*



Load

Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3



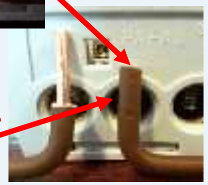
Vector and phase sequence is incomplete, lack of I1 and I2

Current load point for Energy Meter test

	L1	L2	L3		
U:	229.993 V	239.993 V	219.995 V	f:	50.000 Hz
U_{Δ}:	407.052 V	398.441 V	389.847 V	$U_{\emptyset}$:	17.3346 V
I:	0.19752 mA	0.17212 mA	5.99999 A	$I_{\emptyset}$:	5.99981 A
φ:	14.230 °	14.379 °	24.934 °		
PF:	0.96321	0.95858	0.90679	Σ:	0.90679
sin:	0.24425	0.24575	0.42158	Σ:	0.42157
tgφ:	0.25358	0.25637	0.46491	Σ:	0.46490
$Φ_{uu}$:	0.000	120.007 °	-120.016 °	↻:	L123
P:	43.7556	9.5958 mW	1.19693 kW	Σ:	1.19702 kW
Q:	11.095	0.1512 mvar	556.472 var	Σ:	556.494 var
S:	45.42	1.3066 mVA	1.31997 kVA	Σ:	1.32006 kVA

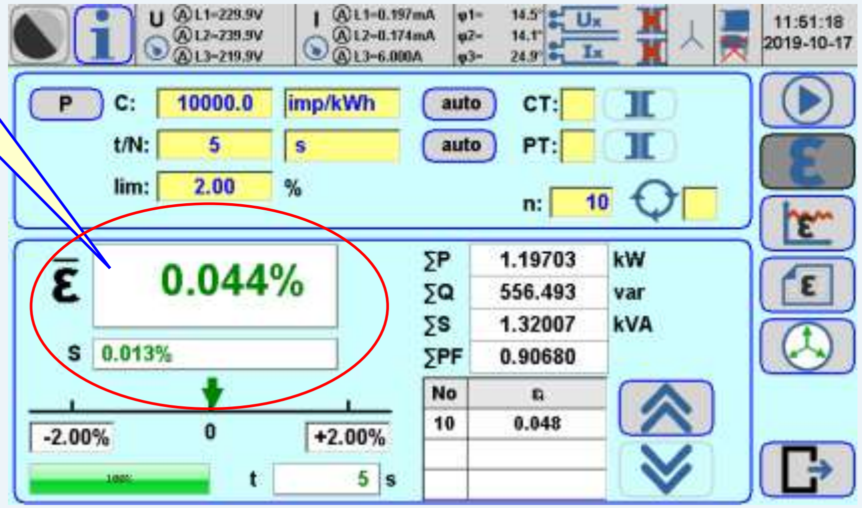
The currents I1 and I2 in phase L1 and L2 are very small

The value of meter error is OK'



Isolated!

Error test result at load point



The current can be low because of lack of load, break in connection or wrong installation. As a power is P=U x I(=0) x cos(φ), it causes lack of about 2/3 of power for symmetrical load, however power is measured correctly.

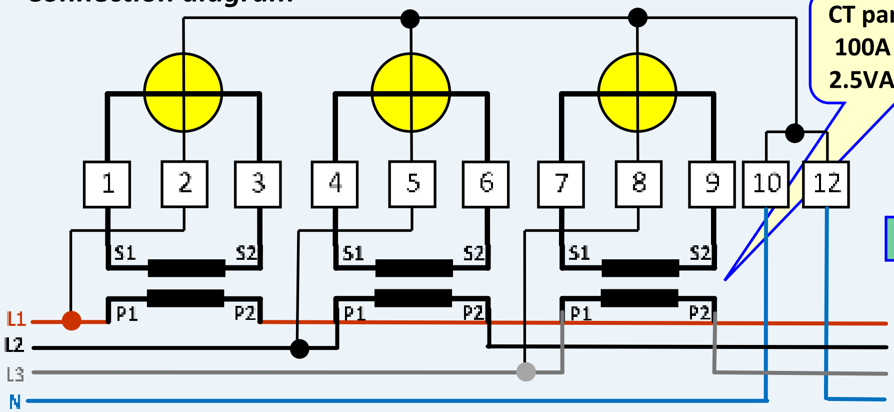
Conclusion: if the value of one or more currents is extremely low, it is possible, that there is break in current connection

Meter testing – typical meter installation errors recognizing

CALMET

Reference connection and results for CT connected, active energy meter – secondary side testing

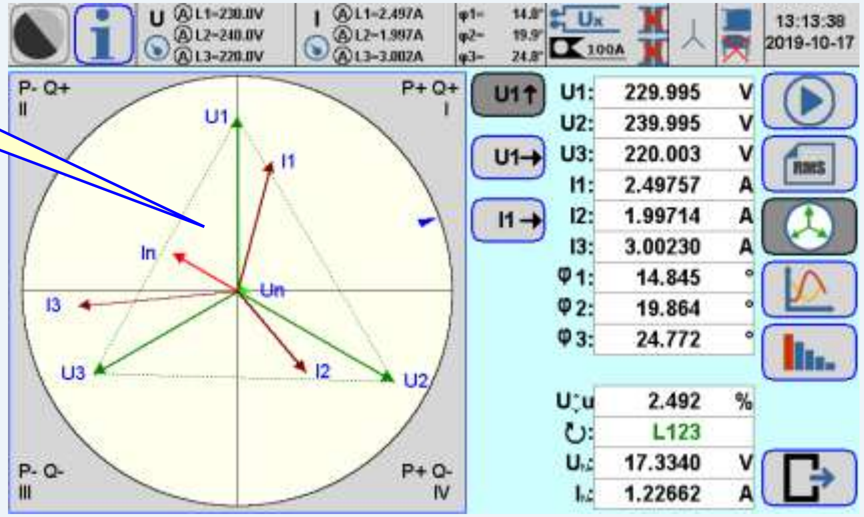
Connection diagram



CT parameters:
100A / 5A =20
2.5VA Class 0.2

Load

Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3



Correct vector diagram
and phase sequence

Current load point for Energy Meter test (current is measured on **secondary side** by clamps)

	L1		L2		L3				
U:	229.996	V	239.997	V	220.004	V	f:	50.000	Hz
U_{Δ}:	407.056	V	398.448	V	389.863	V	U_N:	17.3379	V
I:	2.49756	A	1.99713	A	3.00232	A	[illegible]	[illegible]	[illegible]
φ:	14.845	°	19.863	°	24.772	°			
PF:	0.96662		0.94051		0.90798		Σ:	[illegible]	
sin:	0.25621		0.33977		0.41900		Σ:	0.34230	
tgφ:	0.26505		0.36127		0.46146		Σ:	0.36542	
$Φ_{UU}$:	0.000	°	120.006	°	-120.019	°	↻:	L123	
P:	555.255	W	450.789	W	599.744	W	Σ:	1.60579	kW
Q:	147.171	var	162.856	var	276.760	var	Σ:	586.787	var
S:	574.428	VA	479.305	VA	660.522	VA	Σ:	1.71426	kVA

Voltage:
U1~230V
U2~240V
U3~220V

Current:

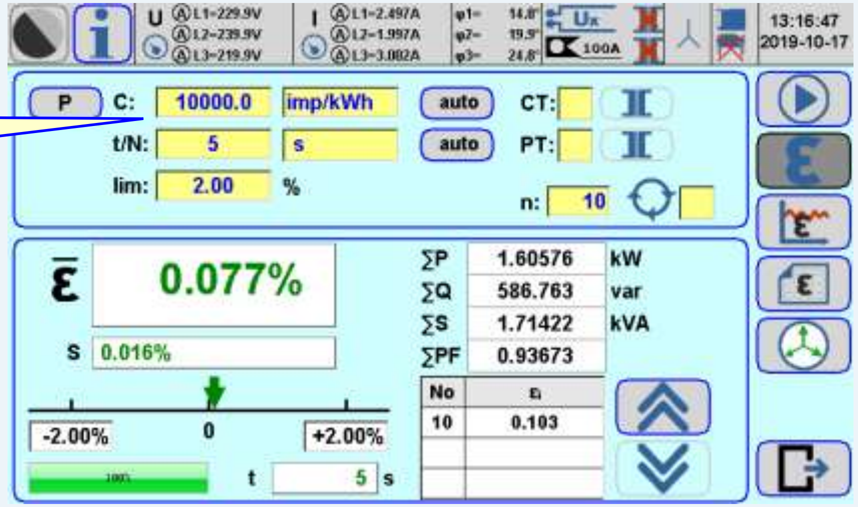
	Secondary	Primary
I1	~2.5A	50A
I2	~2A	40A
I3	~3A	60A

Phase shift:
φ1~15°
φ2~20°
φ3~25°

Secondary meter constant

Vector rotation:
Correct L123

Error test result at load point



*The **initial assessment** of the installation, consists in checking whether the basic parameters are within the **typical** limits:*
Voltage: $U_{nominal}$ ±20%, Current: I_{min}<I<I_{max}, φ: 0…±60°, ∠U-U: 120° or -120° ±10°, Rotation: L123, meter Error: ±5%

Conclusion: knowledge of expected results makes troubleshooting more easy

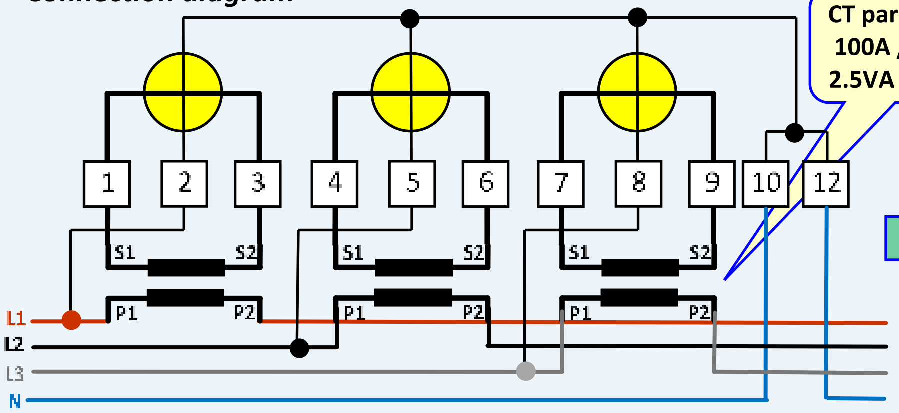
Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

Meter testing – typical meter installation errors recognizing

CALMET

Reference connection and results for CT connected, active energy meter – primary side testing

Connection diagram

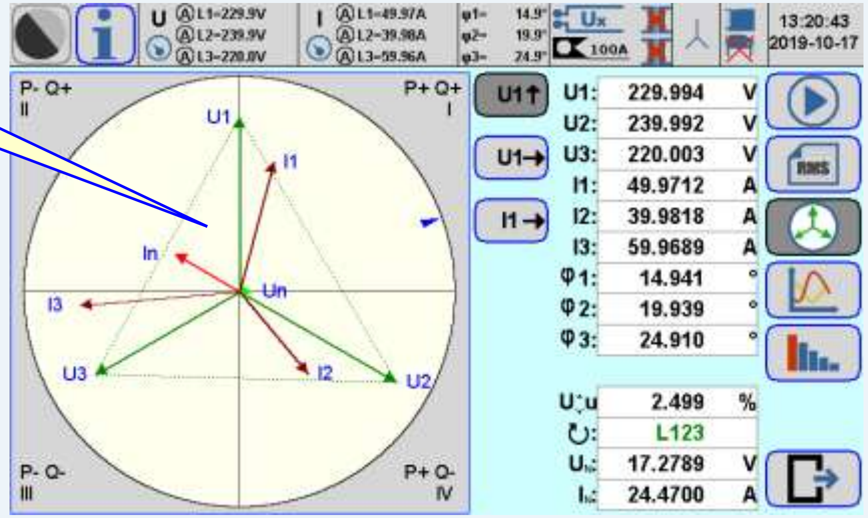


CT parameters:
100A / 5A =20
2.5VA Class 0.2

Load

Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3

Correct vector diagram and phase sequence



Current load point for Energy Meter test (current is measured on **primary side** by clamps)

	L1		L2		L3				
U:	229.991	V	239.989	V	220.001	V	f:	50.000	Hz
U_Δ:	407.072	V	398.440	V	389.829	V	U_N:	17.2808	V
I:	49.9711	A	39.9820	A	59.9687	A			
φ:	14.940	°	19.939	°	24.909	°			
PF:	0.96619		0.94006		0.90698		Σ:		
sin:	0.25781		0.34101		0.42118		Σ:	0.34397	
tgφ:	0.26683		0.36276		0.46438		Σ:	0.36746	
$Φ_{uu}$:	0.000	°	120.019	°	-120.005	°	↻:	L123	
P:	11.1044	kW	9.02007	kW	11.9659	kW	Σ:	32.0904	kW
Q:	2.96300	kvar	3.27210	kvar	5.55668	kvar	Σ:	11.7918	kvar
S:	11.4929	kVA	9.59524	kVA	13.1932	kVA	Σ:	34.2813	kVA

Voltage:
U1~230V
U2~240V
U3~220V

Current:

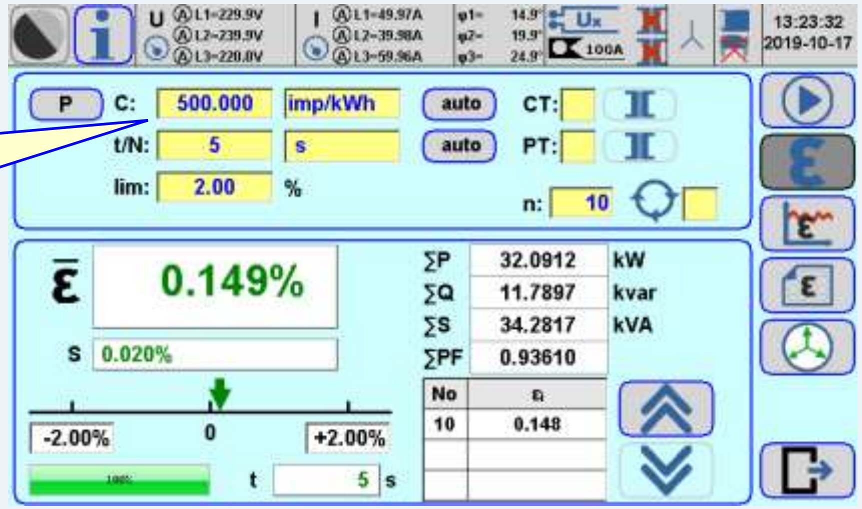
	Primary	Secondary
I1	50A	~2.5A
I2	40A	~2A
I3	60A	~3A

Phase shift:
φ1~15°
φ2~20°
φ3~25°

Primary meter constant = meter constant / CT ratio

Vector rotation:
Correct L123

Error test result at load point



The initial assessment of the installation, consists in checking whether the basic parameters are within the typical limits:
Voltage: $U_{nominal}$ ±20%, Current: 20%I_{nom}<I<100%I_{nom} (I_{nom} – nominal CT primary current) , φ: 0…±60°, ∠U-U: 120° or -120° ±10°, Rotation: L123, meter Error: ±5%

Conclusion: knowledge of expected results makes troubleshooting more easy

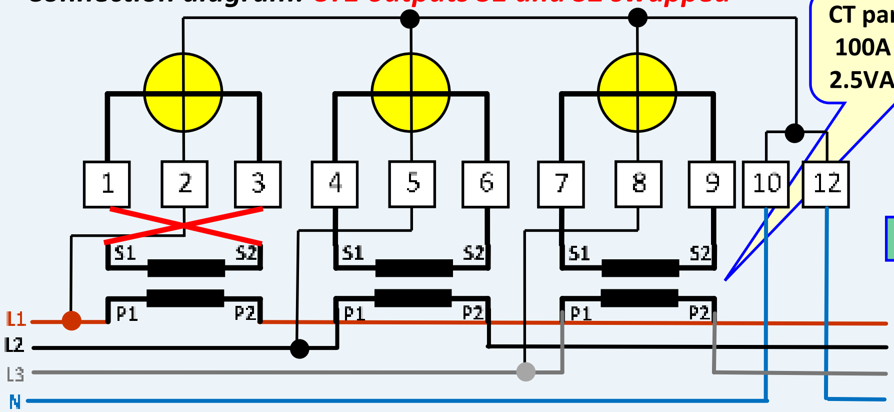
Recommendation & Standards: OIML R46-1/-2 2012 IEC62052-11 2006, IEC62053-xx 2006 IEC50470-1/-2/-3 2006, IEC62057-1/-2 draft

Meter testing – typical meter installation errors recognizing

CALMET

Phase L1 CT outputs S1 and S2 swapped, active energy meter – secondary side testing

Connection diagram: *CT1 outputs S1 and S2 swapped*

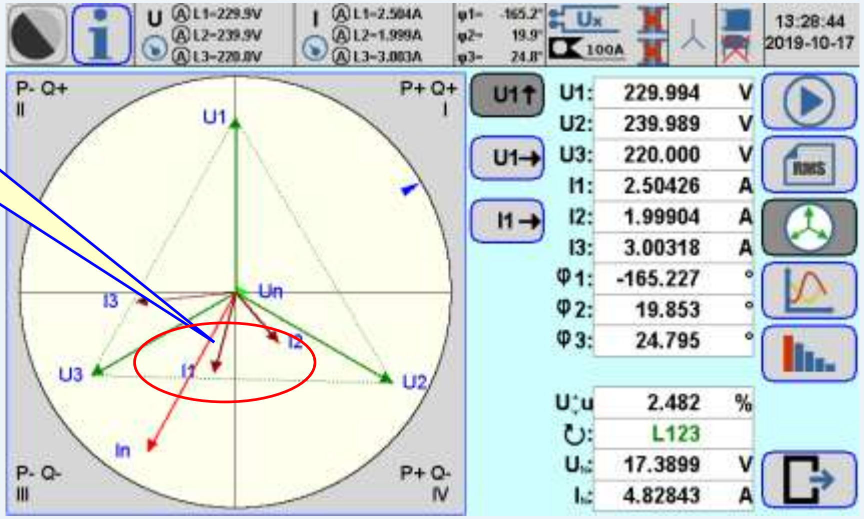


CT parameters:
100A / 5A =20
2.5VA Class 0.2

Load

Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3

Incorrect I1 vector



Current load point for Energy Meter test (current is measured on secondary side by clamps)

	L1		L2		L3				
U:	229.992	V	239.989	V	219.999	V	f:	[illegible]	Hz
U△:	407.009	V	398.449	V	389.880	V	Un:	17.3964	V
I:	2.50426	A	1.99904	A	3.00317	A	In:	4.82797	A
φ:	-165.226	°	19.844		[illegible]				
PF:	-0.96694		0.94062		0.90782		Σ:	0.28789	
sin:	-0.25500		0.33945		0.41936		Σ:	0.17074	
tgΦ:	0.26372		0.36088		0.46195		Σ:	0.59307	
Φuu:	0.000	°	119.988	°	-120.031	°	↻:	L123	
P:	-556.919	W	451.261	W	599.790	W	Σ:	494.132	W
Q:	-146.870	var	162.853	var	277.070	var	Σ:	293.053	var
S:	575.961	VA	479.748	VA	660.695	VA	Σ:	1.71640	kVA

Current:

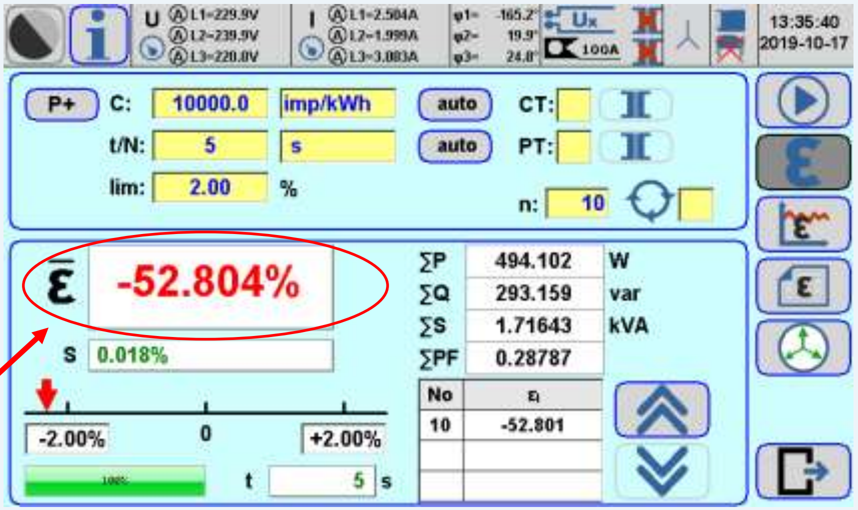
	Secondary	Primary
I1	~2.5A	50A
I2	~2A	40A
I3	~3A	60A

Abnormally high neutral current I_n

Phase shift:
φ1~-165° [-(180°-15°)]
φ2~20° φ3~25°

Vector rotation:
Correct L123

Error test result at load point



There can be a few reasons of secondary current 180° shift: CT outputs swapped, CT inputs swapped, wrong direction on cable assembly. The active power in L1 phase has "-" sign, what causes that only 1/3 of power is counted by energy meter for symmetrical load. This can cause error on -66% level

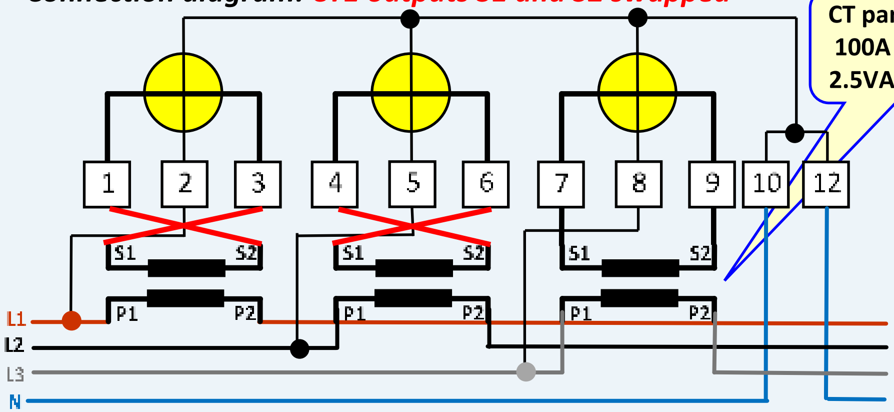
Conclusion: if the value of error is on -66% ±20% level, it is possible, that one of the CT's is not connected properly

Meter testing – typical meter installation errors recognizing

CALMET

Phase L1, L2 CT outputs S1 and S2 swapped, active energy meter – secondary side testing

Connection diagram: *CT1 outputs S1 and S2 swapped*

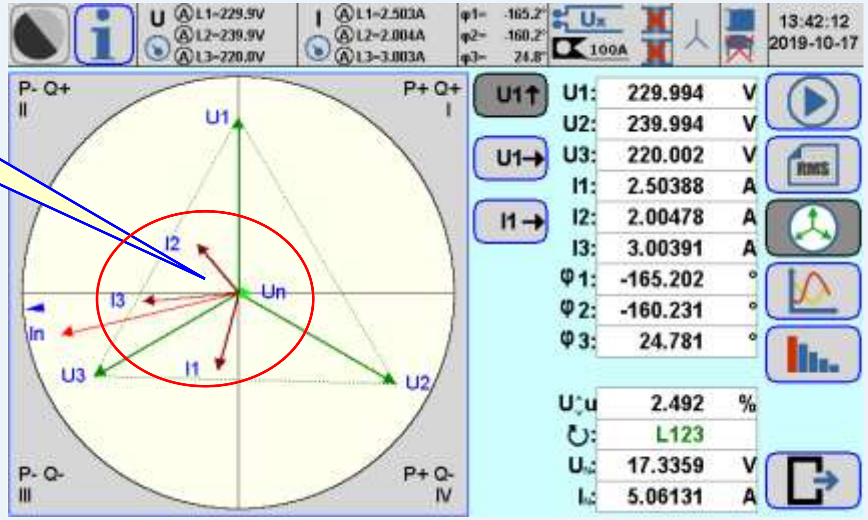


CT parameters:
100A / 5A =20
2.5VA Class 0.2

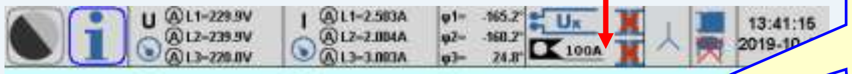
Incorrect I1 and I2 vector

Load

Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3



Current load point for Energy Meter test (current is measured on **secondary side** by clamps)



	L1		L2		L3				
U:	229.992	V	239.991	V	220.000	V	f:	[illegible]	Hz
U$_{LL}$:	407.044	V	398.441	V	389.857	V		17.3410	V
I:	2.50386	A	2.00476	A	3.00388	A	I:	5.06128	A
φ:	-165.203	°	-160.231	°	24.781	°			
PF:	-0.96684		-0.94106		0.90791		Σ:	-0.23840	
sin:	-0.25540		-0.33823		0.41916		Σ:	-0.01910	
tgΦ:	0.26416		0.35942		0.46167		Σ:	0.08010	
Φ$_{ui}$:	0.000	°	120.004	°	-120.019	°		L123	
P:	-556.770	W	-452.767	W	599.998	W	Σ:	-409.539	W
Q:	-147.075	var	-162.732	var	277.001	var	Σ:	-32.8059	var
S:	575.868	VA	481.124	VA	660.854	VA	Σ:	1.71785	kVA

Current:

	Secondary	Primary
I1	~2.5A	50A
I2	~2A	40A
I3	~3A	60A

Abnormally high neutral current I_n

Phase shift:
φ1~-165° [-(180°-15°)]
φ2~-160° [-(180°-20°)]
φ3~25°

Vector rotation: Correct L123

Negative total active power

Error test result at load point

No pulses to test active energy meter error

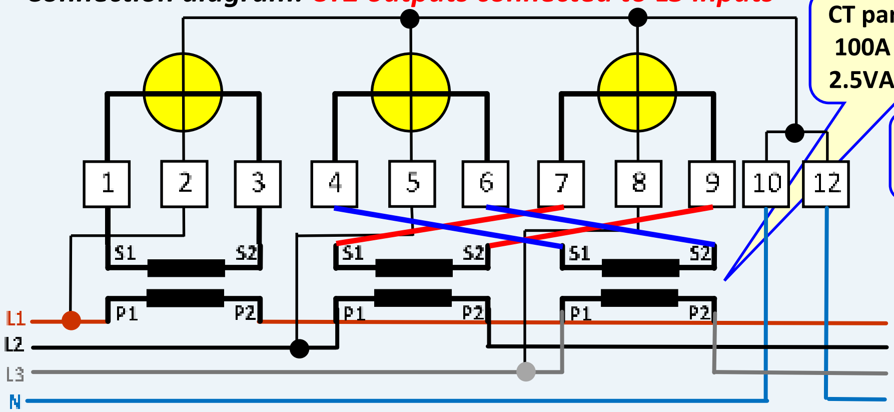
There can be a few reasons of secondary current 180° shift: CT outputs swapped, CT inputs swapped, wrong direction on cable assembly. The active power in L1 andL2 phases have "-" sign, what causes, that total power counted by energy meter is negative for symmetrical load. This makes error test impossible because of pulses lack.

Conclusion: if there is no pulses from meter under test, it is possible, that two of the CT's are not connected properly

Meter testing – typical meter installation errors recognizing

CT of L2 connected to L3 and L3 to L2, active energy meter – secondary side testing

Connection diagram: CT2 outputs connected to L3 inputs

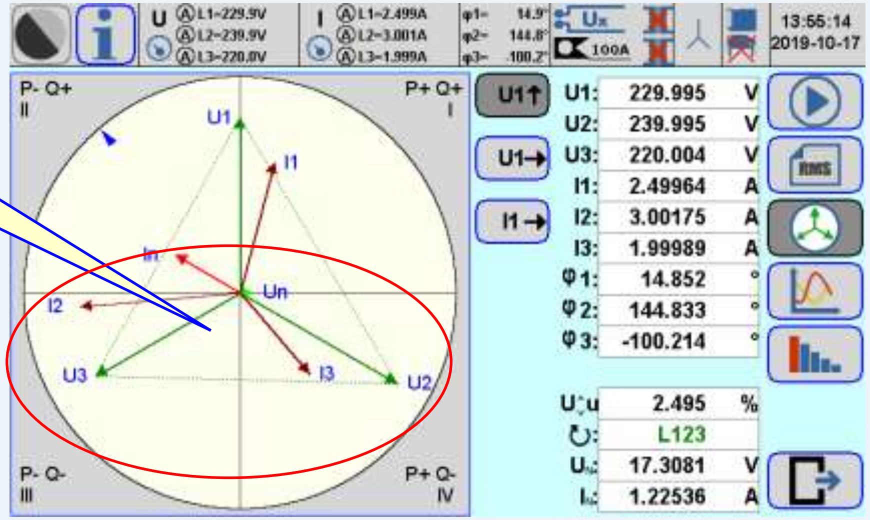


CT parameters:
100A / 5A =20
2.5VA Class 0.2

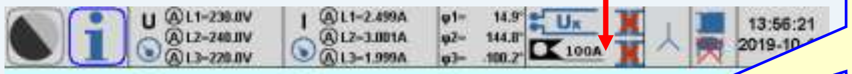
Incorrect I2 and I3 vector with reference to voltage

Load

Vector diagram: positive sequence U1 ⇨ U2 ⇨ U3



Current load point for Energy Meter test (current is measured on **secondary side** by clamps)



	L1		L2		L3				
U:	229.996	V	239.996	V	220.004	V	f:	[illegible]	Hz
U₂:	407.056	V	398.449	V	389.860	V	Uₙ:	17.3337	V
I:	2.49962	A	3.00174	A	1.99990	A	Iₙ:	1.22491	A
φ:	14.853	°	144.818	°	-100.199	°			
PF:	0.96659		-0.81732		-0.17706		Σ:	-0.06398	
sin:	0.25633		0.57618		-0.98420		Σ:	0.07458	
tgφ:	0.26519		-0.70495		5.55844		Σ:	-1.16567	
Φᵤᵤ:	0.000	°	120.006	°	-120.017	°	↻:	L123	
P:	555.692	W	-588.806	W	-77.9058	W	Σ:	-111.019	W
Q:	147.365	var	415.081	var	-433.035	var	Σ:	129.412	var
S:	574.901	VA	720.407	VA	439.987	VA	Σ:	1.73530	kVA

Current:	Secondary	Primary
I1	~2.5A	50A
I2	~3A	40A
I3	~2A	60A

Phase shift:
φ1~15°
φ2~120°+25°=145°
φ3~-120°+20°=-100°

Vector rotation:
Correct L123

Negative total active power

Error test result at load point

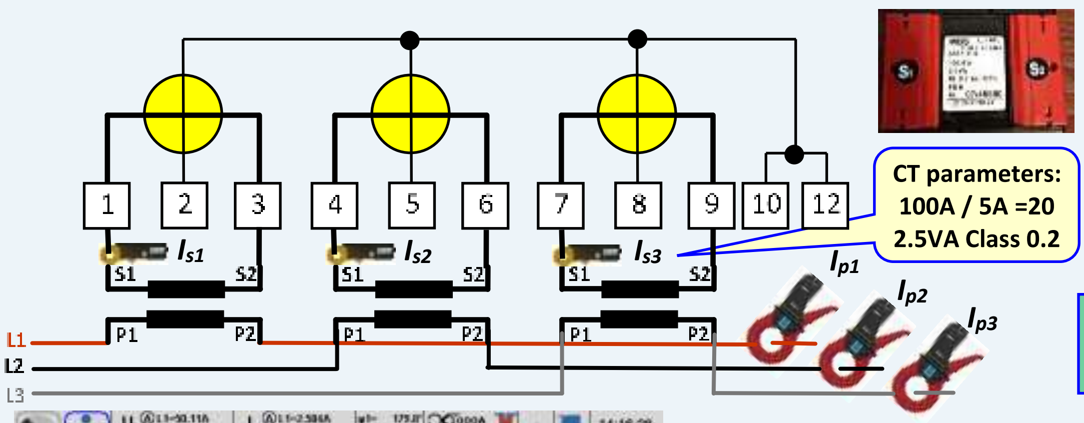
No pulses
to test active energy meter error

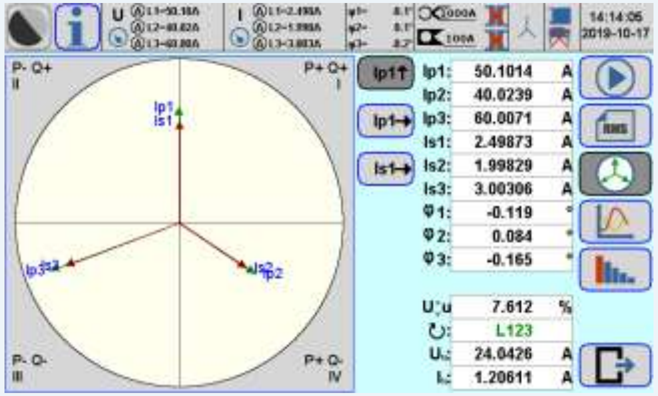
Wrong CT outputs (inputs) connection to different phases can cause unpredicted results. Lack of meter under test pulses and wrong vector diagram enables to find out the reason.

Conclusion: if there is no pulses from meter under test, it is possible, that two or more CT outputs are not connected properly

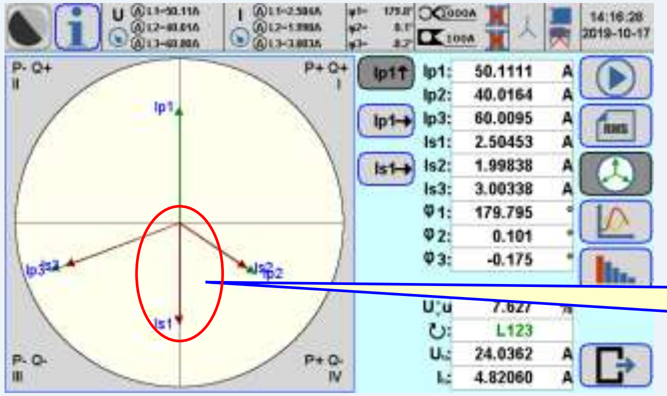
Meter testing – typical meter installation errors recognizing

CT's testing for correct connection with two sets of 3 current clamps

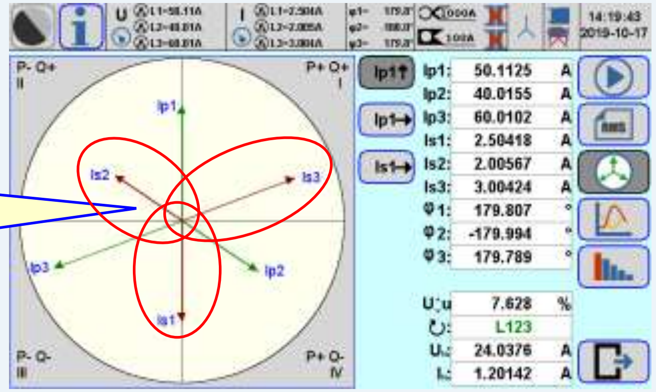




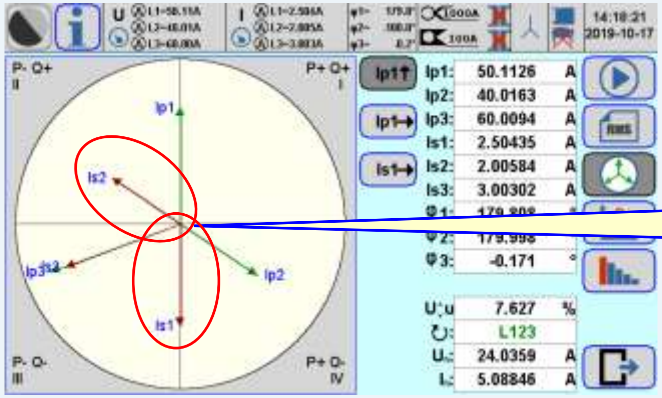
Correct vector diagram.
Primary and secondary currents are in phase



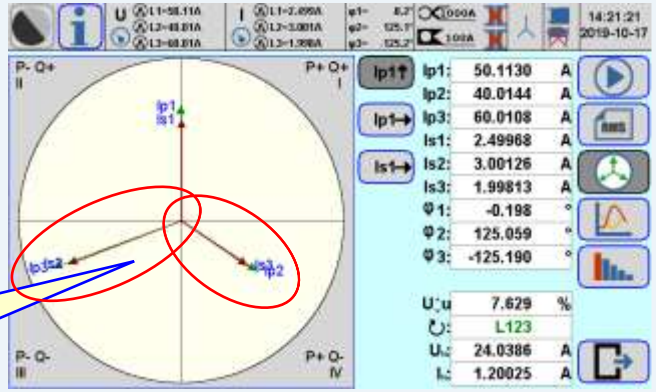
Current I_{s1} is rotated by 180°



All three currents I_{s1}, I_{s2} and I_{s3} are rotated by 180°



Current I_{s1} and I_{s2} are rotated by 180°



Current I_{s2} is swapped with I_{s3}

Conclusion: two sets of three current clamps allows for easy CT connection testing

Interesting standards, recommendations, articles and www sites

IEC Standards (https://www.iec.ch)

IEC 60050 International electrotechnical vocabulary (IEV)
IEC 62052 - 11 Electricity metering equipment (a.c.) - General requirements, tests and test conditions – Part 11: Metering Equipment
IEC 62053 - 11 Electricity metering equipment (a.c.) - Particular requirements – Part 11: Electromechanical meters for active energy class 0.5, 1and 2
IEC 62053 - 12 Electricity metering equipment (a.c.) - Particular requirements – Part 12: Electromechanical meters for reactive energy class 2 and 3
IEC 62053 - 21 Electricity metering equipment (a.c.) - Particular requirements – Part 21: Static meters for active energy class 1 and 2
IEC 62053 - 22 Electricity metering equipment (a.c.) - Particular requirements – Part 22: Static meters for active energy class 0.2 S and 0.5 S
IEC 62053 - 23 Electricity metering equipment (a.c.) - Particular requirements – Part 23: Static meters for reactive energy class 2 and 3
IEC 62053 - 24 Electricity metering equipment (a.c.) - Particular requirements – Part 24: Static meters for apparent energy class 1 and 2
IEC 60044-1 Instrument transformers – Part 1: Current transformer
IEC 60044-2 Instrument transformers – Part 2: Inductive voltage transformer
IEC 60736 Testing equipment for electrical energy meters
IEC 62057-1 (draft) Test equipment, techniques and procedures for electrical energy meters - Part 1: Stationary Meter Test Units
EC 62057- 2 (draft) Test equipment, techniques and procedures for electrical energy meters - Part 2: Portable test equipment and test procedure for electricity meters and electricity meter installations

European Standards (https://www.cenelec.eu/)

EN 50470 -1 Electricity metering equipment (a.c.) – General requirements - Part 1: Tests and test conditions for metering equipment class A, B and C
EN 50470 -2 Electricity metering equipment (a.c.) – Particular requirements – Part 2: Electromechanical meters for active energy class A and B
EN 50470 -3 Electricity metering equipment (a.c.) – Particular requirements – Part 3: Static meters for active energy class A, B and C control

Indian Standards (https://bis.gov.in/)

IS-14697 Specification for AC Static Transformer operated Watt Hour & VAR-Hour meters (class 0.5S)
IS 12346 Testing equipment for AC electrical energy meters
IS 15707 Testing, evaluation, installation & maintenance of AC Electricity Meters-Code of Practice

OIML recommendation (https://www.oiml.org/en)

OIML 46-1/-2 Active electrical energy meters. Part 1: Metrological and technical requirements Part 2: Metrological controls and performance tests

NPL publication (https://www.npl.co.uk/)

No.11 The beginners guide to uncertainty of mesurement

Canadian Standards (https://www.ic.gc.ca/eic/site/mc-mc.nsf/eng/home)

LMB-EG-07 Specifications for Approval of Type of Electricity Meters, Instrument Transformers and Auxiliary Devices
PE-E-03 Procedures for the verification and reverification of electricity meters

Testing Equipment manufacturers

Applied Precision - Slovakia (https://www.appliedp.com)
Calmet Ltd – Poland (https://www.calmet.com.pl/en)
Clou – China (https://clouglobal.com)
EMH Energie Messtechnik GmbH – Germany (https://emh.eu)
Emsyst – Bulgaria (https://emsyst.com)
Geny – China (https://www.genymetertestequipment.com/electricity-meter-test-systems/)
Metertest Ltd – Poland (http://www.meter-test-equipment.com/en/)
MTE Meter test equipment AG – Switzerland (https://www.mte.ch)
Radian Research – USA (http://www.radianresearch.com/)
ZERA GmbH – Germany (https://www.zera.de)