# APPLICATIONS OF LOW POWER CURRENT AND VOLTAGE SENSORS

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## *ABSTRACT*

*Protection relays, meters and control units in up-to-date switchgear are built with digital technology. The modern secondary equipment does not need the high power output of the instrument transformers (ITs) as this was necessary for electromechanical relays. As a consequence the requirements for ITs changed. Requests for a universal use of ITs for measurement, protection and even metering applications and the reduction of the overall costs of switchgear are common. Further requirements to modern ITs beside reliability and safety are easy handling, the reduction of the expenditure of work during planning and installation and short lead times.*

*By using established and highly proven components such as iron cores, capacitors, resistors and quadripol shunts it is possible to produce sensors which are fulfilling all the requirements. Compared with traditional ITs, low power ITs have less overall costs, lower weight and are immune to the electromagnetic interference in the substation. One low power IT can be used for metering and protection purposes. For that reason the number of different types for all application can be dramatically reduced in a wide range of primary current.*

*Nowadays relays with inputs for low power ITs are available from several relay manufacturers. By using such relays together with the wide measuring range of low power ITs users get a system with a high reliability, functionality and flexibility.*

*The paper has its focus on the applications of low power current and voltage sensors, such as the optimization of switchgear in dimensions, weight and costs, power measurement in a compressor test field and new possible applications (i.e. DC measurement, Power Quality Measurement).*

## INTRODUCTION

This paper describes low power current and voltage sensors which are in accordance to the IEC standards 60044-7 or 60044-8. It explains the different principles of low power ITs and describes features and advantages of the technology. The main part describes miscellaneous applications which have been developed, tested and installed during the last several years.

The requirements regarding power, primary current, measuring- and protection- accuracy classes make it necessary that conventional ITs need to be dimensioned always newly for each application. On the other hand, low power ITs with their wide measuring range can be used for a big number of different applications without the need of new dimensioning. They are compatible with the modern microprocessor controlled relays and other secondary equipment and can be used at medium- and high-voltage applications to replace conventional ITs for measurement and protection purposes. Low power ITs fit into existing as well as future designs of switchgear.

## LOW POWER SENSORS

Microprocessor-based relays are self-powered and have high input impedance. For this reason their burdens to ITs are very low. Modern low power sensors for voltage measurement according IEC 60044-7 [1] and for current measurement according IEC 60044-8 [2] have been developed during the last decades. They are not only providing the same functionality as conventional ITs but have a lot of additional advantages. They are smaller concerning size and weight and for this reason handling is easier and less space is required in the switchgear. Low power sensors have a very good linearity and an extended measuring range. Both, current and voltage sensors provide a low voltage signal output (mV to some Volts). Thereby the safety for the connected equipment and for the field service staff increases and the risk of damages caused by human errors is reduced.

### Low Power Current Transformers

The Low Power Current Transformer (LPCT) operates on the proven instrument transformer principle basing on the specific matching to an internal shunt resistor [3]. This principle is exceptionally non-sensitive to external stray fields. The secondary current produces a voltage across the internal shunt resistor which is directly proportional to the primary current. This voltage is the output signal of the LPCT. The shunt itself is designed to withstand short circuit currents without any change of its resistance value. LPCTs operate linearly and saturation-free up to the short circuit currents.

### Compensated Low Power Voltage Transformers

The compensated Low Power Voltage Transformer (LPVT) consists of a resistive voltage divider. The separate resistors have a very low inductance. The resistors of the primary side are “zig-zag” or spirally arranged [4]. For voltage levels between 1 and 72 kV the resistors are embedded into a casted resin. The “zig-zag” arrangement and the permittivity of the resin result in a capacitance, which is bigger than the stray capacitance to ground. For this reason the influence of the stray capacitance to the accuracy is compensated and the behaviour within a defined frequency range is improved (see also chapter about Power Quality Measurement). LPVTs do not contain ferromagnetic material and for this reason they cannot have ferroresonance. They are linear over a large voltage range. The linearity allows reducing the number of different required types and as a result the order specific engineering can be reduced.

Also a combination of a current and a voltage transformer is possible and described in the following applications.

## APPLICATIONS

Since launching the low-power instrument transformer technology in 1999 [4],[5] numerous development projects were conducted to allow the installation of the technology for different new applications.

### Power Measurement

To evaluate the efficiency of a compressor either the mechanical or the electrical power measurement method can be used. In the case described in the following, this measurement was done first mechanically by torque and speed measurement. Due to the lack of some measuring ranges during the test sequence the user decided to upgrade the test stand with an additional electrical power measurement system in parallel to the mechanical power measurement system. With the additional electrical measurement it is not only possible to measure the whole range but also to compare the values from the different measurement methods. Thus, also mismeasurements can be detected and avoided. Fig. 1 shows a block diagram of the upgraded compressor.

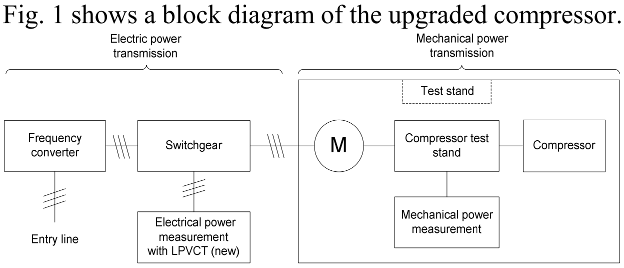


**Figure 1**-Block diagram of a compressor test stand with electrical and mechanical power measurement

Mainly because of the following reasons the user decided to install low power sensor technology for the electrical power measurement:

- Lower costs compared to comparable measurement systems.
- Limited space inside the switchgear.
- Easy exchange of the existing conventional current transformers by the new low power sensors.
- Accurate measurement in the frequency range between 25 Hz and 300 Hz.
- Harmonic measurement up to 2500 Hz possible.

For the described three phase application three combined one phase low power ITs with dimensions according to DIN 42600, part 8 (see figure 2) have been installed.

**Figure 2**-Combined instrument transformer 12 kV- Type LPVCT (LPVT and LPCT) - used for power measurement

For the evaluation and calculation, the sensors are connected to a digital power meter with a high-speed data acquisition rate. Figure 3 shows the general set up for detecting, recording and processing the data.

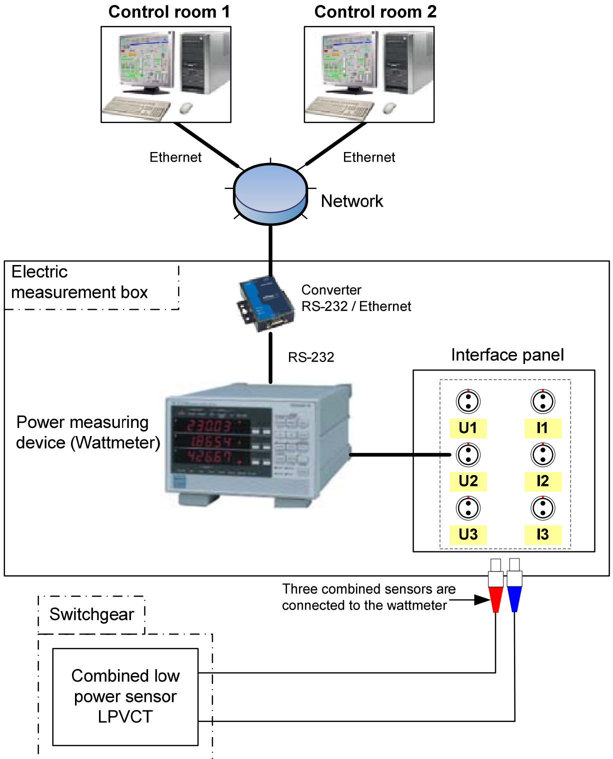


**Figure 3**-General set up of the electrical power measurement, bus system and data acquisition

A comparison of the mechanical and electrical power measurement confirmed that the electrical power measurement works accurately and reliably.
The required overall accuracy of the electrical power measurement of 2% is fulfilled at 50 Hz down to a power factor cosφ of 0.3 and at 300 Hz down to power factor cosφ of 0.8. The electrical power measurement system (LPVCT and wattmeter) was also able to measure harmonics up to 2500 Hz (i.e. caused by the use of a frequency converter).

## DC Measurement

Another application for LoPo voltage sensors is the measurement of a DC voltage. LOPO sensors have been installed to monitor the voltage across a capacitor bank discharged by resistors after disconnected from the bus. The mechanical switched capacitor bank is normally connected to an AC-bus that is running at up to 10 kV AC RMS. Depending on the kind of monitoring device connected to the LPVT, it is possible to detect both, the AC voltage during normal operation and the decreasing DC voltage during the discharge of the capacitor bank. The accuracy was for AC lower than 3% and for DC below 0.1%.

Figure 4 shows the equivalent circuit of such an installation.

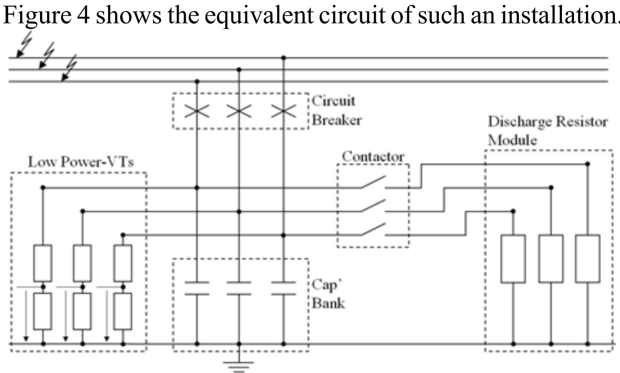


**Figure 4**-Equivalent circuit of voltage measurement with LPVT at a capacitor bank

## Power Quality Measurement

One of the requirements to low power ITs is that the behaviour over a certain frequency range is comparable with the behaviour of the conventional inductive CTs and VTs. For the measurement of power quality parameters according to IEC 60000-4-30 in medium- and high voltage networks the use of "measurement transducers" ([6], p 21) is necessary, i.e. voltage sensors or voltage transformers.

Measurements on LPVTs and LPCTs confirmed that they are basically suitable to detect the parameters up to the required 50th harmonic [7].

Figures 5 and 6 illustrate measurements for the verification of the suitability of low power CTs and VTs for the power quality measurement. As can be seen, good frequency behaviour can be expected up to several tens of Kilohertz for LPCTs and several thousand of Hertz for the LPVTs.

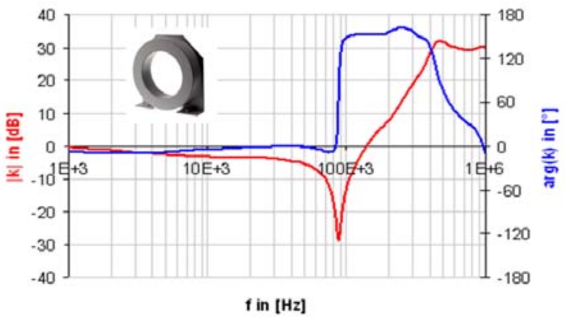


**Figure 5**-Typical frequency response behaviour of a LPCT

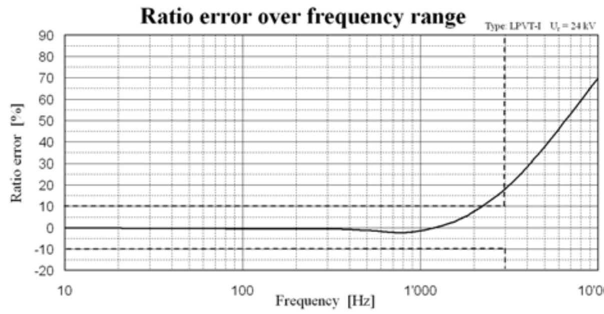


**Figure 6**-Typical frequency response behaviour (ratio error) of a LPVT

Better frequency response behaviour can be achieved with resistive-capacitive voltage dividers (RC-dividers). By adding capacitors in parallel to the primary and secondary resistor columns of the R-divider, the influence of the stray capacitance is significantly reduced. The transfer function for an RC-divider [8], see formula (1), shows that the ratio of the divider is independent of the frequency if the formula (2) is valid.

$$\frac{\underline{U}_S}{\underline{U}_P} = \frac{R_S}{R_S + R_P\frac{(1+R_S j\omega C_S)}{(1+R_P j\omega C_P)}} = \frac{C_P}{C_P + C_S\frac{\left(1+\frac{1}{j\omega R_S C_S}\right)}{\left(1+\frac{1}{j\omega R_P C_P}\right)}} \qquad (1)$$

$$R_S \bullet C_S = R_P \bullet C_P \qquad (2)$$

The RC divider is then fully compensated and can be used for measurements starting from DC up to several tens of Kilohertz (for special applications up to several Megahertz). Hence, it can be used for power quality measurement including the measurement of transient voltages.

## Earth-Fault Measurement

A special wiring allows using the LPVT for earth fault protection in three phase networks. For this application the output signals of all three LPVTs are interconnected in parallel as shown in figure 7.

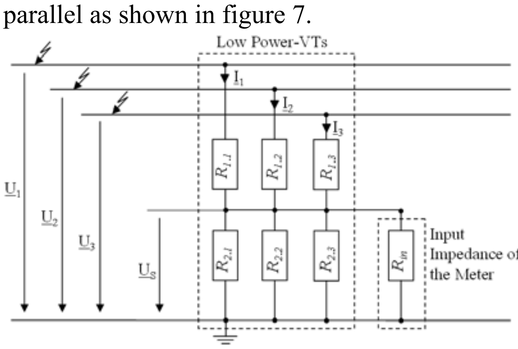


**Figure 7**-Scheme for earth fault measurement with LPVTs

Without any earth faults in the system, the output voltage $\underline{U}_s$ can be calculated with the following formula:

$$\underline{U}_1 + \underline{U}_2 + \underline{U}_3 = 0 \qquad (3)$$

$$\frac{1}{R_{2_g}} = \frac{1}{R_{2.1}} + \frac{1}{R_{2.2}} + \frac{1}{R_{2.3}} + \frac{1}{R_{in}} \qquad (4)$$

with $R_{in}$: Input impedance of the meter

$$R_{1.1} = R_{1.2} = R_{1.3} = R_1 \quad \text{(assumption)} \tag{5}$$

$$R_1 \bullet \left( \underbrace{\underline{I}_1 + \underline{I}_2 + \underline{I}_3}_{I_{s\cdot tot}} \right) + 3 \bullet \underline{U}_s = 0 \tag{6}$$

$$\underline{U}_s = R_{2_g} \bullet \underline{I}_{s\cdot tot} \tag{7}$$

$$R_1 \bullet \underline{I}_{s\cdot tot} + 3 \bullet R_{2_g} \bullet \underline{I}_{s\cdot tot} = 0 \tag{8}$$

$$\underline{I}_{s\cdot tot} = 0 \Rightarrow \underline{U}_s = 0 \tag{9}$$

Conclusion: Without any earth fault, the output voltage $\underline{U}_s$ is zero.

With an earth fault, the output voltage $\underline{U}_s$ is:

$$\underline{U}_1 + \underline{U}_2 + \underline{U}_3 \neq 0 = \underline{U}_F \tag{10}$$

$$R_1 \bullet \left( \underbrace{\underline{I}_1 + \underline{I}_2 + \underline{I}_3}_{\underline{I}_{s\cdot tot}} \right) + 3 \bullet R_{2_g} \bullet \underline{I}_{s\cdot tot} = \underline{U}_F \tag{11}$$

$$\underline{I}_{s\cdot tot} \bullet \left( R_1 + 3 \bullet R_{2_g} \right) = \underline{U}_F \tag{12}$$

$$\underline{U}_s = R_{2_g} \bullet \underline{I}_{s\cdot tot} \tag{13}$$

$$\underline{U}_s = \frac{R_{2_g}}{R_1 + 3 \bullet R_{2_g}} \bullet \underline{U}_F \tag{14}$$

Conclusion: In case of an earth fault, an output voltage proportional to the vector sum of the residual phase voltages is measured.

## Switchgear Optimisation

Due to the reduced dimensions and weights of low power sensors new application fields can be defined leading to switchgear designs with reduced size and overall cost. Figure 8 shows a combined unit where the LPCT and LPVT sensors are integrated into an epoxy resin cast bushing.

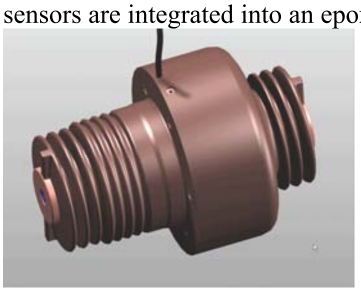

**Figure 8**-Combined voltage and current sensors in an epoxy-resin bushing ($U_r$=12 kV, $I_r$=2500 A)

Bushings with combined low power sensors withstand short circuit currents up to 31.5 kA, 3 s and ambient temperatures up to 80°C. The standard accuracy class is 0.5 and 0.2 as an option for voltage and current measurement. The connection cable with connector ("RJ45") is part of the sensor. The signals from both sensors (VT and CT) are transmitted by only one cable to the relay.

Other integrations of LPVTs into the substation are possible. Figure 9 shows the integration into a GIS bus bar-system as well as the implementation into a support insulator for air insulated switchgear.

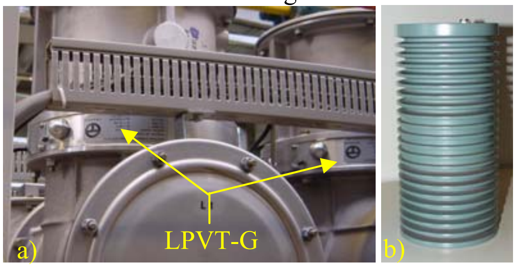


**Figure 9**-a) LPVT integrated into a 36 kV GIS-bus system and b) implemented into a 24 kV support insulator

## CONCLUSION

Compared to conventional ITs, low power current and voltage sensors show some crucial advantages. The main advantages are the wide linearity, the high frequency range, the small size and the low weight. This further leads to less customisation effort and reduces the huge number of different required types of instrument transformers.

The application of this new technology allows designing switchgear with optimized size and cost. In addition further applications are possible such as power measurement, DC-measurement and Power Quality measurement.

## REFERENCES

[1] IEC 60044-7, 1999, "Electronic voltage transformers".

[2] IEC 60044-8, 2002, „Electronic current transformers".

[3] R. Minkner, 2003, "Universeller Ringkern Stromwandler für Mess- und Schutzzwecke", *etz Elektrotech. + Autom.*, vol. 22, 2-9.

[4] R. Minkner, J. Schmid, 1999, "Koaxiale Spannungssensoren in gasisolierten Mittelspannungsanlagen", *etz Elektrotech. + Autom.*, vol. 19, 62-64.

[5] R. Minkner, E.O. Schweitzer, 1999, "Low Power Voltage and Current Transducers for Protecting and Measuring Medium and High Voltage Systems", 26th Western Protective Relay Conference (WPRC), Spokane, Washington/USA.

[6] IEC 61000-4-30, 2003, "Electromagnetic compatibility (EMC)–Part 4-30: Testing and measurement techniques–Power quality measurement methods"

[7] IEC 61000-2-4, 2003, "Electromagnetic compatibility (EMC)– Part 2-4: Environment – Compatibility levels in industrial plants for low-frequency conducted disturbances"

[8] R.Minkner, 2002, "Ein universeller RC-Spannungswandler für Hochspannungs Versorgungsnetze", *etz Elektrotech. + Autom.*, vol. 22, 2-9.