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AC ripple over DC: new solutions for measurements and calibrations

Presentation Contributors

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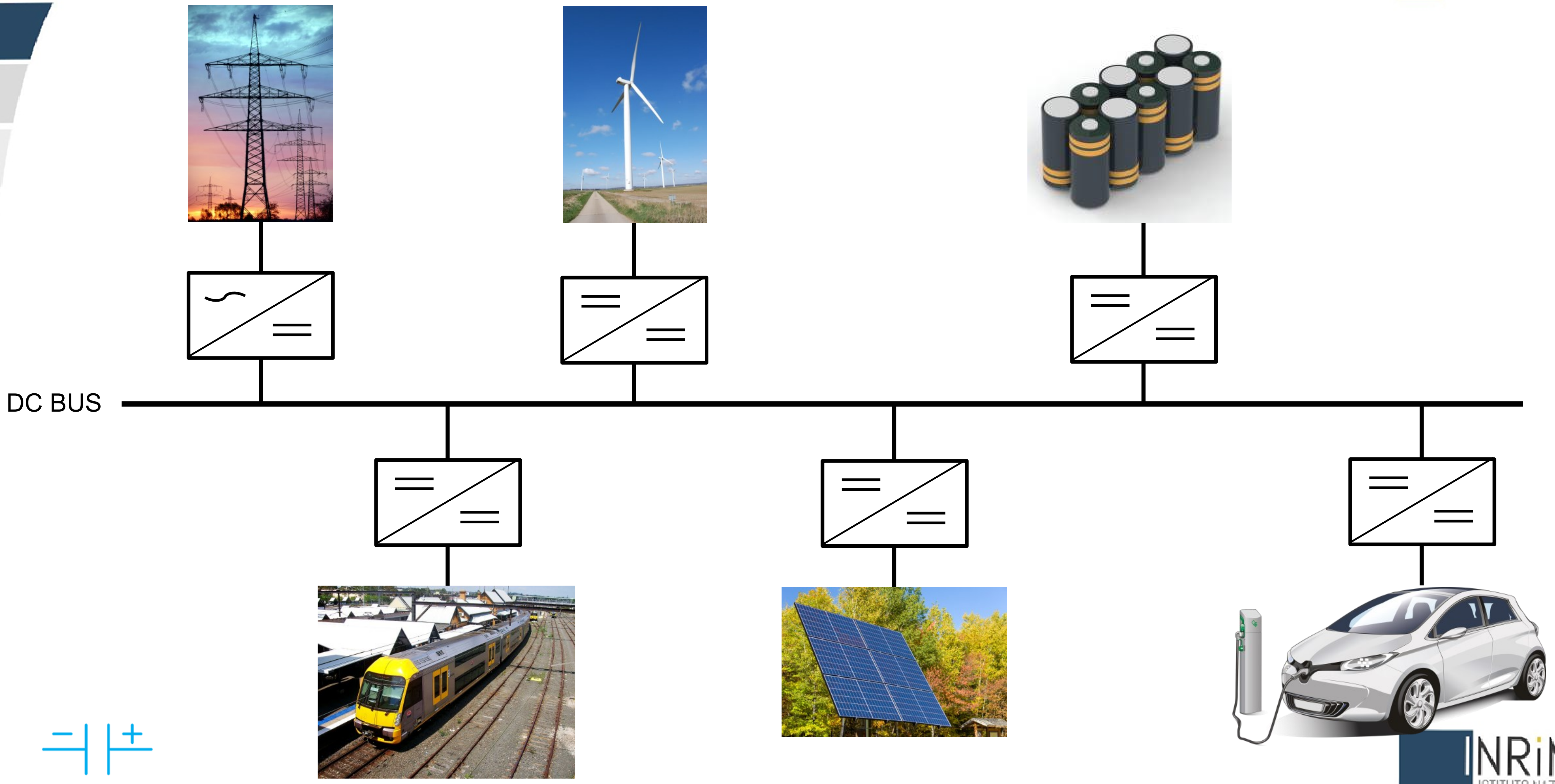
Overview

- The ac ripple over dc issue in dc grids
- Novel Method for Accurate Measurement of Ripple for Power Quality Applications in dc Grids
  - The proposed methodology
  - Validation of the methodology
  - Experimental results
- Traceability for ac Ripple Over DC Current
  - Proposed approach: ALFO
  - Systematic errors analysis
  - Uncertainty analysis
- Conclusions

Modern dc grids



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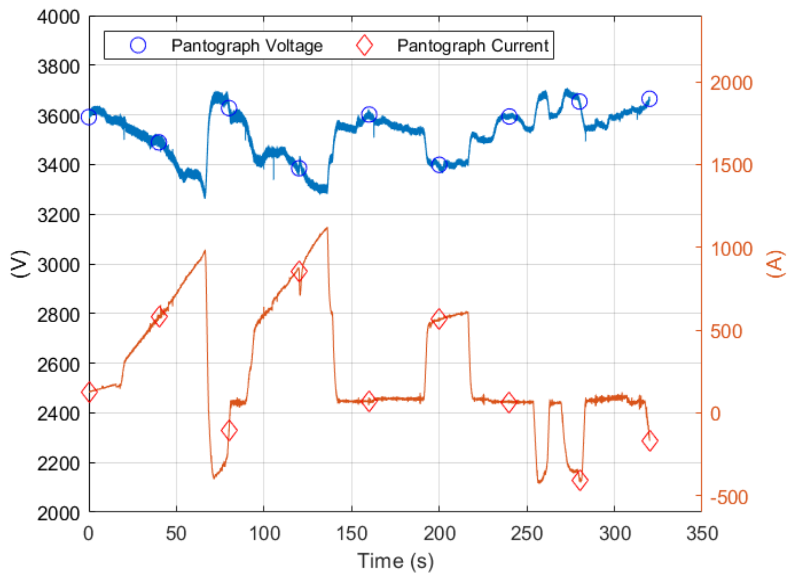
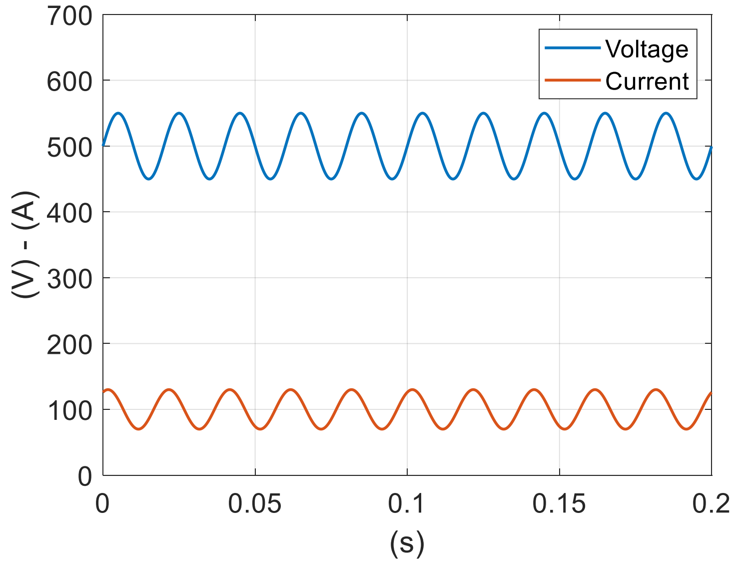
Fluctuation of voltage and current

- As for ac, it is **essential to monitor** the characteristics of the electricity in dc power system evaluated against a set of reference technical parameters, that is the power quality (PQ) .
- Voltage and current in a dc power system **are not perfectly constant**, but their average values change in time with operating conditions.





- The mechanisms of the generation of dc power supply typically imply the overlap of a stationary fluctuation, named **ripple**. Modern switching dc/dc and ac/dc converters produce ripple at frequencies **up to hundreds of kHz** or more.

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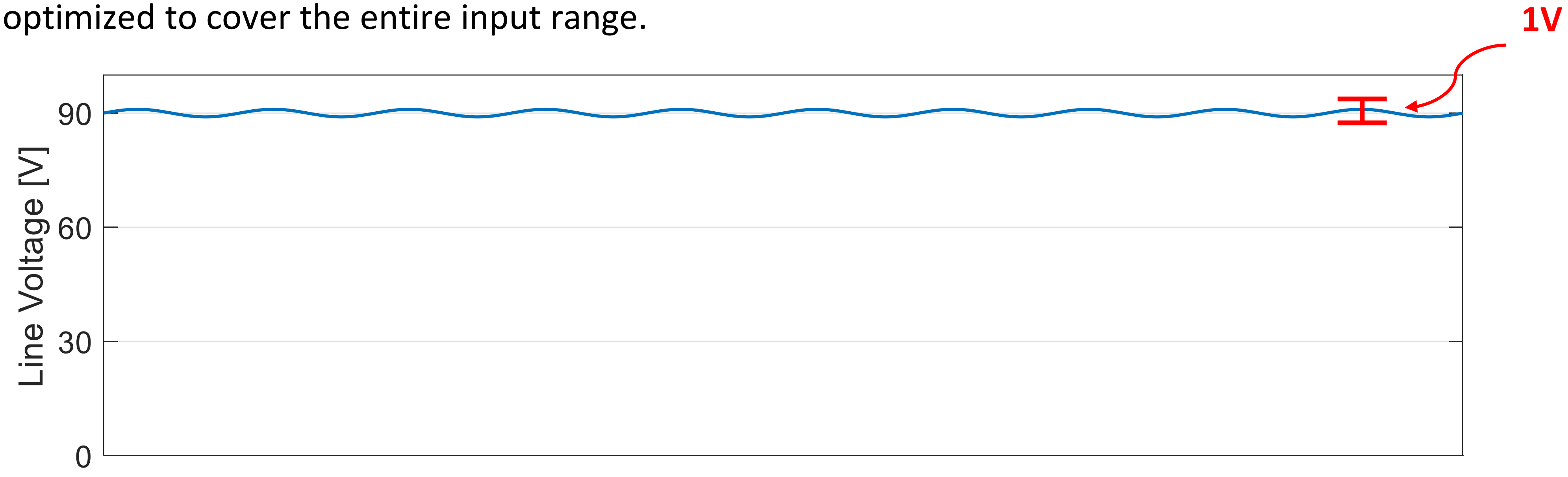
Novel Method for Accurate Measurement of Ripple for Power Quality Applications in DC Grids

- The acquisition of a relatively small ac component superposed to a dc component represents an unresolved challenge.
- The sensors installed are selected for the full variation of the dc component, therefore the measure of a very low signal can be corrupted. Similar considerations apply for the digitizer stage, whose resolution is optimized to cover the entire input range.

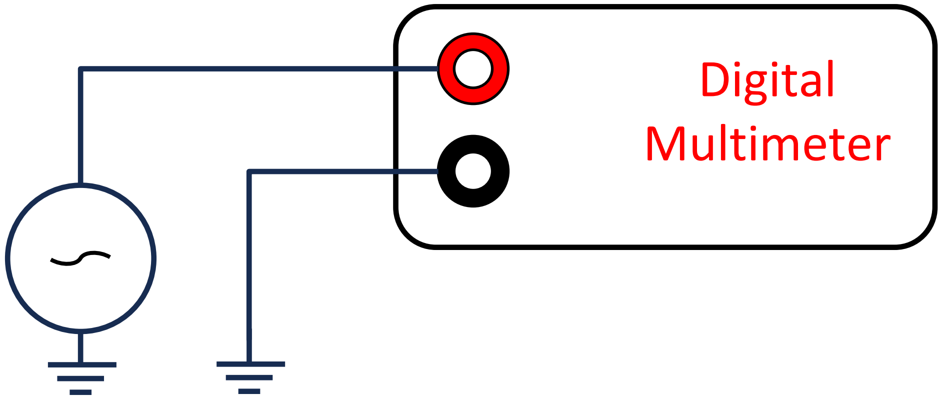


- The uncertainty, (i.e., the doubt about the validity of the result of a measurement*), associated with the measurement depends on the reading range.

*GUM: Guide to the Expression of Uncertainty in Measurement

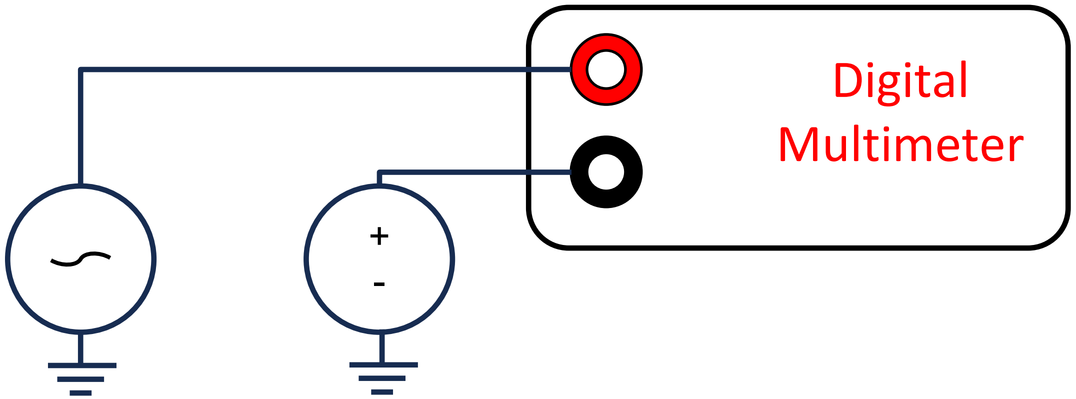
Proposed Methodology

Conventional



dc + ac signal

Novel Method



Voltage Calibrator
/
ac voltage generator

Novel Method characteristics:

Uncertainty improvement on the measurand
The info about dc is still available
No modification to the signal in frequency
No phase displacement due to the presence of a ac filter
Can be applied for on-field measurement

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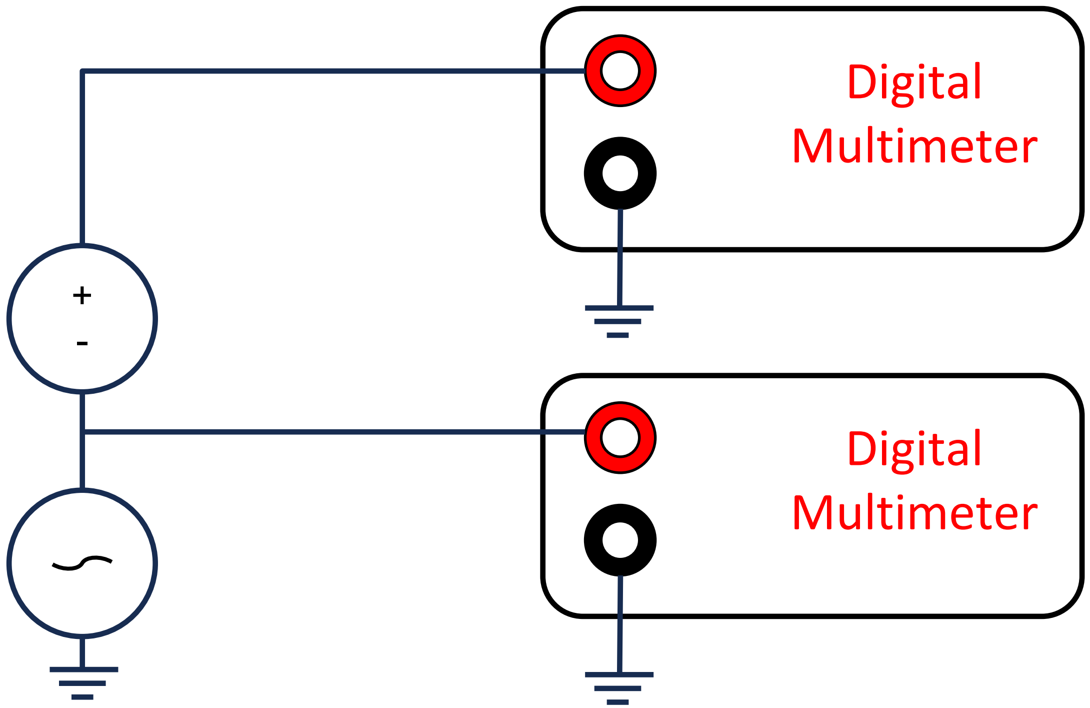
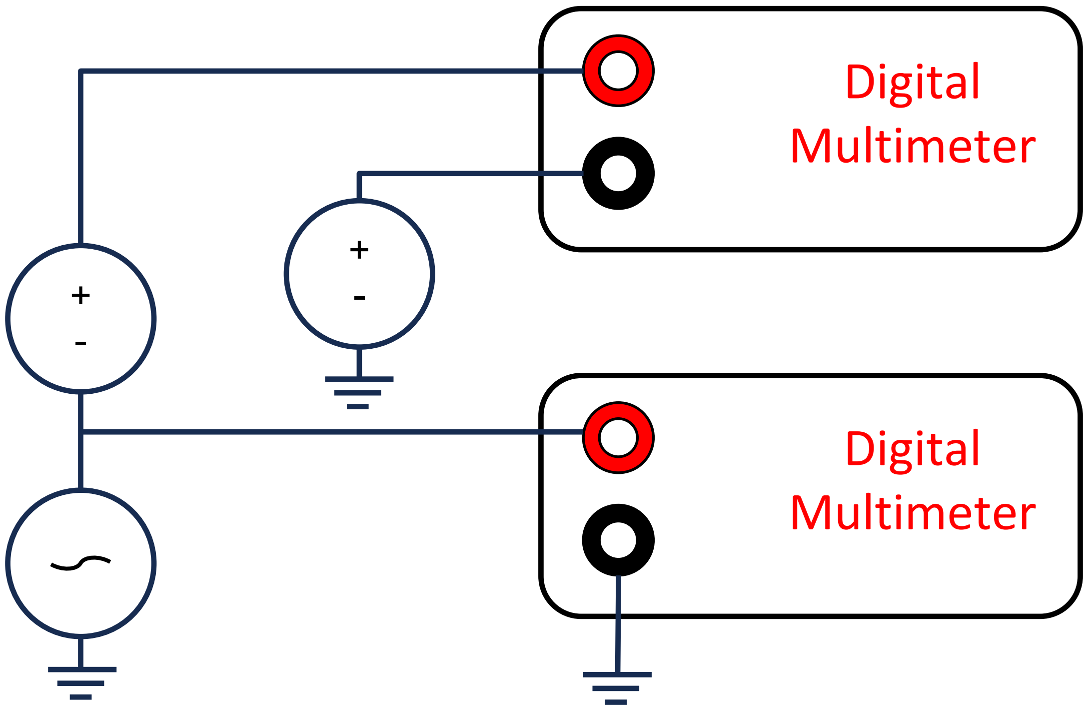
Validation of the methodology

STEP I



STEP II



DC Grids

NI 5433

2 x FLUKE 5730A

KEYSIGHT 3458A

FLUKE 8588A

Experimental result: Ratio error and Uncertainty Evaluation

$$\varepsilon = \frac{V_{DUT} - V_{REF}}{V_{REF}} \quad U_c(\varepsilon) = k \cdot \sqrt{c_1^2 u_A^2(V_{R_{REF}}) + c_2^2 u_A^2(V_{R_{DUT}}) + c_3^2 u_B^2(V_{REF}) + c_4^2 u_B^2(V_{DUT}) + c_5^2 u_R^2(V_{DUT})}$$

$V_{DC} = 50\ V, V_{AC} = 1\ V\ @\ 300\ Hz$, Range 100 V

Method	ε [%]	u_A [ppm]	$u_B(V_{REF})$ [ppm]	$u_B(V_{DUT})$ [ppm]	u_r [ppm]	U_c [%]
Conventional	0.010	11	55	1381	220	0.280
Novel	-0.020	4	55	45	0	0.028

$V_{DC} = 200\ V, V_{AC} = 1\ V\ @\ 300\ Hz$, Range 1000 V

Method	ε [%]	u_A [ppm]	$u_B(V_{REF})$ [ppm]	$u_B(V_{DUT})$ [ppm]	u_r [ppm]	U_c [%]
Conventional	-0.017	75	55	13531	2202	2.74
Novel	-0.014	4	55	45	0	0.028

Traceability for AC Ripple Over DC Current

NEED

- Measurements are crucial to quantify energy and evaluate efficiency, helping designers and final customers make the best choices, and it is also essential to monitor the DC Power Quality (PQ).
  How can we calibrate sensors in these harsh conditions?
- What we need is a traceable reference systems able to evaluate the performance of measuring systems in operating conditions characterized by DC with AC components (up to hundreds of kHz).

SOLUTION

A methodology to calibrate high-current measuring systems experiencing DC with AC ripple **providing the metrological traceability** for this combined signal.

Traceability is provided for DC and AC signal separately

Metrological traceability is a property of a measurement result by which that result is related to specified reference standards, not to institutions.
(National Institute of Standards and Technology)

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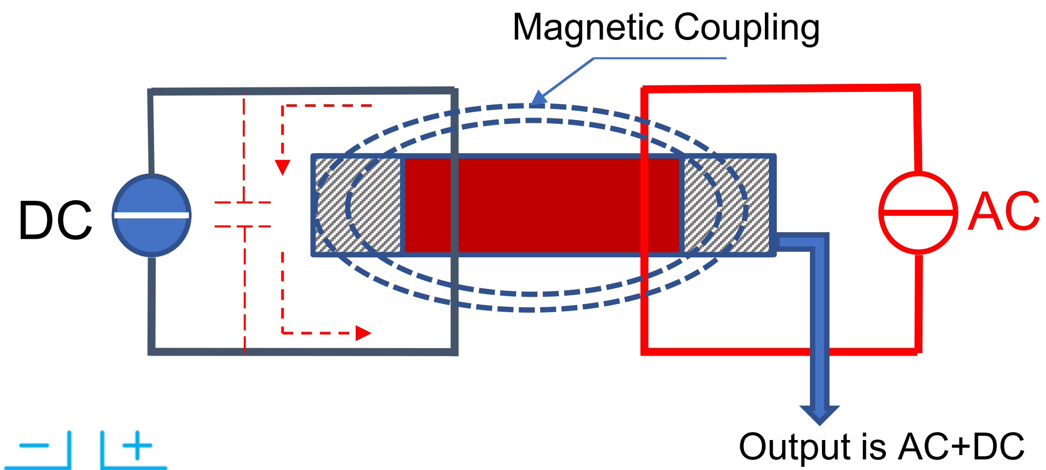
Two different solutions

Two-step approach

1. To calibrate a windowed DCCT by two different circuit, one for DC and the other for AC
2. To use it as reference in the calibration of the DUT



Limited resolution degrades the accuracy of AC determination

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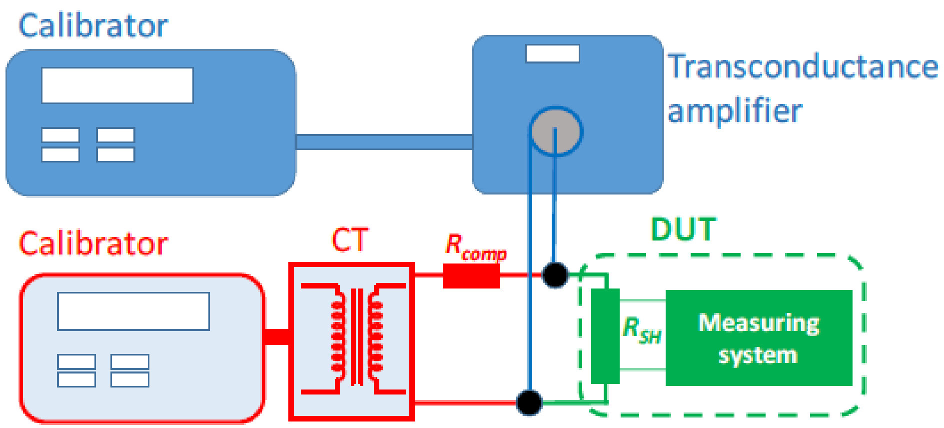
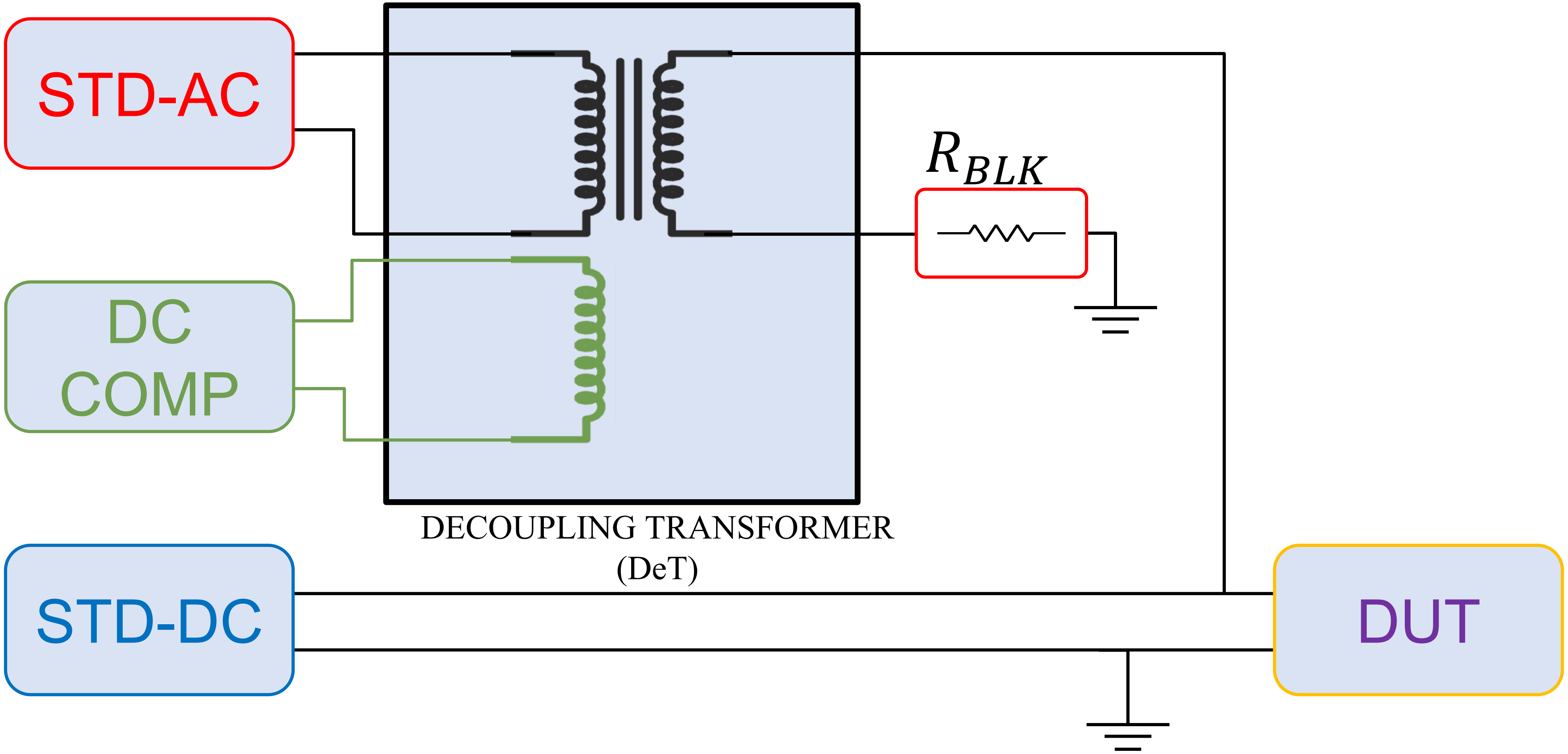
Single-step approach

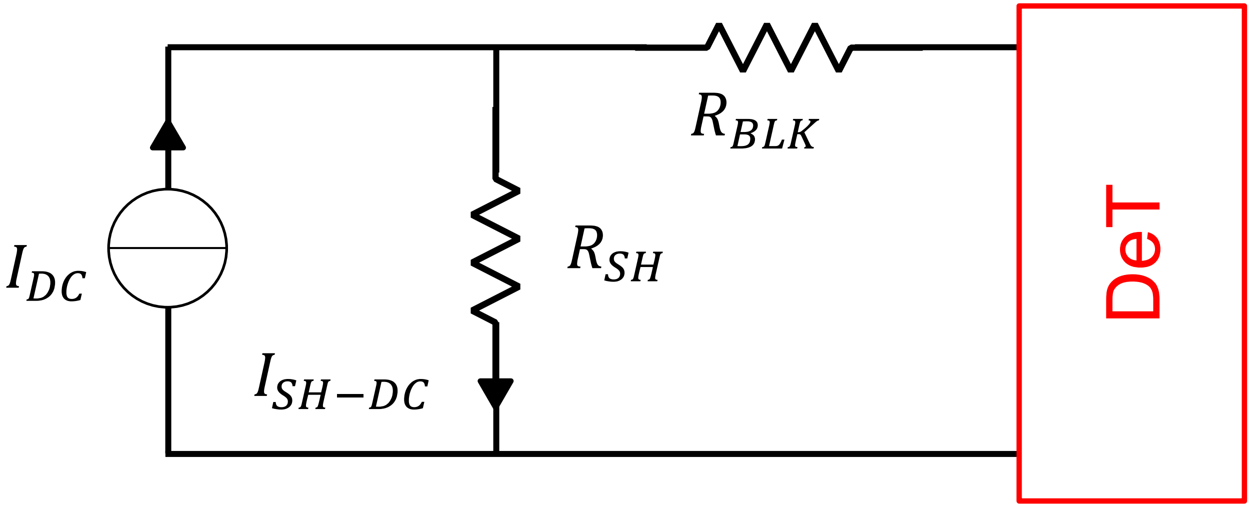


Blue: DC (constant) circuit
Red: AC circuit
Green: mixed

Proposed approach: ALFO



Systematic Error Affecting the dc component



$$I_{SH-dc} = I_{DC} \cdot k_{dc}$$

$$k_{dc} = \frac{1}{\left(1 + \frac{R_{SH}}{R_{BLK}}\right)}$$

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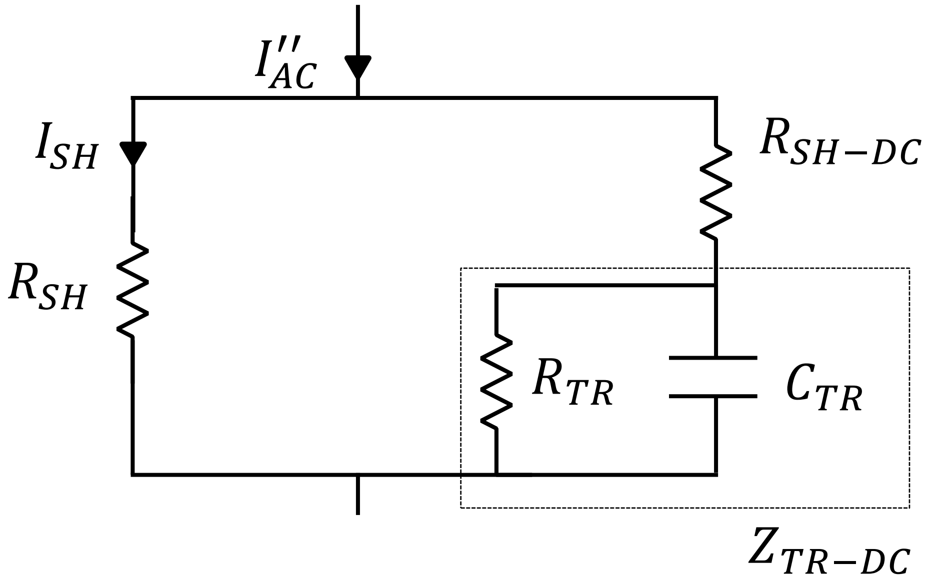
Systematic Error Affecting the ac component



$$I_{SH} = I''_{AC} \cdot k_{TR}$$

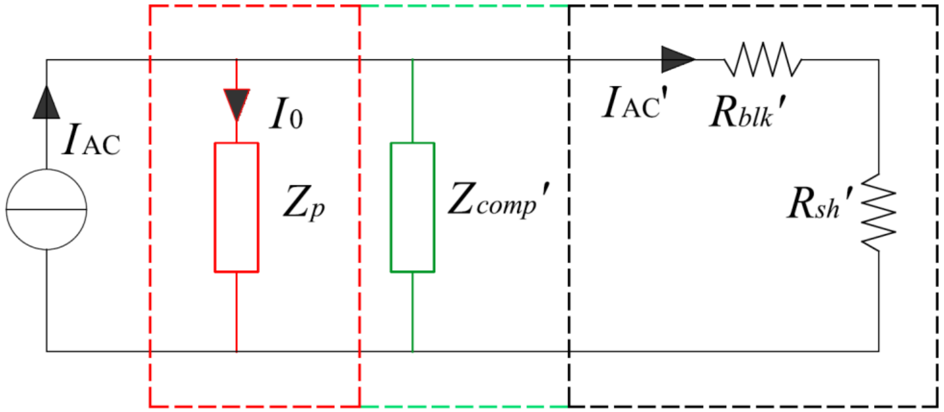
$$k_{TR} = \frac{Z_{TR-dc} + R_{SH\_DC}}{(Z_{TR-dc} + R_{SH-DC} + R_{SH})}$$

Systematic Error Affecting the ac component

The CT injector: effects of the CT impedance

The AC current is provided to DUT by an iron-core CT.
Considering $t = \frac{N_1}{N_2}$ N_1 and N_2 are the primary and secondary turn numbers

$$\overline{k_{DeT}} = \frac{\overline{I_{AC}}}{\overline{I''_{AC}}} = \frac{\overline{I_{AC}}}{\overline{I'_{AC} \cdot t}}$$



Parameters of the CT archetype

N_3	10
N_2	30
N_1	20
t_{rated}	0.667
R_{load}	1.02 Ω
Iron section [mm²]	120

$t_{rated} < 1$ - advantages:
- the effect of R_{load} to the ratio error is lower
- the voltage at primary is lower

The number of turns, thus the turn ratio is selected according to design constraints:
- Frequency badwith
- Voltage compliance of the AC transconductance amplifier

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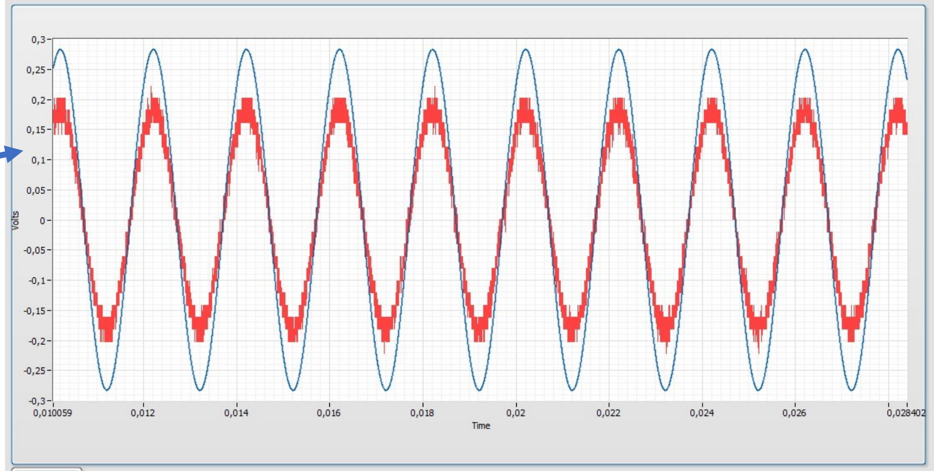
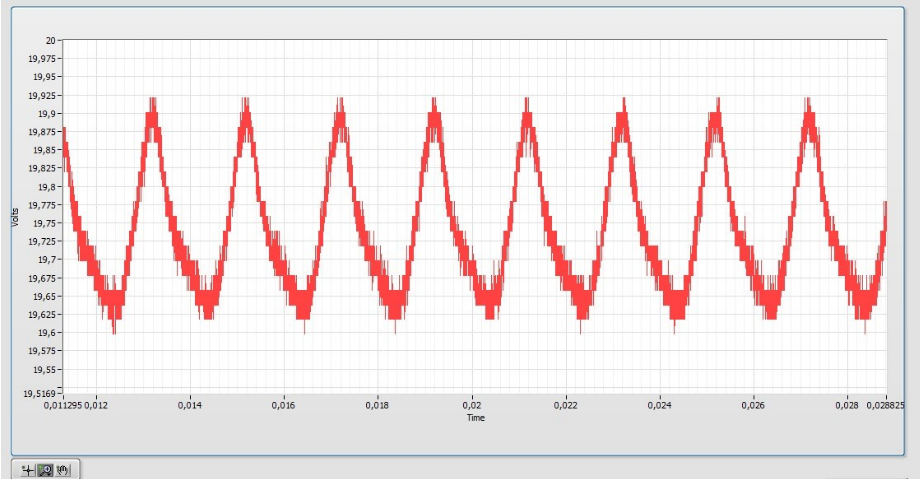
Preliminary Experimental results

***f* = 500 Hz**			
	$I_{DC\text{-}REF}$ = 0.0 A	$I_{DC\text{-}REF}$ = 19.74 A	$I_{DC\text{-}REF}$ = 19.74 A
$I_{AC\text{-}REF}$	200 mA	200 mA	200 mA
I_{AC}	199.3 mA	123 mA	199.3 mA
$I_{DC\text{-}COMP}$	0.0 A	0.0 A	0.8 A
$\|\varepsilon\|$ *(%)*	0.35	38.5	0.35





Uncertainty Budget

Sources	u_r @ 300 Hz (10^{-6})	u_r @ 1 kHz (10^{-6})	u_r @ 100 kHz (10^{-6})	u_r @ 150 kHz (10^{-6})
k_{acq} $(type\ B)$	30	30	50	50
R_{AC} $(type\ B)$	13	14	16	-*
k_{DeT} $(type\ B)$	23	21	34	130
k_{TR} $(type\ B)$	160	160	160	160
V_{AC} $(type\ A)$	10	10	18	20
u_C	165	165	173	214
U_C $(k = 2)$	330	330	346	428

$*$ R_{AC} uncertainty @150 kHz is undefined
Normal distribution functions are adopted for all the uncertainty contributions

D. Giordano, A. D. Femine, D. Gallo and D. Signorino, **"Traceability for AC Ripple Over DC Current"** in IEEE Transactions on Instrumentation and Measurement.

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Conclusions

- A novel method for the accurate measure small ripple superposed to DC signals. Instead of relying on the digitizer coupling mode which could introduce high-pass filtering effects, the proposed method is based on an acquisition system operating in differential mode.

- The preliminary performance characterization shows a significant reduction in the expanded uncertainty and confirms the potential of the proposed method

- A facility for calibration of measuring systems of composite dc with ac ripple current, traceable to Italian national standards, has been developed and characterized.

- The developed setup, named ALFO, allows the calibration, with rated current up to 100 A with ac current up to 1% of the dc and with a frequency range from 300 Hz to 150 kHz.