TECHNICAL CHARACTERISTICS OF LPITs FOR RGDM/RGDAT

Revision	Data	List of modifications
Rev. 0	August 2018	First emission
Rev. 1	February 2019	Updated the rated secondary voltage and the secondary voltage noise level for current sensors, updated the integration tests paragraph. Updated input impedance part. Updated calibration factor part. Updated C2 capacity part.
Rev. 2	December 2019	Updated C2 capacity range. Updated current and voltage sensors shields. Added ATS (Automatic Test System) according to GSTX001.

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SCOPE

To describe common technical characteristics of Low Power Instrument Transformers to be interfaced with RGDM and RGDAT devices.

REFERENCE DOCUMENTS

IEC 61869-10 (Additional Requirements for low-power passive current transformers)

IEC 61869-11 (Additional requirements for low-power passive voltage transformers)

APPLICATIONS

LPITs to be integrated in:

- Smart Termination (DJ5400, GSCC012)
- Metal-enclosed indoor switchgears (DY803, DY800, GSM001, DY900)
- Stand-alone LPITs
- Pole-mounted switchgears (GSCM002, GSCM003)

COMMON CHARACTERISTICS

- Passive LPITs
- derivative or proportional LPCT
- Combined connector for LPCT and LPVT, compliant with IEC 61869-6, table 603, type RJ45, with the PIN assignments provided by Table 1003 of IEC 61869-10 and the Table 1104 of IEC 61869-11. As an example, a table extracted from the Table 1003 of IEC 61869-10 is reported here:

RJ 45 connector for:	Pin:	1	2	3	4	5	6	7	8
Passive LPCT		S1	S2						
Passive LPVT								a	n
Reserved for TEDS				+			-		
Reserved for power supply					+	-			

If the signal cable length ≥ 10 m, the RJ45 connector can be compliant to the requirements valid for cables with length < 10 m, as reported in Table 601 of the IEC 61869-6.

RJ45 connector shall be industrial and rugged type (e.g. fully printed/die-cast connectors). Connectors with “tool free” crimp are not allowed.

On sensors side no connectors are allowed. In case of removable sensors, if a connector is needed, the solution must be approved by Enel and must ensure the ground connection of the sensor cable.

Voltage and current sensors must be shielded. Shields must be connected to ground on sensors side. Moreover manufacturer must implement solutions in order to satisfy all safety necessities imposed by standards.

- Use of Transducer Electronic Data Sheet – TEDS (for future developments)
- Following common ratings:

Rated frequency	50/60 Hz
highest voltage of equipment	36 kV
Rated power-frequency withstand voltage	70 kV
Rated lightning-impulse withstand voltage	170 kV
Temperature category	–5/50 indoor, plus the heating due to the rated current –30/50 outdoor
Signal cable type	Twisted pair, category ≥ CAT 6
Input circuit on the protection device side	• Balanced pure differential • Unbalanced differential • Single-ended without polarization, i.e. one terminal is connected to the electronic ground and/or to the grounding network of the substation • Single-ended with polarization, i.e. one terminal is connected to a polarization voltage and/or to a resistance that separates the terminal from the ground

LOW-POWER CURRENT TRANSFORMERS

Compliant with IEC 61869-10, with the following characteristics:

rated primary current (Ipr)	500 A

rated secondary voltage (Usr)	150 mV
Secondary voltage noise level at rated primary current	0,075 mV relative to the rated primary current (this noise is equivalent to 0,25 A at rated primary current) and -80 dB/√Hz relative to the rated primary current.
Rated short-time thermal current (Ith)	20 kA
Rated burden	According to IEC 61869-10, the rated burden is: 20 kΩ for the resistance, and 500 pF for the parallel capacitance. The tolerance of the resistive part of the impedance is ± 5 %, i.e. 20 kΩ ± 5 %. The accuracy of the sensor, connected with its cable to the protection device, shall be guaranteed also with in the following cases: Resistance: ≥ 20 kΩ (including tolerance) Capacitance: ≤ 500 pF
Maximum common-mode voltage output	≤ 10 mV (RMS, at highest voltage of equipment, rated frequency, and no primary current).
Frequency Response (for derivative sensors)	The derivative sensor frequency response shall be “high pass (HP) filter like”, with: • linear behavior (+20 dB/dec), until the HP cutoff frequency • HP cutoff frequency ≥ 800 kHz
Accuracy based on individual corrected transformation ratio and corrected phase offset, with ranges and resolutions given by IEC 61869-10	
Accuracy class	0,5 S / 5P 10000 A. Summarization in following tables:

Accuracy class	Ratio error ε, $\varepsilon_{cor\ I}$ ± %					± phase error at primary current shown below									
						Minutes					Centiradians				
	at current					at current					at current				
	0,01 I_{pr}	0,05 I_{pr}	0,2I_{pr}	I_{pr}	K_{pcr} x I_{pr}	0,01 I_{pr}	0,05 I_{pr}	0,2I_{pr}	I_{pr}	K_{pcr} x I_{pr}	0,01 I_{pr}	0,05 I_{pr}	0,2I_{pr}	I_{pr}	K_{pcr} x I_{pr}
0,5 S	1,5	0,75	0,5	0,5	0,5	90	45	30	30	30	2,7	1,35	0,9	0,9	0,9

Accuracy class	± Ratio error at rated primary current ε, $\varepsilon_{cor\ I}$ in %	± Phase error at rated primary current		Composite error at rated accuracy limit primary current ε_c, $\varepsilon_{cor\ I}$ in %	Maximum peak instantaneous error at rated primary short circuit current I_{psc} %
		Minutes	Centiradians		
5P	1	60	1,8	5	-

<table>
<tr><td>Deviations respect to the prototype</td><td>
<table>
<tr><th>Current (I/Ipr)</th><th>Deviation of ratio error respect to the prototype (%)</th><th>Deviation of phase displacement respect to the prototype (degree)</th></tr>
<tr><td>0,01</td><td>0,8</td><td>0,8</td></tr>
<tr><td>0,05</td><td>0,2</td><td>0,2</td></tr>
<tr><td>1</td><td>0,01</td><td>0,01</td></tr>
</table>
</td></tr>
<tr><td>Rated primary time constant for transient performance (Tpr) (not for derivative LPCT)</td><td>150 ms</td></tr>
<tr><td>Expected life</td><td>All of the characteristics shall be guaranteed in compliance to the expected life of the application in which the sensor is installed.</td></tr>
<tr><td>Voltage calibration coefficients

(ratio and phase-shift correction factors)</td><td>It is recommended to avoid voltage calibration coefficients in order to have plug and play sensors. In case of necessity of calibration coefficients, it must have these characteristics:
the voltage calibration coefficient (ratio correction factor) defined by the quantity “rated voltage transformation ratio / real voltage transformation ratio” shall be defined using 5 digits, and shall be in the range: 1 ± 0,0500.
the voltage calibration coefficient (phase-shift correction factor) shall be defined using 4 digits, and shall be in the range: ± 5°.</td></tr>
</table>

CURRENT SENSOR INTERNAL CIRCUIT

Inside the current sensor (linear or derivative), no additive components, passive and/or active, i.e. resistors etc., are allowed, in addition to the sensor device. Other solutions shall be approved by Enel: e.g. additive passive components may be exceptionally allowed by Enel only if the Manufacturer justify, with a technical report, the benefits obtained using these components.

The current sensor shall be completely insulated (floating) with respect to any part of the primary circuit (ground and primary wire).

The shield of the sensor cable shall be connected to the ground only on sensor side. In case of voltage and current integrate sensor, a common shield is present, for both current and voltage sensors wires. The ground connection must be solid and guaranteed.

Moreover, all of the current sensors shields, shall be connected to the ground inside of the sensor. It is never allowed to use the ground eventually taken from the protection device for grounding sensor and/or cable shields.

CURRENT SENSOR OUTPUT SIGNAL

The current sensor shall be completely insulated (floating) with respect to any part of the primary circuit (ground and primary wire), so the output information is a differential-mode voltage $v_{IL+,IL-}$, as reported in Fig. 1; this voltage shall be proportional to the primary current (in case of linear sensor) or to the derivative of the primary current (in case of derivative sensor).

Referring to Fig. 1, voltages $v_{IL+,G}$ and $v_{IL-,G}$ can be present, e.g. due to a non-perfect and/or non homogeneous sensor shield (capacitive and/or inductive coupling). These voltages, creates a common-mode voltage that can create problems to the protection device.

For the correct operation of the protection system, it is mandatory that:

1. both open-circuit voltages $v_{IL+,G}$ and $v_{IL-,G}$, shall be ≤ 10 mV (RMS) measured when the primary circuit is supply with the highest voltage of equipment, at rated frequency, but without any current (no load test).
2. both open-circuit voltages $v_{IL+,G}$ and $v_{IL-,G}$, shall be "high source impedance signal type". Practically, this means that voltages $v_{IL+,G}$ and $v_{IL-,G}$ shall go to zero when a resistive pull-down load (value: 15 kΩ ≤ $R_{pull\text{-}down}$ ≤ 100 kΩ) is connected between one and/or both wire of the current sensor (IL+ and/or IL-) and the ground. The same behavior shall occur when a balanced pull-down load is connected to the current sensor terminals, i.e. a load realized with a couple or two identical resistors (value: 15 kΩ ≤ $R_{pull\text{-}down}$ ≤ 100 kΩ) connected between both sensor wires and the ground.
3. voltages $v_{IL+,G}$ and $v_{IL-,G}$, shall have no effect on differential-mode voltage $v_{IL+,IL-}$. This shall be valid in any regime (any steady state and any transient – e.g. during any kind of fault). This shall be valid for any type of input circuit of the protection device listed in "Input circuit on the protection device side".
4. In any regime (any steady state and any transient), and for any type of input circuit of the protection device listed in "Input circuit on the protection device side", the differential voltage $v_{IL+,IL-}$ shall not be influenced by spurious transient that can be generated, for example, from unwanted coupling with other part of the network, and/or from EMC issues.

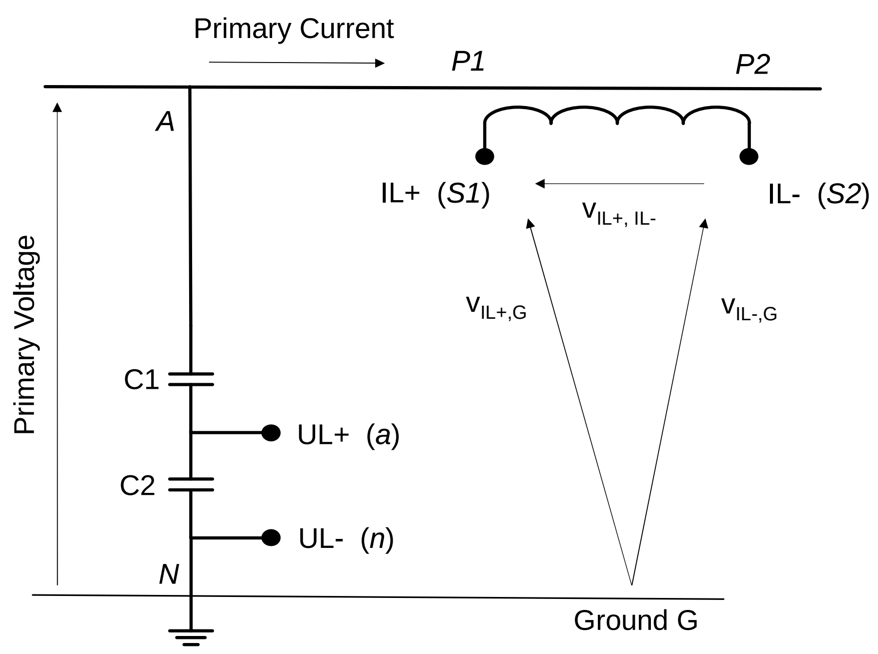

Fig. 1. General schema of an integrated low power voltage-current sensor.

CURRENT SENSOR TESTING

The LPCT shall be tested according to Table 10 of IEC 61869-10, with the following addition: the accuracy routine tests shall also include the verification of deviation requirements.

Moreover, in addition, the following mandatory tests shall be performed.

1. Common-mode voltage and effect on the differential voltage test, in open-circuit condition

considering the schema of Fig. 1, the sensor shall be supply at the highest voltage of equipment, rated frequency, without any current (i.e., no load) and without any burden and pull-down load. In these conditions, both voltages $v_{IL+,G}$ and $v_{IL-,G}$ shall be ≤ 10 mV (RMS). The verification measurement shall be done with a "thru RMS" voltmeter. The voltmeter input impedance shall have these characteristics: R ≥ 10 MΩ, C ≤ 100 pF. In the same condition, with the same instrument, the voltage $v_{IL+,IL-}$ shall be verified. The result shall be $v_{IL+,IL-}$ = 0.

2. Common-mode voltage and effect on the differential voltage test, in pull-down condition

The previous tests, with the same supply conditions, shall be performed with a single pull-down resistance (value: 15 kΩ ≤ $R_{pull-down}$ ≤ 100 kΩ) and with a balanced pull-down load (value: 15 kΩ ≤ $R_{pull-down}$ ≤ 100 kΩ), but without any protection device connected. Measuring voltages with the same voltmeter of the previous test, the result shall be: $v_{IL+,G}$ and $v_{IL-,G}$ equal to zero, and also $v_{IL+,IL-}$ equal to zero.

3. Frequency response tests

The Manufacturer shall draw a report that contains the frequency response test. The report shall contains: the Bode diagram of the frequency response, a table that summarizes the frequency response parameter (gain, slope, cutoff frequency, …). In case of resonances, these phenomena shall me underlined and it is necessary an explanation of the origin of the phenomena shall be declared and minimized.

LOW-POWER VOLTAGE TRANSFORMERS

Compliant with IEC 61869-11, with the following characteristics:

Range of Rated primary voltages Upr	6/√3 ÷ 34,5/√3 kV
rated transformation ratio	10 000/1 V/V
Secondary voltage noise level at rated primary voltage	3 mV @10 000 V primary voltage (this noise is equivalent to 30 V on primary side)
Rated voltage factor (Ku)	1,9 for 8 h
Rated burden	According to IEC 61869-11, the rated burden is: 2 MΩ for the resistance, and 50 pF for the parallel capacitance. The tolerance of the resistive part of the impedance is ± 5 %, i.e. 2 MΩ ± 5 % The accuracy of the sensor, connected with its cable to the protection device, shall be guaranteed also with in the following cases: Resistance: ≥ 2 MΩ (including tolerance) Capacitance: ≤ 50 pF
Capacity C2 range (see Fig. 1**)**	130 nF ≤ C2 ≤ 350 nF
Accuracy based on individual corrected transformation ratio and corrected phase offset, with ranges and resolutions given by IEC 61869-11	
Accuracy class	1P. Summarization in following tables:

Accuracy class	Ratio error ε, $\varepsilon_{cor\ U}$ ± % at voltage (% of rated)					Phase error φ_e, $\varphi_{cor\ \varphi o}$ ± minutes at voltage (% of rated)					Phase error φ_e, $\varphi_{cor\ \varphi o}$ ± centiradiants at voltage (% of rated)				
	2	20	80	100	F_v x100	2	20	80	100	F_v x100	2	20	80	100	F_v x100
1P	4	2	1	1	1	160	80	40	40	40	4,8	2,4	1,2	1,2	1,2

Deviations respect to the prototype	0,1 (both for ratio (0,1%) and for phase displacement (0,1°)), at all verification points of the accuracy class
Expected life	All of the characteristics shall be guaranteed in compliance to the expected life of the application in which the sensor is installed.
Current calibration coefficients **(ratio and phase-shift correction factors)**	It is recommended to avoid current calibration coefficients in order to have plug and play sensors. In case of necessity of calibration coefficients, it must have these characteristics: • the current calibration coefficient (ratio correction factor) defined by the quantity “rated current transformation ratio / real current transformation ratio” shall be defined using 5 digits, and shall be in the range: 1 ± 0,0500. • the current calibration coefficient (phase-shift correction factor) shall be defined using 4 digits, and shall be in the range: ± 5°.

VOLTAGE SENSOR INTERNAL CIRCUIT

Inside the voltage sensor, an high-accuracy capacitive divider is present. No other additive components, passive and/or active, i.e. resistors etc., are allowed. Other solutions shall be approved by Enel: e.g. additive passive components may be exceptionally allowed by Enel only if the Manufacturer justify, with a technical report, the benefits obtained using these components.

The shield of the sensor cable shall be connected to the ground only inside the sensor. In case of voltage and current integrate sensor, a common shield is present, for both current and voltage sensors wires.

Moreover, all of the voltage sensors shields, shall be connected to the ground inside of the sensor. It is never allowed to use the ground eventually taken from the protection device for grounding sensor and/or cable shields. Also the ground point of the capacitive divider shall be connected to the ground only inside the sensor. The ground eventually taken from the protection device cannot be used to ground the capacitive divider.

VOLTAGE SENSOR TESTING

The LPVT shall be tested according to Table 10 of IEC 61869-11, with the following addition: the accuracy routine tests shall also include the verification of deviation requirements.

DESIGN DOCUMENTATION

The ENEL technical organization unit in charge of the Technical Conformity Assessment will supervise the technical documentation and the execution of the tests required to receive the "Statement of Conformity", according to GSCG002 prescriptions.
All the technical documentation required during that process shall be in English or in the local language of ENEL technical organization unit in charge of the TCA.
The TCA documents that shall be delivered include:

- Type A documentation (Not confidential documents used for product manufacturing and management from which it is possible to verify the product conformity to all technical specification requirements, directly or indirectly).
- Type B documentation (Confidential documents used for product manufacturing and management where all product project details are described, in order to uniquely identify the product object of the TCA).

This type of documentation must be delivered only to the ENEL technical organization unit in charge of the TCA dossier (Set of final documents delivered by the Supplier for the TCA).The supplier shall provide the TCA Dossier on digital support.

The full design of sensors must be contained in the Type B documentation. As example, information to be listed in Type B documentation are:

- component layout
- voltage sensor assembly layout
- current sensor assembly layout
- type of components used in voltage sensor
- type of components used in current sensor
- electrical diagrams

INTEGRATION TESTS

Enel will perform integrations tests in its laboratories to verify correct operation of the whole system, i.e. sensors connected to the RGDAT/RGDM protection devices. This shall be considered for both current and voltage sensors.

As example, tests that can be performed are:

1. Accuracy level, with particular reference to the measured zero-sequence (residual) current and voltage (see the dedicated paragraph)
2. Sensor impedance measurement
3. Transient response (e.g. real fault comtrades, step/dirac/ramp, etc. response)
4. Noise measurement
5. Harmonic response and accuracy level with harmonics
6. Common-mode voltage and effect on the differential voltage test, in any condition, also with a connected RGDAT/RGDM
7. Other tests that Enel considers necessary

RESIDUAL CURRENT AND RESIDUAL VOLTAGE MEASUREMENT

Test will performed using a device that is able to apply phase currents and voltages simultaneously, in order to verify the residual current (3io = ia + ib + ic) and the residual voltage (3vo = va + vb + vc). It is important to note that both 3io and 3vo are calculated by the RGDAT/RGDM protection device, that acquires three sensors. A schematic principle is reported in Fig. 2 and Fig. 3.

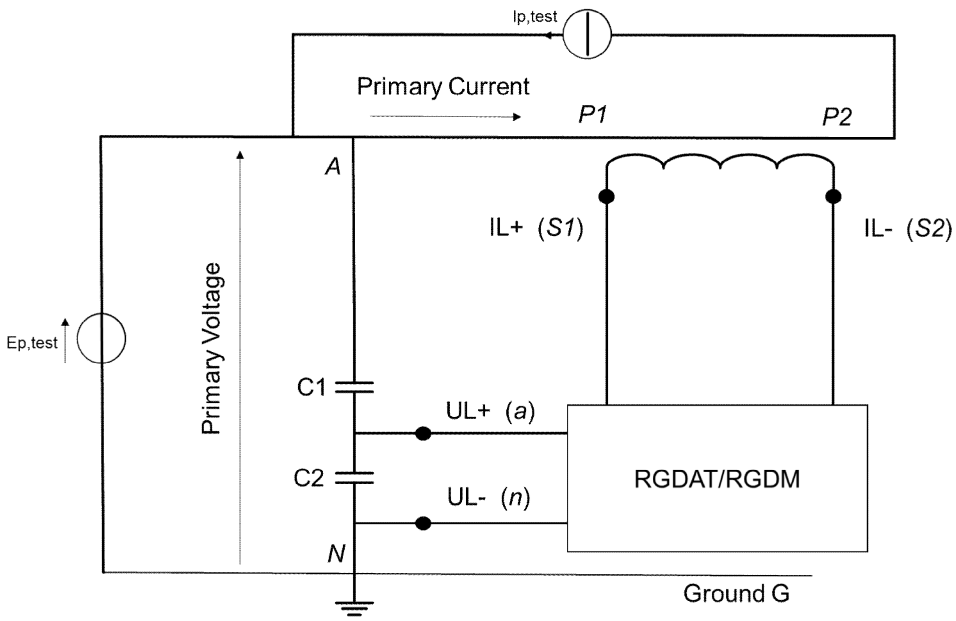

Fig. 2. Schematic principle (electric diagram) of one phase of the test setup for simultaneous current/voltage application.

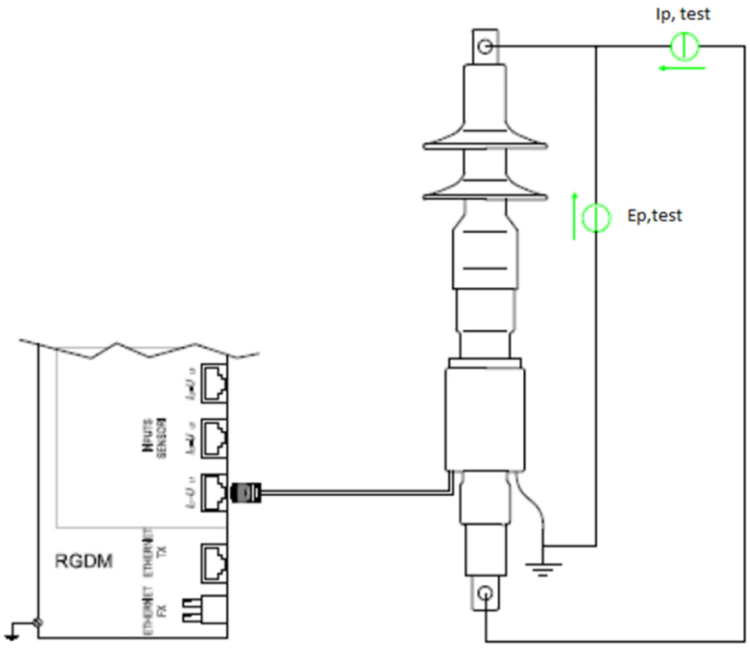

Fig. 3. Schematic principle of one phase of the test setup for simultaneous current/voltage application. This case represents a Smart Termination sensor testing.

RESIDUAL CURRENT MEASUREMENT

This test is necessary to verify the measurement of residual current. Test conditions are here reported:

a. Set-up: three-phase
b. Primary test voltage (Ep,test) = rated value, symmetrical positive sequence
c. Primary test current (Ip,test) = symmetrical positive sequence, magnitude divided in 6 steps:
    a. Step 1: 0,4 % of the rated primary current
    b. Step 2: 1 % of the rated primary current
    c. Step 3: 5 % of the rated primary current
    d. Step 4: 20 % of the rated primary current
    e. Step 5: 50 % of the rated primary current
    f. Step 6: 75 % of the rated primary current
    g. Step 7: 100 % of the rated primary current

For each step, following verifications will be performed:

a. RMS measured current, for each phase
b. Measured angle, with respect to the phase voltage Ep,test
c. RMS residual primary current (RMS of the 3io)

Each parameter must be compliant to the accuracy requested in this specification. For the RMS residual current (primary value), this value must be ≤ of the limit indicated in the following list, for each step:

a. Step 1 (0,4 % of the rated primary current): 3Io ≤ 0,05 A (primary current)
b. Step 2 (1 % of the rated primary current): 3Io ≤ 0,05 A (primary current)
c. Step 3 (5 % of the rated primary current): 3Io ≤ 0,05 A (primary current)
d. Step 4 (20 % of the rated primary current): 3Io ≤ 0,10 A (primary current)
e. Step 5 (50 % of the rated primary current): 3Io ≤ 0,25 A (primary current)
f. Step 6 (75 % of the rated primary current): 3Io ≤ 0,38 A (primary current)
g. Step 7 (100 % of the rated primary current) 3Io ≤ 0,5 A (primary current)

RESIDUAL VOLTAGE MEASUREMENT

This test is necessary to verify the measurement of residual voltage. Test conditions are here reported:

d. Set-up: three-phase
e. Primary test current (Ip,test) = 20% of the rated primary current, symmetrical positive sequence (the test can be repeated also with 100% of the rated primary current)
f. Primary test voltage (Ep,test) = symmetrical positive sequence, magnitude divided in 6 steps:
    a. Step 1: 0,4 % of the rated primary voltage
    b. Step 2: 1 % of the rated primary voltage
    c. Step 3: 5 % of the rated primary voltage
    d. Step 4: 20 % of the rated primary voltage
    e. Step 5: 50 % of the rated primary voltage
    f. Step 6: 75 % of the rated primary voltage
    g. Step 7: 100 % of the rated primary voltage

For each step, following verifications will be performed:

d. RMS measured current, for each phase
e. Measured angle, with respect to the phase voltage Ep,test
f. RMS measured residual primary voltage (RMS of the 3vo)

Each parameter must be compliant to the accuracy requested in this specification. For the RMS residual voltage (primary value), this value must be ≤ of the limit indicated in the following list, for each step:

h. Step 1 (0,4 % of the rated primary voltage): 3Vo ≤ 30 V (primary voltage)
i. Step 2 (1 % of the rated primary voltage): 3Vo ≤ 30 V (primary voltage)
j. Step 3 (5 % of the rated primary voltage): 3Vo ≤ 30 V (primary voltage)
k. Step 4 (20 % of the rated primary voltage): 3Vo ≤ 30 V (primary voltage)

l. Step 5 (50 % of the rated primary voltage): 3Vo ≤ 30 V (primary voltage)
m. Step 6 (75 % of the rated primary voltage): 3Vo ≤ 30 V (primary voltage)
n. Step 7 (100 % of the rated primary voltage): 3Vo ≤ 30 V (primary voltage)

MUTUAL INFLUENCE AND DEVIATION TEST BETWEEN PHASES

This test is necessary to verify mutual influence, for current measurement (phase and residual current), between phases. Moreover the same test is necessary to verify the current measurement error (phase and residual current) deviation between phases.

a. Primary test voltage (Ep,test) = rated value, symmetrical positive sequence
b. Current sensors connections: two in opposition, one without any current
c. Primary test current (Ip,test) = 1 %, 100 % of the primary rated current
d. Test repetition: all of the combination must be tested, rotating the two sensors in opposition and the one without any current (conventionally, the two sensors in opposition are indicated with the first two letters; the third letter, separated with a dash, indicates the sensor without any current). In this way all of the possible combination (AB-C, BC-A, CA-B) are be verified.

Fig. 4 indicates the schematic principle of the first test AB-C. It is important to note that voltage that feeds the two sensors in opposition can be the same (e.g. Ep,test in Fig. 4). Voltage that feeds the sensor without any current can be different in magnitude and in phase.

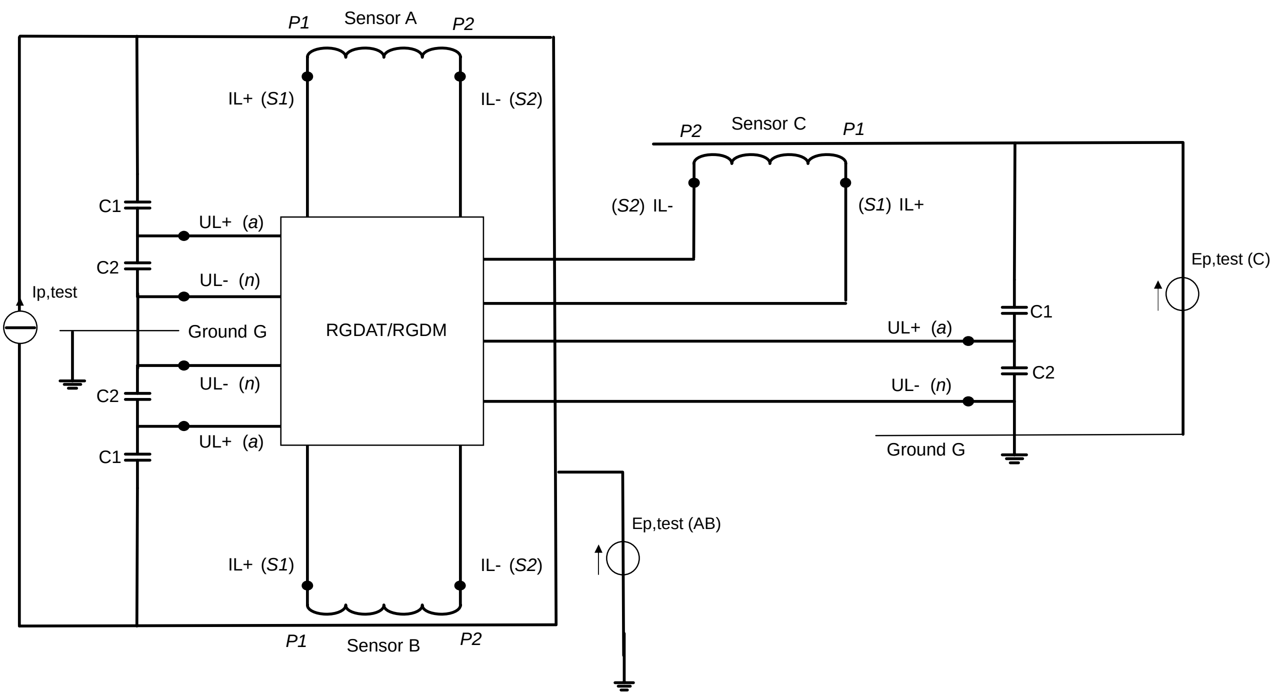

Fig. 4. Schematic principle (electric diagram) the set-up for the mutual influence and deviation test between phases. In the example, sensors A and B are in opposition, C is without any current.

For each test it is necessary to verify the difference between:

- RMS values of the measured current of the two terminals connected in opposition
- phase displacement of the measured current of the two terminals connected in opposition

both values must be compliant to values indicated in the following table:

Current (I/Ipr)	*difference between RMS values of the measured current of the two terminals connected in opposition (%)*	*difference between phase displacement of the measured current of the two terminals connected in opposition (degree)*
0,01	0,8	0,8
1	0,01	0,01

- Moreover, on the sensor connected without any current, the measured primary current must be ≤ of the 0,02 % of the primary rated current.

CHARACTERIZATION SYSTEM

- Calibration System (CS) goal is to verify the component compliancy to this specification. CS shall be compliant to the GSTX001

Each manufactured component must be tested on CS. CS must track the component ID and generate a test report that contain tests list, tests parameters and outputs. CS must execute tests on both voltage and current sensors. The CS shall generate calibration coefficients (ration and phase-shift), if present, and track it in the test report.

CHARACTERIZATION SYSTEM COMPOSITION

CS must be composed by:

- primary voltage and current generator, to supply sensors
- primary measure system, with accuracy class ≤ 0,1 %, to check primary feeding quantities
- secondary measure system, with accuracy class ≤ 0,1 %, to check secondary quantities

CHARACTERIZATION SYSTEM TESTS

CS must do all of the tests indicated in this specification, in order to verify:

- sensors polarity
- sensors accuracy
- calibration coefficients (magnitude and phase-shift)
- sensors output levels
- common mode signal on current sensor output (pull-down resistances are indicated in this specification)
    - common-mode voltage and effect on the differential voltage test, in open-circuit condition
    - common-mode voltage and effect on the differential voltage test, in pull-down condition

All results must be tracked in the test report.