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Bidirectional electricity meter metrological evaluation

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Abstract **– This paper presents metrological evaluation of bidirectional electricity meters, comparing its performance when measuring electrical energy in direct and reverse power flows. Evaluation results shown that the difference between measuring results in both directions is not significant compared to the measurement uncertainty and to the maximum permissible errors. In this evaluation, four IEC 0,2S and 0,5S accuracy classes electricity meters were tested.**

I. INTRODUCTION

Electricity meters have been in use since the late 1800's when electric power began to be used by countries. Today, two types of meter technologies are available: induction electromechanical and static electronic. Both types are considered integrating devices, measuring the power consumed over a period of time. These meters are essentially one way. Figure 1 shows electromechanical and electronic electricity meters.

Fig. 1. Electromechanical and electronic electricity meters.

The advance of smart grids, renewable energy and distributed generation of electrical energy require measurement in bidirectional way, as the users take energy from the grid and also supply energy to the grid. Other situation that requires bidirectional measurement is the energy interchange between electrical grids. Traditional electricity meters are not able to measure bidirectional electrical energy, so a special meter is required [1,2]. National and international standards and other metrological policies state that bidirectional electricity meters should meet metrological requirements in both power flow directions [3, 4, 5, 6].

This paper presents metrological evaluation of bidirectional electricity meters in direct and reverse power flow. Test setup is shown, as well as test results, including measurement uncertainty.

II. BIDIRECTIONAL ELECTRICITY METER

A four-quadrant or bidirectional electricy meter measures electrical energy in both power flow directions: direct (delivered active power), or from the source to the load, and reverse, from the load to the source (received active power). Figure 2 shows four-quadrant operation mode. Table 1 shows four-quadrant power flow relationships [7, 8]. This is the case of smart meters, one of the most important devices used in the smart grids.

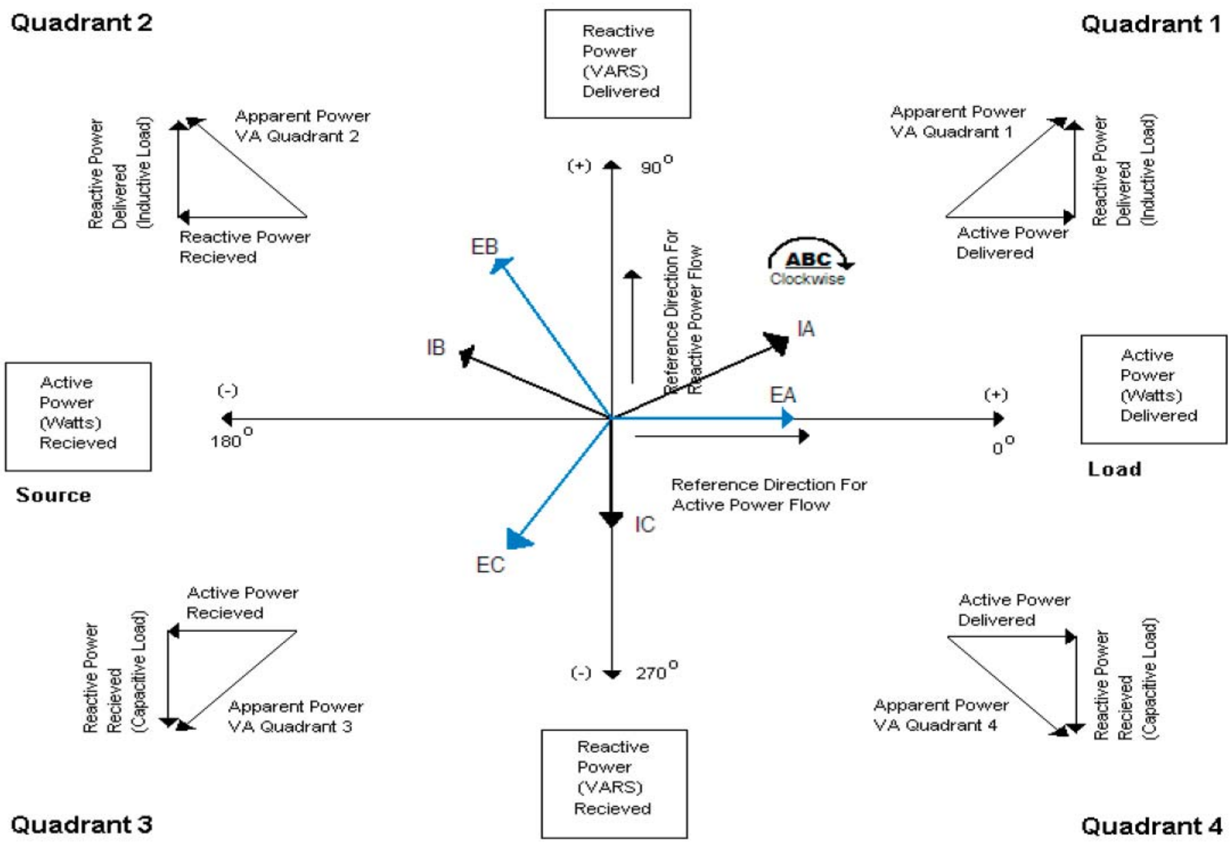

Fig. 2. Four-quadrant electricity measurement [8].

Table 1. Four-quadrant power flow relationships [8].

Apparent power Quadrant	Active power flow direction	Active power flow direction
1	Delivered	Delivered
2	Received	Delivered
3	Received	Received
4	Delivered	Received

Accuracy requirement shoud be met by the meters in both directions, so performance tests must include accuracy evaluation in direct and reverse operation modes.

III. TEST SETUP

In the experimental tests, some electricy meters were calibrated in laboratory conditions, using appropriate methods and standards. Ambient temperatute was (23 ± 2) ºC and relative humidity was (40 ± 10) %. A 3-phase voltage and current source was used to supply electrical energy to the meters under test and to the reference standard. Two power sources were available: one Zera model MT-500 and one Omicron model CMC 256plus.
The reference standard was from Radian Research, model RD-30, which was traceable to the Brazilian standards. Its maximum error is (0.02% / Cos φ) or (0.02% / Sin φ), according to its manufacturer.
Voltage and current from the source were supplied to the meters under test and to the reference standard. After the measurement of a defined amount of energy, meters under test generates a pulse. This amount of energy per pulse is the meter constant, which must be informed to the reference standard. Pulse output of the meters were connected to the reference standard pulse input, which displayed the measurement error of the meters after each integration period of about 50 s. At least 5 readings were taken at each calibration point. Reported measurement uncertainty was estimated using [9]. Figure 3 shows the block diagram of the test setup.

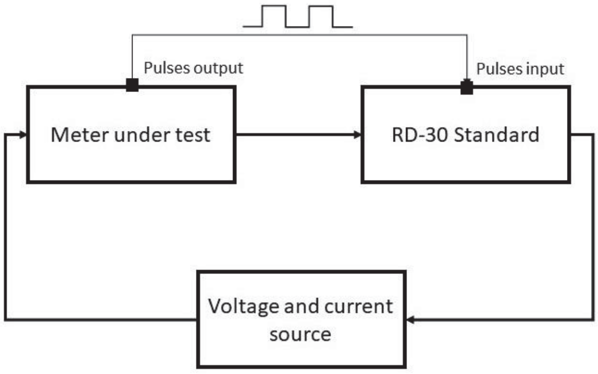

Fig. 3. Block diagram of the test setup.

Calibration points used are shown in Table 2. Frequency was line frequency of 60 Hz, and V_N and I_N are the nominal voltage and current of the meters. Each calibration point was measured in direct and reverse power flow.

Table 2. Calibration points.

Active energy (Wh)			Reactive energy (varh[1])		
Voltage (V)	Current (A)	Cos φ	Voltage (V)	Current (A)	Sin φ
V_N	I_N	1	V_N	I_N	1 i
		0.5 i			0.5 i
		0.8 c			0.8 c
	$0.1I_N$	1		$0.1I_N$	1 i

Four electricity meters were tested: three 0,2S IEC (active energy) and class D INMETRO (active and reactive energy) accuracy class and one 0,5S IEC and class C INMETRO accuracy class. All meters were tested at nominal voltage of 66.4 V and nominal current of 5 A. Figure 4 shows the RD-30 standard and two 0,2S accuracy classe electricity meters, and Figure 5 shows the Omicron CMC 256plus three phase voltage and current source.

Fig. 4. Radian RD-30 standard (left) and two IEC 0,2S accuracy class electricity meters (right).

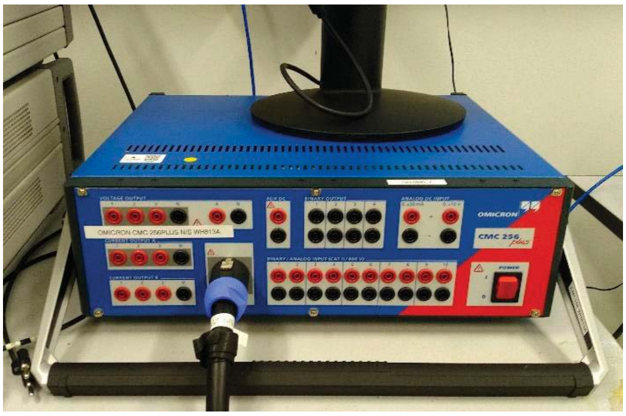

Fig. 5. Omicron CMC 256plus three phase voltage and current source.

IV. TEST RESULTS

This section shows some of the calibration results of the electricity meters under test. The meters were calibrated in active energy and reactive energy, as the meters also meet brazilian metrological requirements and policies for reactive energy meters. Measurement uncertainty was estimated using [10].

Table 3 and Figure 6 show the calibration results for active energy (Wh) of one of the 0,2S and D accuracy class meters, where "D" refers to direct power flow direction and "R" refers to reverse direction, *e* is the measurement error and *U* is the measurement uncertainty (95.45%, 2σ). Maximum permissible error is 0.2 % for cos φ = 1 and 0.3 % for cos φ = 0.5 ind. As it can be seen, absolute error diference is 0.004% in both calibration points, much smaller than measurement uncertainty. For cos φ = 1, the ratio (absolute error diference) / (measurement uncertainty) is 0.2 and measurement uncertainty is 1/10th of the maximum permissible error, while for cos φ = 0.5 ind, the ratio (absolute error diference) / (measurement uncertainty) is about 0.11, and measurement uncertainty is about 1/8 of the maximum permissible error.

Table 3. 0,2S and D accuracy class electricity meter calibration results (Wh).

Calibration point	e (%)	U (%)
66.4 V - 5 A – Cos φ=1 (D)	-0.081	0.020
66.4 V - 5 A - Cos φ=1 (R)	-0.085	0.020
66.4 V - 5 A - Cos φ=0.5 ind (D)	-0.094	0.037
66.4 V - 5 A - Cos φ=0.5 ind (R)	-0.098	0.035

[1] Although VARh is used many times, IEC defines varh or varh.h as the unit symbol for reactive power [9].

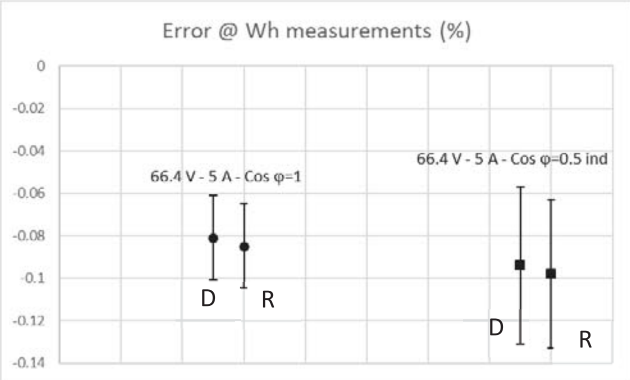

Fig. 6. 0,2S and D accuracy class electricity meter calibration results (Wh).

Table 4 and Figure 7 show the calibration results for reactive energy (varh) of the same ION 8500 electricity meter. Maximum permissible error, according to INMETRO D accuracy class, is 0.4 % for Sin φ = 1 ind and 0.6 % for Sin φ = 0.5 ind. Absolute error difference is quite small for sin φ = 1 ind, but it increases for sin φ = 0.5 ind. For sin φ = 1 ind, the ratio (absolute error diference) / (measurement uncertainty) is 0.25, while for for sin φ = 0.5 ind, the ratio (absolute error diference) / (measurement uncertainty) is about 0.55.

Table 4. D accuracy class electricity meter calibration results (varh).

Calibration point	e (%)	U (%)
66.4 V - 5 A - Sin φ=1 (D)	-0.088	0.020
66.4 V - 5 A - Sin φ=1 (R)	-0.083	0.020
66.4 V - 5 A - Sin φ=0.5 ind (D)	-0.078	0.037
66.4 V - 5 A - Sin φ=0.5 ind (R)	-0.058	0.035

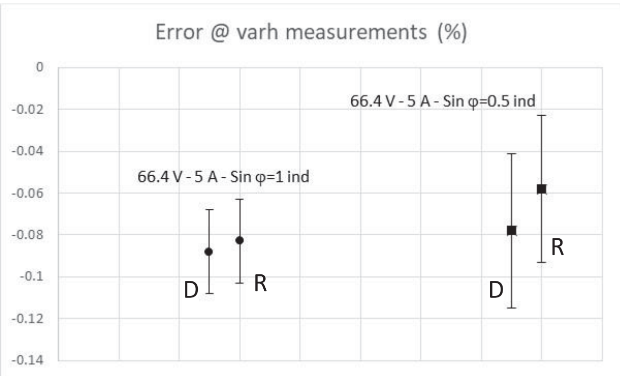

Fig. 7. D accuracy class electricity meter calibration results (varh).

Table 5 and Figure 8 show the calibration results for active energy (Wh) of the IEC 0,5S and INMETRO C accuracy class electricity meter. Maximum permissible error is 0.5 % for cos φ = 1 and 0.6 % for cos φ = 0.5 ind. Absolute error diference is 0.005% and 0.006%, much smaller than measurement uncertainty. For cos φ = 1, the ratio (absolute error diference) / (measurement uncertainty) is 0.25 and measurement uncertainty is about 1/25 of the maximum permissible error, while for for cos φ = 0.5 ind, the ratio (absolute error diference) / (measurement uncertainty) is about 0.16.

Table 5. 0,5S and C accuracy class electricity meter calibration results (Wh).

Calibration point	e (%)	U (%)
66.4 V - 5 A – Cos φ=1 (D)	0.007	0.020
66.4 V - 5 A - Cos φ=1 (R)	0.002	0.020
66.4 V - 5 A - Cos φ=0.5 ind (D)	0.012	0.037
66.4 V - 5 A - Cos φ=0.5 ind (R)	0.006	0.037

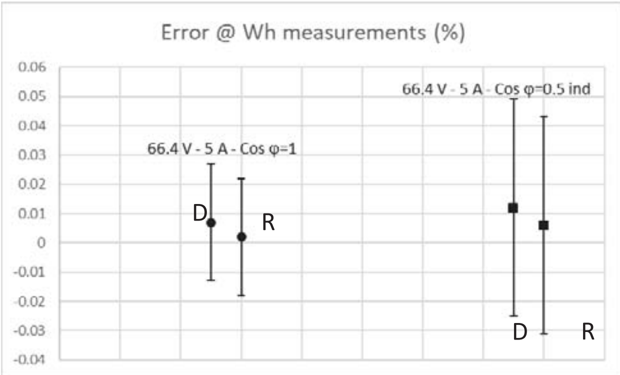

Fig. 8. 0,5S and C accuracy class electricity meter calibration results (Wh).

Table 6 and Figure 9 show the calibration results for reactive energy (varh) of the INMETRO C accuracy class electricity meter. Maximum permissible error is 1.0 % for Sin φ = 1 ind and 1.2 % for Sin φ = 0.5 ind. Absolute error difference is 0.003% for sin φ = 1 ind and sin φ = 0.5 ind, while the ratio (absolute error diference) / (measurement uncertainty) is 0.15 and about 0.08.

Table 6. C accuracy class electricity meter calibration results (varh).

Calibration point	e (%)	U (%)
66.4 V - 5 A – Sin φ=1 (D)	-0.034	0.020
66.4 V - 5 A - Sin φ=1 (R)	-0.037	0.020
66.4 V - 5 A - Sin φ=0.5 ind (D)	-0.035	0.037
66.4 V - 5 A - Sin φ=0.5 ind (R)	-0.032	0.037

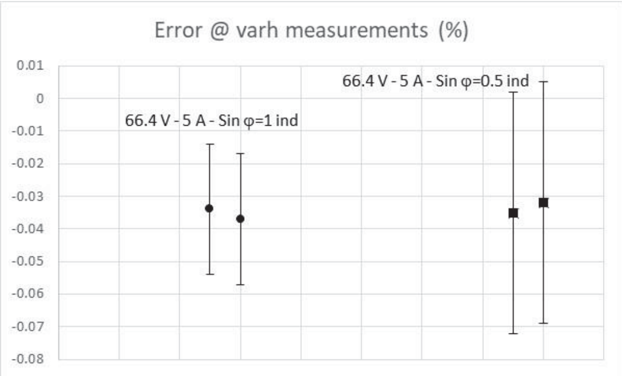

Fig. 9. C accuracy class electricity meter calibration results (varh).

V. ANALYSIS

The tests presented in Section IV shown that, for the four electricity meters tested, calibration results at each point were statistically the same for both direct and reverse power flow directions, since the difference between calibration values were much smaller than associated measurement uncertainty. The highest ratio of (calibration result difference) / (measurement uncertainty) was about 0.55, but most of these ratios were close to 0.1. Measurement uncertainty was appropriate for all calibration points, as it was always smaller than 1/5 of the maximum permissible error. These results were very satisfactory considering meter's maximum permissible error required by IEC and INMETRO standards, so these meters can be reliably used in bidirectional electric energy metering.

As the tests were performed only under sinusoidal voltage and current conditions, it is possible that under different conditions, for example, when voltage and current waveforms are distorted by harmonic components, the results are not so satisfactory. This condition can be found where renewable power generation systems, as photovoltaic, are connected to the grid.

VI. CONCLUSION

This paper presented metrological evaluation of bidirectional electricity meters when measuring electrical energy in direct and reverse power flows. The calibration results shown that the difference of direct and reverse calibration values is not significant, much smaller than measurement uncertainty and maximum permissible errors, so they can be reliably used in bidirectional electric energy metering. As only 0,2S and 0,5S accuracy classes electricity meters were evaluated this time, for further work, it is planned to test less accurate electricity meters, as classes 1 and 2 meters. It is also planned to test the meters under non-sinusoidal conditions, as voltage and current waveforms distorted by harmonic components.

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