Sensor Technology

Applications for medium voltage
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Introduction to sensor technology

Sensors are a new solution for measuring currents and voltages needed for protection and monitoring in medium voltage power systems.

Certain strong trends have been present during the whole period of electrical equipment manufacturing: a continuous reduction of equipment size, a continuous improvement of equipment performance and a continuously growing need for standardization.

However, in some types of equipment the visible effect of those trends has, during long periods of time, been relatively small. A typical example is the transformer, including instrument transformers. The natural properties of the soft iron core, as maximal flux density and lack of linearity in the excitation curve, have set limits for the possibilities to reduce the transformer size and to use the transformer in a wider range of applications. As a consequence, most instrument transformer units have been electrically tailor-made for one certain application and a far-reaching standardisation has never been realised.

This inconvenience can be defeated with the introduction of sensors based on alternative principles like the Rogowski coil and resistive or capacitive dividers for current and voltage sensing respectively.

These principles are far from new, they are generally as old as the principles of conventional inductive instrument transformers. However, the utilisation of the principles has not been possible to carry out – except in special applications – due to the lack of accurate and inexpensive electronic devices required. Not until now, with the introduction of versatile electronic relays, has it been possible to make use of the advantageous properties of sensors.
Current sensor principle

The measurement of currents is based on the Rogowski coil principle. A Rogowski coil is a so-called air-core coil, a toroidal coil without an iron core placed around the primary conductor in the same way as the secondary winding in a current transformer. However, the output signal from a Rogowski coil is different:

- The output from a current transformer with its iron core and nearly short-circuited secondary winding is a current. This so-called secondary current is proportional to the primary current.
- The output signal from a sensor with its air-core and open Rogowski coil is a voltage. This so-called transmitted signal is proportional to the derivative of the primary current.

Thanks to the absence of iron in a Rogowski coil sensor, no saturation occurs. The output is therefore linear over the whole current range up to the highest currents.

Transmitted signal from a Rogowski coil:

- The transmitted signal is a voltage:

\[
\frac{u_{out}}{I_p} = M \frac{di_p}{dt}
\]

- For a sinusoidal current under steady state conditions the voltage is:

\[
\frac{U_{out}}{I_p} = M \cdot j \cdot \omega
\]

The signal is a sinusoidal voltage, proportional to the current, with 90° phase shift (lead).

- In all cases, even if the primary current is non-sinusoidal, a signal reproducing the actual primary current waveform is obtained by integrating the transmitted signal.
Voltage sensor principle
The measurement of voltages is based on the use of voltage dividers, resistive or capacitive. The output is linear over the whole range.

Transmitted signal from a voltage divider:

- The transmitted signal is:

  \[ U_{out} = \frac{R_2}{R_1 + R_2} U_p \]  
  (resistive divider)

  or

  \[ U_{out} = \frac{C_1}{C_1 + C_2} U_p \]  
  (capacitive divider)

- In all cases, the transmitted signal reproduces the actual primary voltage waveform.

Protection and control IEDs (Intelligent Electronic Devices)
The function of a traditional relay, as well as new additional functions, are included in a protection and control IED.

The information transmitted from the sensors to the IED is, during fault conditions, more accurate than the corresponding secondary information from an instrument transformer, hence giving the possibility for a versatile relay function. However, the IED must be able to operate at a sensor’s low input signal level with sufficient accuracy, and the signal from the Rogowski coil must be integrated. Modern IEDs (e.g. ABB’s Feeder terminals in the RE-series) are designed for sensor use and they are also equipped with built-in integrators for Rogowski coil sensor inputs.
Sensors versus instrument transformers

The driving force behind the development of a new family of equipment intended to supersede conventional instrument transformers has been the need to improve the availability, compactness, performance and safety of medium voltage switchgear.

Some advantages obtained with the use of sensors:

- **Short delivery times.** Because of the linearity over a wide range of current and/or voltage, a minimum of order-specific actions are required and consequently the logistic process is short.
- **Compactness.** As sensing elements are noticeably small, they can easily be combined in one device, a combi sensor, or integrated into other equipment like switches, bushings or post insulators, resulting in more compact switchgear.
- **Versatile protection and control solutions.** The sensors are linear up to the highest currents and voltages with a good dynamic performance. As a result, the sensors enable high protection performance and many-sided disturbance analysis.
- **Overvoltage and disturbance withstand.** Voltage sensors do not need to be disconnected for voltage testing at power frequency on the switchgear. They can not cause ferroresonance and are not sensitive to ferroresonance and DC-voltages.
- **Transmitted signal.** The nominal value of the transmitted signal is low enough to be harmless to secondary equipment and people, even when the highest currents and voltages occur on the primary side. A broken circuit or short-circuit in the signal cable will cause no hazards or damage.
Advantages for builders and users of switchgear

Sensors have some unique qualities directly affecting the structure and manufacture of switchgear, as well as the operation and maintenance.

Safety

The total safety of people and equipment can be promoted using sensors. The main reason is the low voltage and current level of the transmitted signal from a sensor. This level is low enough to remain harmless for both people and secondary equipment, even under fault conditions.

Some properties of sensors giving direct impact on safety:

- **Low signal level, even under fault conditions.** During normal service conditions, the transmitted signal is very low: Even under fault conditions such as a primary short-circuit, the transmitted signal is limited to some 10 V. Such a voltage is still harmless to people and cannot cause hazards to secondary insulation and instruments. Consequently, there is no need to calculate an instrument security factor.

- **Shielded cables and connectors.** The signal cables are shielded and connected to the relay with shielded connectors. Terminal block connections are not used and live parts are not visible in the signal circuits.

- **No effects of short-circuited or interrupted signal circuits.** A short-circuit on the transmitted signal side of a voltage sensor will cause no damage to the sensor. Consequently, there is no risk either for a total breakdown of the sensor resulting in serious damage to other equipment. In a corresponding way, an interruption of the transmitted signal from current sensor will cause no overvoltages hazardous to people, the sensor itself, secondary insulation or other equipment.

- **No risk for ferroresonance.** In certain types of distribution networks a major problem has been damaged voltage transformers, caused by ferroresonance and resulting in a grid shut-down. Because voltage sensors do not include unlinear inductive cores, they are not prone to ferroresonance.
Short delivery time
As a basic sensor design can cover a wide range of applications, the amount of product versions is considerably small. Order-specific actions can be minimised and the logistic process will be short. Or seen from the purchaser’s point of view: The delivery time for standard sensors is shorter than for traditional instrument transformers!

Some properties of sensors affecting the delivery time
- **Linearity.** A sensor is linear over a wide range of currents or voltages. One single basic design of current sensors can be used for switchgear rated e.g. from 40 A to 1250 A and one voltage sensor design can be used for primary rated voltages from 7.2 kV to 24 kV. No order-specific calculation for various primary currents is necessary.
- **No saturation.** The linearity extends up to the highest values of currents or voltages. No calculation of accuracy limit factor (nor instrument security factor) for various applications is necessary.
- **No accuracy versus burden calculation.** A sensor is tested and delivered equipped with its specific signal cable. The input impedance of the protection and control IED is high enough to have no significant influence on the accuracy of the sensor. No calculation for accuracy versus burden is required.

Smart integration
Traditionally, current and voltage transformers have been separate, relatively large components. In addition, the current transformers have typically been equipped with a number of secondary windings needing a lot of low-voltage cabling. As a result, instrument transformers have had a remarkably big influence on the cubicle design. Sensors, on the other hand, are considerably small and current and voltage sensors can therefore easily be combined in so called combi sensors, or be integrated in other equipment as insulators, bushings or switches. Combi sensors and integrated sensors can be used to achieve switchgear with smaller overall dimensions and uncomplicated designs.

Some advantages of combined and integrated sensors:
- **Traditionally, separate secondary windings for measurement and protection have been used.** The wide range linearity of sensors makes it possible to combine sensors for measurement and protection in one single device, resulting in smaller sensor dimensions, simpler low-voltage circuit cabling, and more uniform cubicle design.
- **Measurement of current and voltage has usually been performed with separate current and voltage transformers.** Thanks to the small dimensions of the sensing elements, a current and voltage sensor can easily be combined in one single so-called combi sensor, no bigger than a traditional current or voltage transformer. Such combi sensors enable the design of cubicles with smaller overall dimensions and uncomplicated designs
- **In the same manner,** current and voltage sensors can easily be integrated in other equipment such as bushings, circuit breakers, switches, post insulators and housings, giving a very uncomplicated design for the cubicles.
The impact of new IED technology on switchgear performance

Besides the impact on switchgear dimensions and design, sensor technology supporting modern protection and controll IEDs, gives required qualifications for building more intelligent switchgear. The main reason for this is the improved ability of modern IEDs to perform complex calculations when accurate input data is available. From the sensor point of view, the key properties are their ability to exact reproduce primary currents and voltages, inclusively harmonics and high-frequency disturbances, up to highest values, e.g. short-circuit currents.

Switchgear features enhanced by modern relays and sensors

• Better selectivity
• Improved fault location
• Better disturbance analyses
• Power quality measurements
• Remote monitoring and control
• Easy maintenance
• Optimised maintenance programme
• Simplified IED testing
Environmental aspects

Certain strong trends have been present during the whole period of electrifying. They are e.g. reduction of equipment size, improvement of its performance and grooving need for standardisation. Besides these demands, additional ones concerning sustainable development and ecological care have risen during the last decades. These demands are met by ABB in design and manufacture, and therefore even a single product can provide its contribution.

Sensors from an environmental point of view:

- **Less use of raw materials.** Sensors with small dimensions, as well as combined and integrated sensors leading to compact and uncomplicated cubicles, give savings in highly-valuable raw materials.

- **Less copper inside cast resin.** In Life Cycle Assessment, the use of copper does not automatically give a high environmental impact because copper can, in most cases, easily be recycled. However, casting copper into cast resin is negative because the recycling of copper is more difficult or impossible. The amount of copper in the single Rogowski coil of a current sensor is only a fraction of that used in a corresponding multi-core current transformer. The absence of iron cores makes the recycling of the primary winding possible. A voltage sensor does not contain copper windings at all!

- **Small power consumption.** The efficiency of a sensor is high compared with instrument transformers. In addition, there are no losses in the secondary cabling. These savings add up with a long lifespan of the equipment and at a utility level these savings could be significant.

Standards

Sensors from ABB are designed, manufactured and tested according to the latest international standards in the field, when they are applicable.

**Such standards are e.g.**

**Voltage sensors:** IEC 60044-7 (1999-12)
- Instrument transformers – Part 7: Electronic voltage transformers

**Current sensors:** IEC 60044-8 (2002-07)
- Instrument transformers – Part 8: Electronic current transformers

**Combi sensors:** IEC 60044-3 (1980-01)
- Instrument transformers – Part 3: Combined transformers
**Product survey**

The presentation below gives examples of the use of various sensors. Further technical information is provided in product brochures.

<table>
<thead>
<tr>
<th>Sensor design</th>
<th>Example of sensor type</th>
<th>Voltage/ current</th>
<th>Type of switchgear</th>
<th>Switchgear insulation medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>KEVCD</td>
<td>V, C</td>
<td>Primary</td>
<td>Air</td>
</tr>
<tr>
<td>Standard</td>
<td>KECA</td>
<td>V, C</td>
<td>Secondary</td>
<td>Gas</td>
</tr>
<tr>
<td>Standard</td>
<td>KEVA</td>
<td>V, C</td>
<td>Switch</td>
<td></td>
</tr>
<tr>
<td>Tailor-made</td>
<td>KEVCI</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tailor-made</td>
<td>KEVCI</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tailor-made integrated</td>
<td>KEVCI 24 SA2</td>
<td>V, C</td>
<td></td>
<td></td>
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<tr>
<td>Tailor-made integrated</td>
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<td>V, C</td>
<td></td>
<td></td>
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<tr>
<td>Tailor-made integrated</td>
<td>KEVCI 24AE1</td>
<td>V, C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sensor KEVCD in various switchgear
- Standard design
- Dimensions acc. to DIN-standard
- For air insulation
- Combi sensor for current and voltage
- Coupling electrode for voltage detecting systems

Sensor KEVCI in switchgear ZX2
- Designed for this particular use
- For gas insulation
- Combi sensor for current and voltage
- Coupling electrode for voltage detecting systems

Sensor KEVCI in switchgear AX1
- Designed for this particular use
- Integrated in a post insulator-plug-in type bushing combination
- For air insulation
- Combi sensor for current and voltage
- Coupling electrode for voltage detecting systems

Sensor KEVCI in switchgear ZY2
- Designed for this particular use
- For gas insulation
- Combi sensor for current and voltage
- Coupling electrode for voltage detecting systems
The technical data and dimensions are valid at the time of publishing. We reserve the right to subsequent alterations.