Understanding the 0-FLUCS technology and its advantages in Current and Power Measurement Applications

Introduction. Precision current measurements are needed in a wide range of fields of industrial or research applications. The growth of electrical-based system related to renewable energy, smart grids, EVs, battery energy storage and many more are requiring an accurate and precise measurement of current for power evaluation. While measuring voltage values can be done in many different ways and can be performed with high accuracy, low noise and high stability (in terms of temperature and time drifts), the measurement of current values is not always an easy task. Different technologies are available for current measurements but all of them present some advantages and some limitations.

Figure 1: *Logo of the 0-FLUCS Technology*

Measurements with **shunt resistors** have a reasonable linearity behaviour but they are not isolated from the electrical conductor to be measured and especially for large currents they have a high power dissipation and cannot be manufactured with a high temperature stability. **Hall effect** tranducers are isolated from the conductor to be measured but they don't have good linearity, low temperature dependence and precision. Standard **current transformers** have the big disadvantage of reading only AC currents so that DC measurements cannot be performed.

Working Principle. The 0-FLUCS (0-FLUx Current Sensor - **Figure 1**) technology is based on a DC Current Transformer – i.e. DCCT – principle and it represents the best solution in order to obtain maximum performances. The basic concept behind this sensor series that allows measuring both **DC and AC currents** with a large bandwidth, is briefly presented.

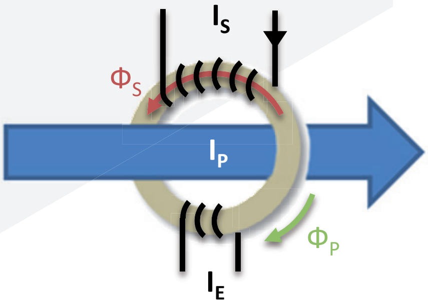

Figure 2: *Basic principle of the 0-FLUCS technology*

Referring to **Figure 2**, by applying a signal – i.e. the excitation signal I_E - to a particular ferromagnetic material, a **symmetical saturation** behaviour is obtained. This symmetry is then unbalanced by the application of an external field, which is generated by the current flowing into the electrical conductor that has to be measured (the primary current I_P).

The application of an additional current into a separate winding – i.e. secondary current I_S with a transformation ratio of N respect to the primary current I_P – allows the symmetical saturation behaviour to be restored. This secondary current I_S is then a scaled version of the primary current that has to be measured. By sensing this secondary current I_S, the value of the primary one could be estimated:

$$I_P = N \cdot I_S \qquad (1)$$

The zero flux condition then refers to the the situation where a **null magnetic flux** is restored on the sensor:

$$\Phi_P + \Phi_S = 0 \qquad (2)$$

The described basic approach has some **secondary effects** that need to be considered: the excitation current I_E generates a magnetic flux - i.e. Φ_E – that induces a current onto the primary conductor and can then affect the measurement (perturbating also the secondary circuit). By adding an extra-core, identical to the one where the excitation signal is applied, and by applying the same inverted excitation signal, the induced magnetic field generated is greatly reduced and theoretically nulled, thus eliminating the perturbation on the primary conductor. This solution is schematically shown in **Figure 3**.

The addition of a further winding, dedicated to improve the **AC response** of the whole detecting system, leads to a flat frequency response over some hundreds of kHz.

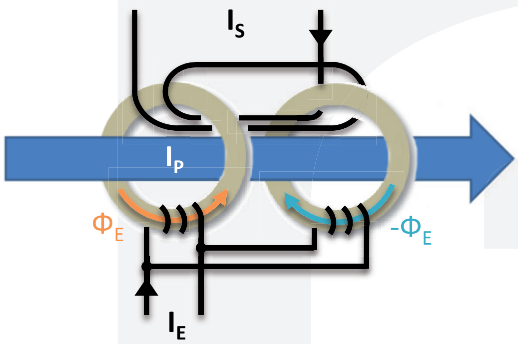

Figure 3: *Compensation of excitation field*

Advantages. The advantages of this current detecting architecture respect to other techniques are several and can be listed hereafter:

- DC and AC current measuring capability;
- electrical isolation from the circuit to be measured;
- high measuring range (up to kA);
- excellent linearity;
- large bandwidth;
- low phase shift;
- high efficiency (at higher currents);
- negligible temperature dependance (sub-ppm level);
- extremely low offset;
- very high precision and accuracy.

One critical task is to convert the secondary current to a measurable voltage level: this is greatly affected by the burden resistor specifications and by the conversion circuit performances. By considering a K conversion ratio between output voltage V_O and current I_S, expressed in [V/A] the value of the primary current can be estimated:

$$I_P = \frac{N}{K} \cdot V_O \qquad (3)$$

CAEN ELS catalogue presents transducers with a secondary **current output** (preferable in industrial environments where noise pick-up could be critical) or with an integrated current-to-voltage conversion in order to guarantee the best performances on the market having ppm-level temperature dependance also on **voltage output** versions.

Several applications require the use of such current measurement technology to improve the overall performance and accuracy.

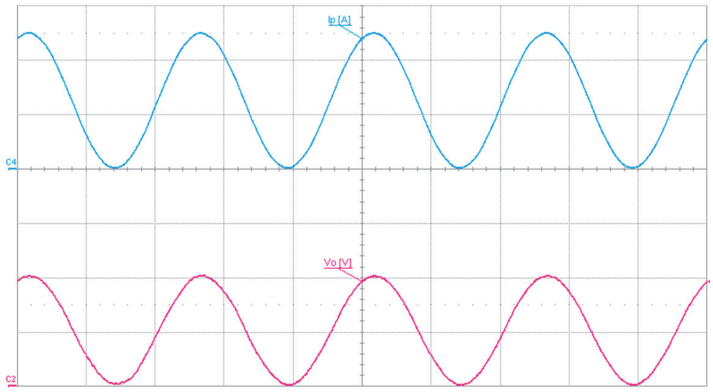

Figure 4: *Primary current I_P and output voltage V_O*

Applications. The applications that benefits from the specifications of this unique technology range from **MRI** (Magnetic Resonance Imaging) to **current calibration** systems, from precision **energy monitoring** to **battery test stands**.

The importance of having a very accurate and precise current measurement can be explicated considering the applications of power measurements. Considering the measurement of the voltage value (in terms amplitude and phase) completely accurate as in an ideal case, the two most important factors in estimating active power, reactive power and apparent power (as well as power factor) are represented by the **current measurement amplitude and phase error**.

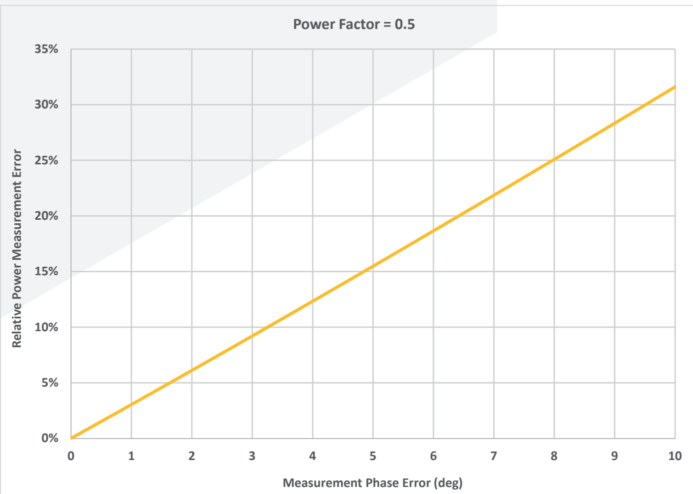

Figure 5: *Relative power measurement error for PF = 0.5*

The outstanding characteristics of the 0-FLUCS tranducers allow monitoring very accurately the current value with low amplitude and phase errors in a large bandwidth. By considering the **power measurement** for a system with a Power Factor PF = 0.5 - equivalent to a phase shift of 60° between the voltage and the current - we can calculate the relative **power measurement error** (percentage) E_P as a function of the phase error of the current measurement system as shown in **Figure 5**.

As it can be seen, EP already reaches a value of 6.1 % if the current measurement system has a phase shift of only 2° and reaches the value of 31.6 % for a phase shift of 10°. The situation gets worse as the system under

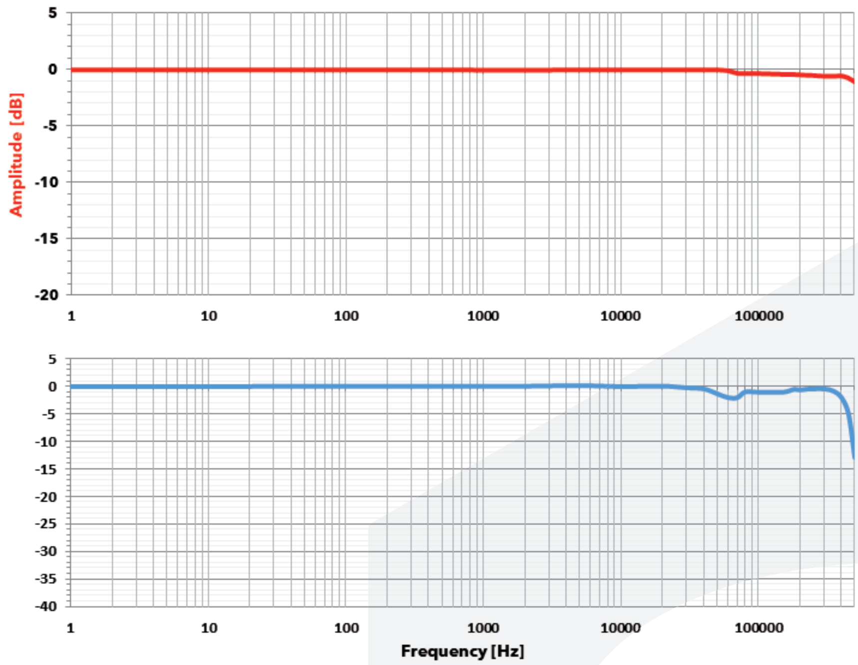

Figure 6: *amplitude and phase response of a CT-150 transducer*

measurement has a lower PF - e.g. the error increases to 11.1 % for a current measurement phase shift of 2° and a system with a PF = 0.3 and to 56.6 % for a current measurement phase shift of 10°.

The accurate values of amplitude and phase given by the DC Current Tranducers are so key factors in the evaluation of the active power of a system that cannot be matched by other current tranducer technologies. The specifications also make this technology ideal for current calibration systems for power supplies of any other current transducer that has less demanding requirements (e.g. Hall Effect sensors).

Ordering. The 0-FLUCS series includes many different current transducers differing by their current full-scale range and their output type. PCB-mount transducers are commercially available up to currents of ±52 A while the entire family reaches full-scale ranges up to ±1000 A - i.e 1 kA. The CT-BOX, a turnkey system for current measurement and calibration with multiple communication interfaces and with a sampling resolution of 24-bit @ 100 kHz, is also available. Please visit the corresponding product pages on our website www.caenels.com for more information about the 0-FLUCS current transducer series and the CT-BOX systems.

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