Technical Information

Current sensors and transformers

When **energy** matters

socomec
Innovative Power Solutions

Sommaire

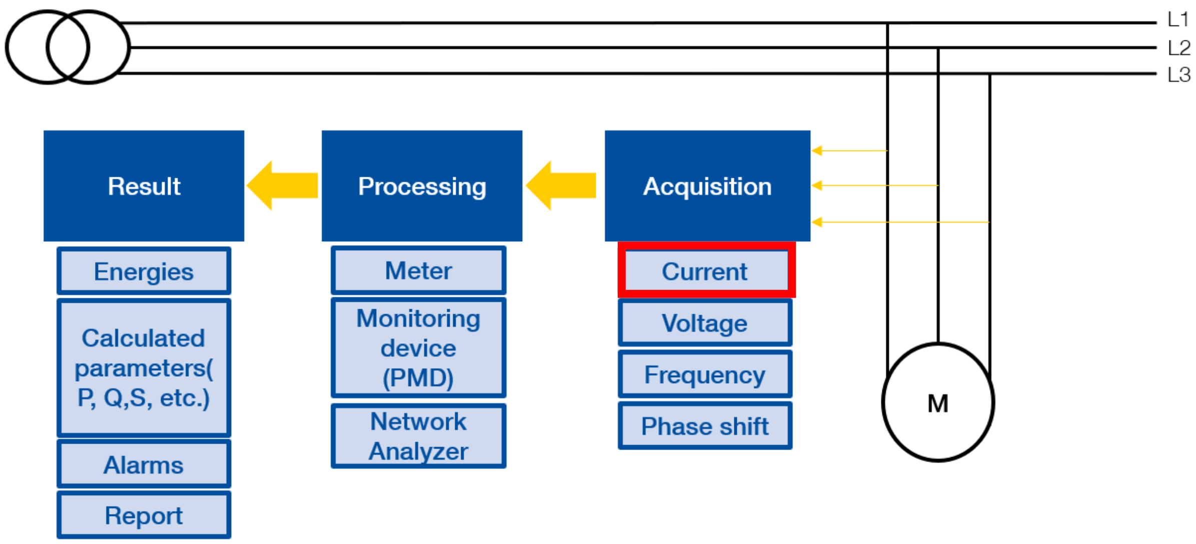
WHAT IS A CURRENT TRANSFORMER/SENSOR USED FOR?

The current transformer (CT), like the current sensor, is an essential part in the electrical energy measurement chains.

In fact, the current transformer transforms a primary current, generally too high for the measuring device, into a secondary current or voltage, of a lower value, compatible with the latter.

The current sensor, for its part, is a more generic name which encompasses all measurement technologies (Rogowski, Hall effect, Fluxgate, etc.). Like the CT, it is used to convert a primary current into a secondary signal that can be interpreted by the connected device.

In summary, the role of the transformer and the current sensor is to adapt the current measurement for measuring devices (meters, PMD, network analysers, etc.). This measurement is then used by the measurement units to calculate different electrical parameters (power, energy, harmonics, etc…).



Furthermore, current transformers also play a role in the protection of electrical networks and the safety of electrical installations (differential currents and protection measurement).

WHAT ARE THE DIFFERENT TYPES OF CURRENT TRANSFORMER/SENSOR

We can distinguish 4 types of current sensor:

Measurement current sensors and transformers

Their roles are to measure and lower the load current at the secondary level of an electrical circuit so that it can be easily interpreted by the measurement device.

Billing current sensors and transformers

These transformers are like measurement current transformers but require precision on a wide current range and extreme reliability linked to the use for billing.

Protection current sensors and transformers

In addition to measuring and lowering the load current at the secondary level, these transformers are capable of measuring current whose intensity can reach 5 to 30 times the nominal current. This type of phenomenon is called “short circuit”. Associated with a relay, the protective current transformer makes it possible to isolate the fault and avoid damage to an installation.

Differential current sensors and transformers

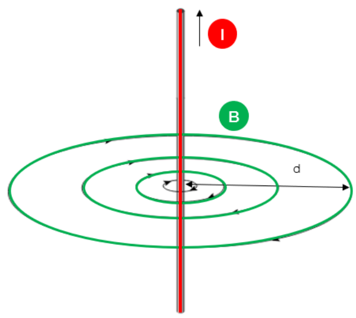
Under normal conditions, the vector sum of currents in a circuit must be zero. If this sum is not zero, this indicates a current leak in the network, which can present a danger to people and the installation (fire). Differential current transformers make it possible to check this condition and measure this so-called differential fault current. Associated with a relay, the differential current transformer helps protect people against indirect contact.

HOW A CURRENT TRANSFORMER WORKS?

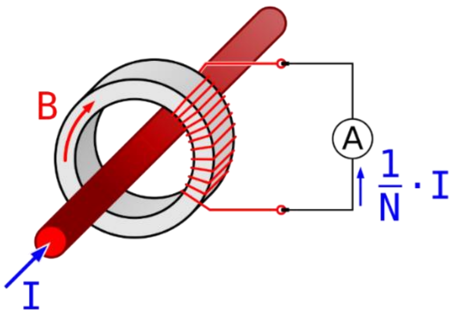
A current transformer makes it possible to measure the current flowing in a conductor by measuring the magnetic field emitted by it.

Indeed, when an electric current flows in a conductor, a magnetic field, proportional to this current, is induced. (Lenz-Faraday law).

To recover the current value from the magnetic field, ferromagnetic materials are used. The latter in fact, thanks to their high permeability, have the property of bending magnetic fields to better capture them.



$$B = \frac{\mu_0 I}{2\pi d} \Rightarrow B \Leftrightarrow I \text{ Proportionnel}$$



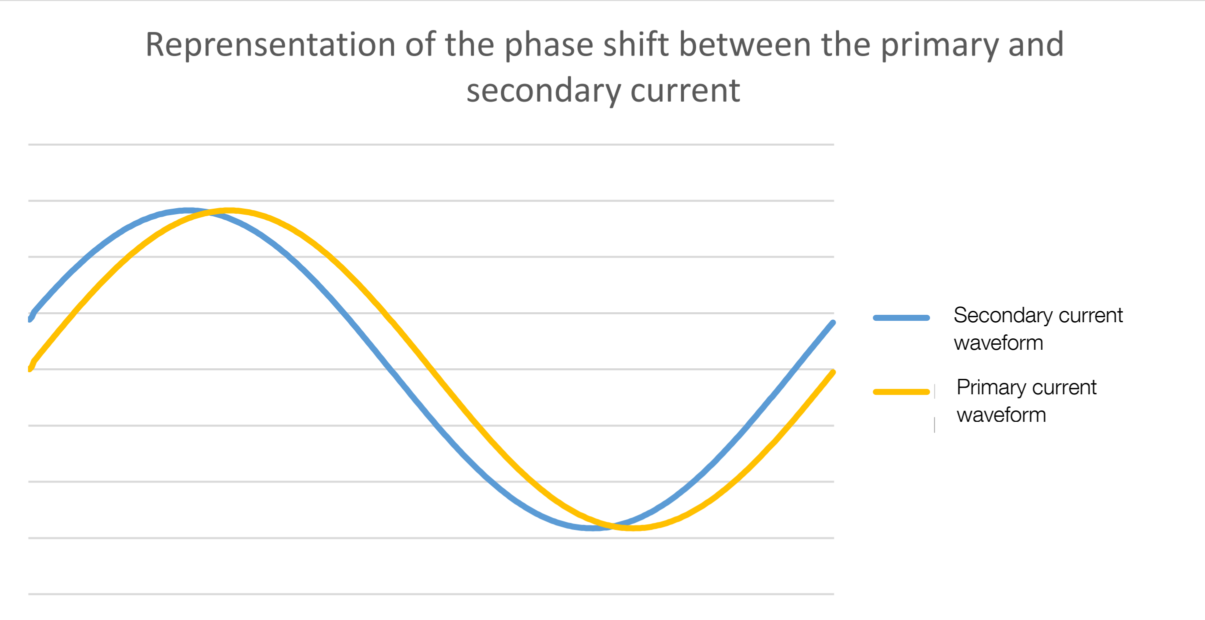
Consequently, by circulating the magnetic field in a core made of ferromagnetic materials we will be able to recover a proportional image of the primary current Ip across the secondary winding. The number of turns of the windings then conditions the transformation ratio and the value of the secondary current Is.

The choice of ferromagnetic material is crucial for the measurement performance of measurement, protection or differential current transformers.

However, some technologies, like Rogowski, do not use the properties of ferromagnetic materials.

Phase shift impact on measurement

The phase shift represents a time difference between the primary signal and the secondary signal of the CT. This phase shift is caused by the presence of inductive and capacitive elements in the circuit.

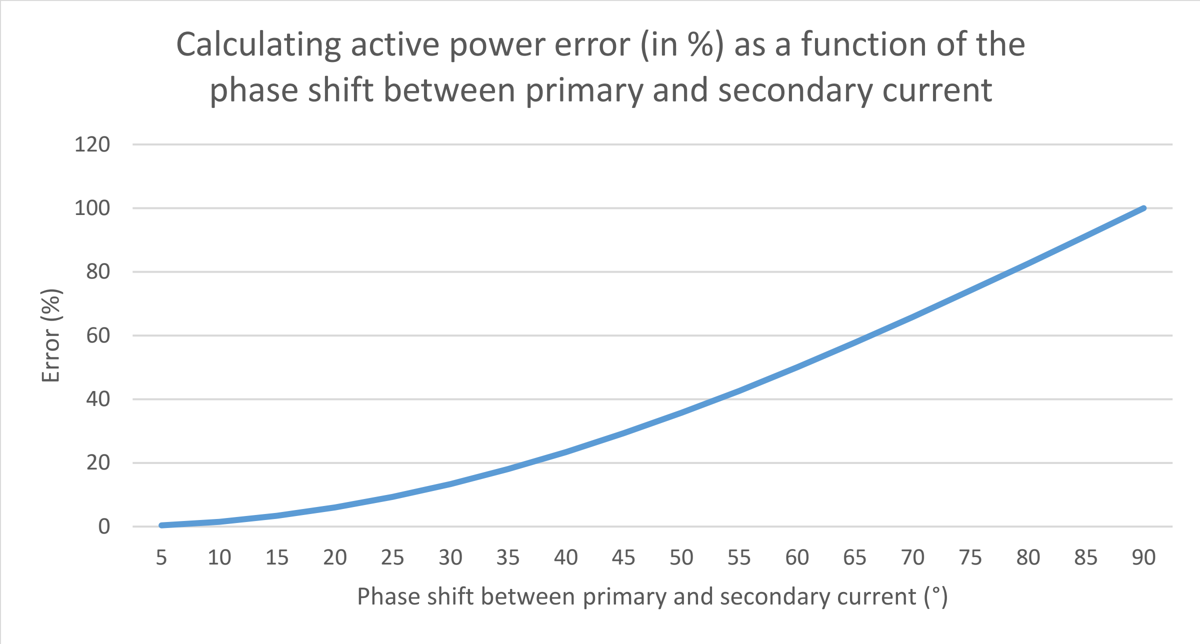


However, the active and reactive power calculated by the measuring unit depends directly on the phase shift because:

$P = V * I * \cos(\varphi)$, φ being the phase shift between the current and the voltage

$Q = V * I * \sin(\varphi)$, φ being the phase shift between the current and the voltage

The secondary current therefore provides an additional phase shift between the real current and the one measured by the control unit, which can increase the precision error for the active and reactive power.

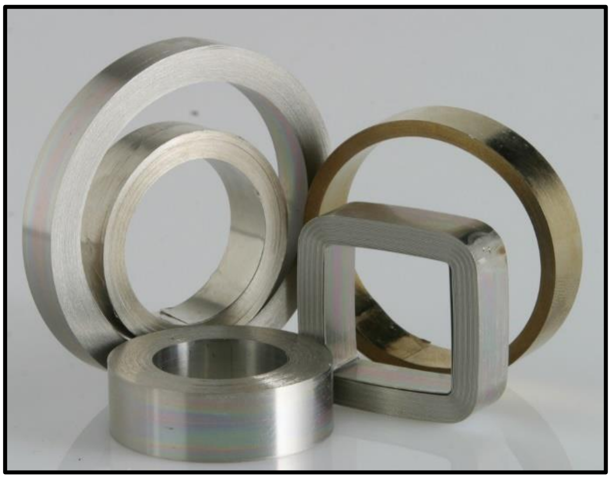


To limit the phase shift, the ferromagnetic material of the core must be of very good quality and extremely permeable.

THE ESSENTIAL QUALITY AND PERFORMANCE CRITERIA FOR A MAGNETIC CORE OF A CURRENT TRANSFORMER

Permeability

Permeability is one of the essential criteria for evaluating the quality of an alloy, because it determines its ability to interact with a magnetic field. The higher the permeability of a ferromagnetic material, the more effectively it influences magnetic flux lines, thereby improving the accuracy of current transformers. High permeability allows the transformer core to more effectively capture the magnetic fields created by current. At the same time, a larger magnetic core captures a larger volume of magnetic flux, which further enhances the accuracy of the measurement, since the current is proportional to these fields.



The maximum inductance (Bmax)

Maximum magnetic induction (Bmax) is the maximum magnetic flux density that the core can withstand before saturating.

If the core saturates, the transformer loses its linearity and its measurement performance becomes erratic, potentially leading to critical errors in sensitive applications such as power grid protection.

In practice, the maximum inductance is defined in such a way as to allow safe use, even in the event of temporary overload

The stability in temperature

Current transformers must operate in environments where temperature varies, sometimes significantly.

An increase in temperature can affect the magnetic properties of the core, winding resistances and even mechanical stability. This can cause performance drifts and reduce transformer life.

Modern magnetic alloys and advanced design techniques ensure low variation in electrical and magnetic characteristics over a wide temperature range. In addition, thermal insulators are essential to protect the windings and prevent damage linked to thermal cycles.

WHAT ARE THE DIFFERENT TECHNOLOGIES TO MEASURE CURRENT?

Ferromagnetic core current transformers and sensors

Current transformers with a ferromagnetic core are based on the principle explained above. They use a core made of ferromagnetic materials to capture the magnetic field created by the flow of current, called primary, in the conductor. A winding around the toroid then makes it possible to measure this current, called secondary, which is an image of the primary current and the number of winding turns.

In a perfect current transformer, we therefore have the following mathematical relationship:

$Np * Ip = Ns * Is$ with Np the number of primary windings turns, Ns the number of secondary windings turns and Ip and Is respectively the primary and secondary current

However, in reality, it must be considered that part of the primary current is used to magnetize the core and is therefore not transmitted to the secondary (magnetizing current), and part of the transmitted current is dissipated in the core (iron losses), causing errors in the measurement

The equation therefore becomes:

$$Np * Ip = Ns * Is + \boldsymbol{errors}$$

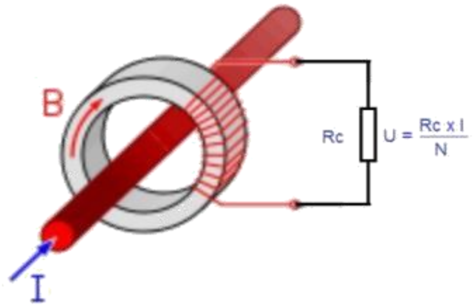
These phenomena have a direct impact on the accuracy of the current sensor. The quality and quantity of the ferromagnetic material makes it possible to limit these losses. Indeed, the higher the permeability of the ferromagnetic material, the more precise the current transformer. Likewise, the larger the section of the magnetic core, the more precise the current transformer.

There are 2 types of outputs for ferromagnetic core current sensors:

- Current output

- Voltage output

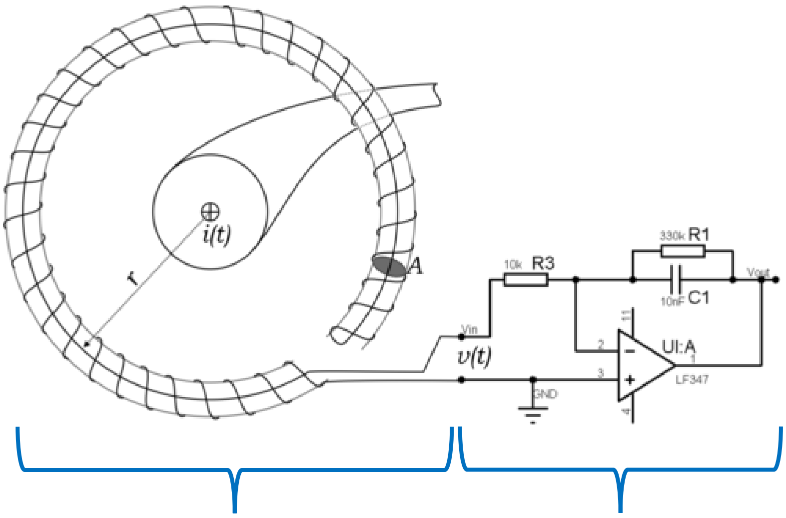
The voltage output is obtained by adding an RC resistor in the secondary circuit.



Rogowski current sensors

Rogowski current sensors do not use ferromagnetic materials to capture the induced magnetic field but are based on one of the principles of Faraday's law which states that any electric circuit crossed by a variable magnetic field induces a voltage which is equal to the derivative of this field. To simplify, a Rogowski sensor delivers a voltage equal to the derivative of the variable magnetic field induced by the flowing of a primary current in a conductor.

In most cases, Rogowski toroid are accompanied by an integrator. Without this integrator, the measured signal would be out of phase by 90 degrees and therefore difficult to interpret by the measuring units.



Current measurement

Correction of 90-degree phase shift by signal integration

The advantage of these current sensors is that they remain very flexible and space-saving due to their design. They are therefore very popular for retrofit applications. They also offer a wide measuring range since they do not saturate. (Absence of ferromagnetic materials)

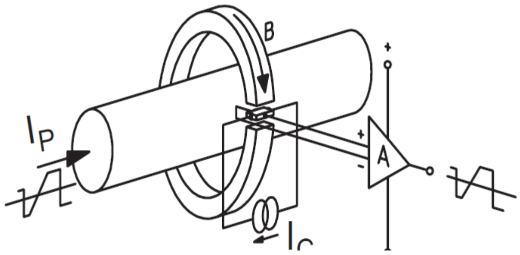
Hall effect current sensor

"Any electric current passing through a material immersed in a magnetic field generates a voltage perpendicular to the latter" Edwin Herbert Hall. Hall effect sensors use this measurement principle.

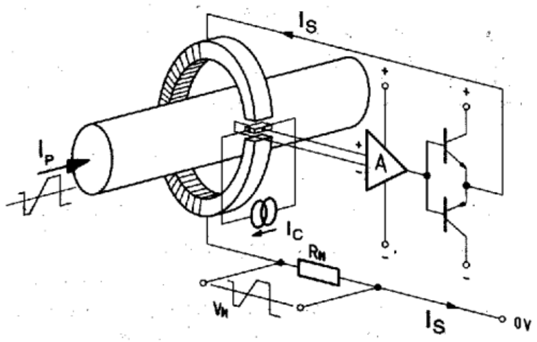
Here we use a ferromagnetic toroid to capture the magnetic field, which then passes through a Hall cell. This configuration generates a potential difference called "Hall Voltage", proportional to the magnetic field and therefore to the primary current

It exists 2 types of hall effect sensor :

- Open-loop Hall effect sensors. They directly measure the magnetic field generated by the electric current and produce a voltage proportional to this field. Their design is relatively simple.



- Closed-loop Hall effect sensors. They use a feedback system to compensate for variations in the magnetic field. They incorporate a magnetic core and continually adjust the detected field to maintain a constant measurement. This more complex approach ensures better sensor performance



The advantage of this type of technology is that it is possible to measure both AC and DC currents. However, they remain less accurate than Rogowski or ferromagnetic core current sensors, particularly for sensors operating in open loop. These sensors also require an external power supply to bias the Hall cell.

Note: Current sensors can be either open or closed. Opening sensors have the advantage of being easier to install, particularly on existing installations. However, they are less precise than closed sensors because of the presence of an air gap in the ferromagnetic torus.

WHAT ARE THE CHARACTERISTICS OF A CURRENT SENSOR?

Historically, the IEC 61869-2 standard is the reference standard for current sensors. This standard defines the different parameters which characterize transformers and current sensors.

However, this standard has recently evolved, and its field of application is closer to high voltage by omitting current sensors having a voltage output signal. As a result, the IEC 60688 standard came into existence. This standard incorporates the requirements of IEC 61869-2 while providing details on the impact of the driver's position on measurement accuracy.

Output signal

A current sensor delivers an output signal which is a proportional image of the measured primary current. This output signal is often of 2 types:

- A voltage signal, generally 100 or 333mV
- A current signal, generally 5 or 1A.

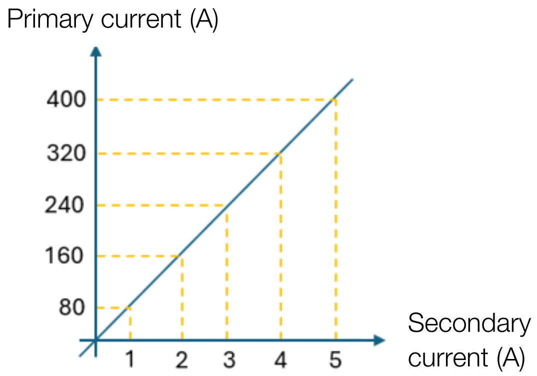
The advantage of a voltage output is that there is no Joule loss (heating due to the flowing of the current in the cable) during the transmission of the signal between the current transformer and the measuring unit. Consequently, for the same precision, we can reduce the size of the CT and not be limited by the distance of the cable. A voltage output also offers the advantage of being able to open the secondary circuit while under load, which is not the case with current transformers where a risk for people and equipment remains.

Rated primary current

It is the value of the primary current based on which the operating characteristics of a transformer are determined.

For example, a 500A/5A transformer will have a primary current of 500A and a secondary current of 5A. At 300A, the secondary current will be 3A, etc…

The rated primary current is commonly called the current sensor rating.



The accuracy

The IEC 60688 standard defines the term precision class whose performance in terms of error percentage and phase shift is specified in the following tables:

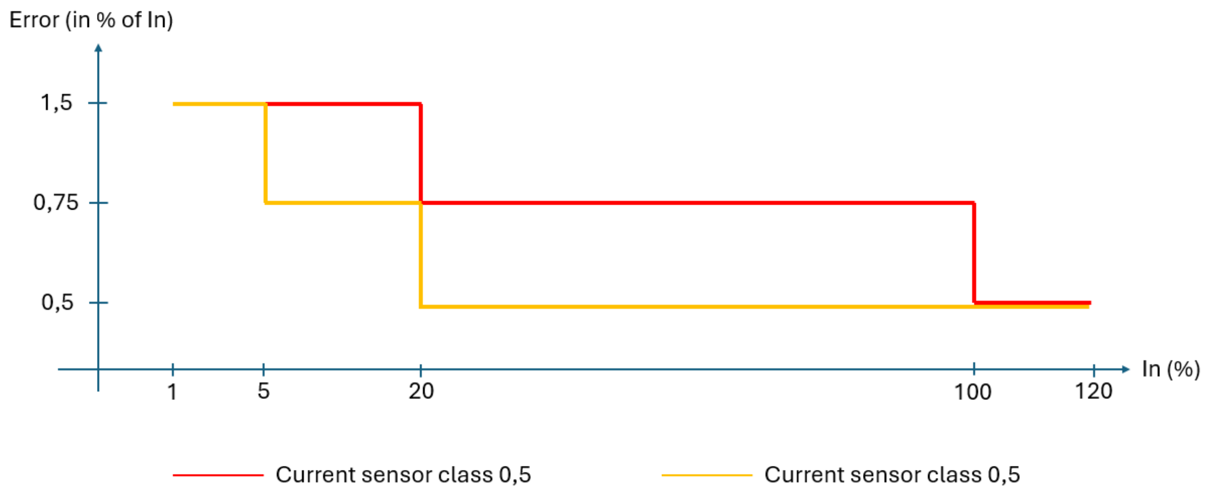
Accuracy class	Error in +/- % as a function of the percentage of the nominal current						
	0,20%	1%	5%	20%	50%	100%	120%
5					5		5
3					3		3
1			3	1,5		1	1

0,5			1,5	0,75		0,5	1
0,5s		1,5	0,75	0,5		0,5	0,5
0,2			0,75	0,35		0,2	0,2
0,2s		0,75	0,35	0,2		0,2	0,2
0,2smax	0,2					0,2	0,2
0,1			0,4	0,2		0,1	0,1

Accuracy class	Phase shift (in°) as a function of the percentage of the nominal current						
	0,20%	1%	5%	20%	50%	100%	120%
5							
3							
1			2	1,5		1	1
0,5			1,5	0,75		0,5	0,5
0,5s		1,5	0,75	0,5		0,5	0,5
0,2			0,5	0,25		0,167	0,167
0,2s		0,5	0,25	0,167		0,167	0,167
0,2smax	0,167					0,167	0,167
0,1			0,25	0,125		0,084	0,084

Generally speaking, the accuracy of the class is obtained at full scale, that is when the load current is equal to the nominal current of the current sensor. There is, however, an exception for 0.5s or 0.2s class sensors where maximum precision is obtained as soon as 20% of the sensor's nominal current is reached.

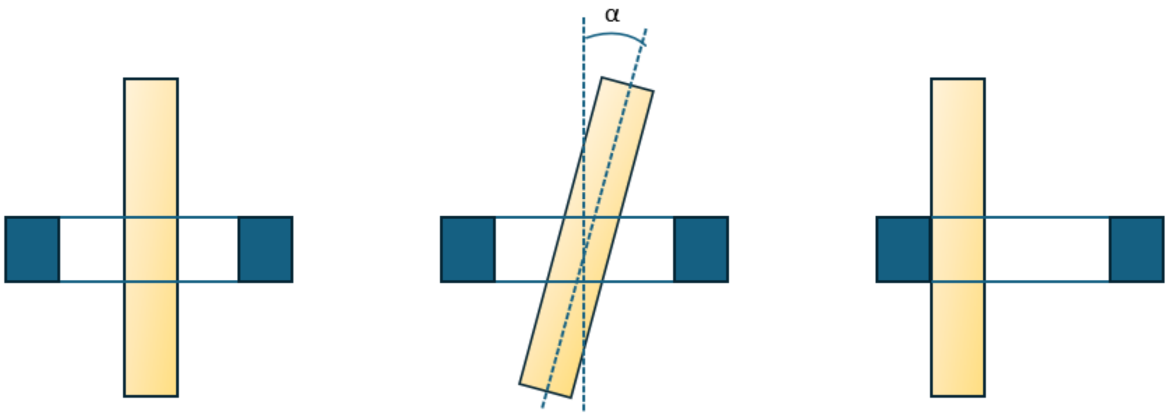
For comparison, a class 0.5 current sensor will have an accuracy of +/- 0.5% In between 100 and 120% of In, while a class 0.5s current sensor will have an accuracy of + /- 0.5% between 20 and 120% of In



Note: The 0.2smax accuracy class is a class specific to Socomec which is based on IEC 60688 and IEC 61869-2 while increasing performance significantly in amplitude and phase shift from very low primary currents.

IEC 60688 also defines classes regarding the influence of the positioning of the conductor in the transformer.

Extension of the accuracy class designation	Max position factor (Pf) up to which the accuracy class is guaranteed	Max angle (α) up to which the accuracy class is guaranteed
A1	0	0
A2	0,5	15°
A3	1	45°



A class 0.5 A2 current sensor will therefore have guaranteed accuracy as long as the conductor is centered and an angle of 15° is not exceeded.

The power

The power (in VA) of a current transformer defines the power that the transformer delivers at the secondary level. This characteristic only concerns current transformers. Indeed, given that the output signal is a current, there are losses due to the Joule effect and due to the consumption of the current inputs of the measuring units.

Losses are calculated as follows:

$$\boldsymbol{Losses = \frac{I^2 * 2}{S * 56} * L}$$

With :

- *I (A)*: Transformer secondary current (1 or 5)

- *S (mm²)*: Cross section of cable
- *L (m)*: Cable length between the CT and the measuring device.

It is therefore wise to size a current transformer with sufficient power to compensate for losses in order to respect the following equation:

$$\boldsymbol{P_{TC} > Pertes_{Joules} + Consommation_{PMD}}$$

Maximum operating voltage

This is the maximum permissible operating voltage. Beyond this limit, the conductor must be insulated to continue using the current sensor

Insulation voltage

This is the dielectric property of the sensor. The value is obtained through a test where a voltage higher than the maximum operating voltage is applied for a limited period according to normative recommendations. If a voltage higher than the insulation voltage is applied, a destructive breakdown of the insulators between the primary and the secondary, causing a risk for the equipment and people downstream may occur.

Intermittent overload

This is the ability of the current sensor to withstand high overload currents for a very short time. IEC 60688 determines the overload conditions to apply to the sensor:

- For a sensor with current output, a current equal to 20 x In over 1s is applied
- For a sensor with voltage output, a current equal to 10 x In over 1s is applied

Measurement category

IEC 60688 takes up the recommendations of IEC 61010 to define the measurement categories. Commonly called overvoltage category, these designate specific areas in an electrical installation.

CAT I: Measurements carried out on electronic devices (mobile phone, PC, etc.)

CAT II: Measurements carried out on circuits directly connected to the installation (domestic installation, power outlet, etc.)

CAT III: Measurements carried out in the building installation (Fixed load in industrial installations, industrial lighting, etc.)

CAT IV: Measurements carried out at the source of the installation (busbars, overhead lines, etc.)

The table below also shows the resistance to transient overvoltages depending on the voltage and the category of use.

Category	Phase-neutral voltage (AC or DC)	Max transient overload
CAT I	300	1,5 kV
	600	2,5 kV
	1000	4 kV
CAT II	300	2,5 kV
	600	4 kV
	1000	6 kV
CAT III	300	4 kV
	600	6 kV
	1000	8 kV
CAT IV	300	6 kV
	600	8 kV
	1000	12 kV

WHAT ARE THE MAIN CRITERIA FOR CHOOSING A CURRENT SENSOR?

Several criteria must be taken into account when choosing a current sensor:

- The type of output signal: To be chosen according to the characteristics of the current inputs of the measuring unit used
- The type of application: If it is a new installation, preferred closed toroids. On the other hand, if it is for a retrofit application, prefer split toroids or Rogowski to avoid operate the loads.
- Dimensions: If the space is cramped or reduced, the Rogowski toroids will be more suitable. The use of sensors with voltage output can also correspond to this need given that they are much smaller in terms of size compared to an equivalent current transformer.
- The Power: To be determined for current transformers depending on the cable section and the length between the current transformer and the measuring unit
- The accuracy class: If the error wants to be reduced as much as possible over a wide measuring range, prefer the use of sensors with a precision class of 0.5s or 0.2s

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