FOCS Fiber Optic Current Sensors
Enabling smart grids and digital substations
Future-oriented utilities continuously look for opportunities to improve reliability, drive down costs and enhance safety of their systems. The focus on these advancements resonates through the power industry on all levels. Digital substations are an important cornerstone of the grand endeavor to achieve those goals.

ABB has a long history of development and production of instrument transformers for control and protection of electric power grids. Since the 1990s non-conventional fiber optic current sensors (FOCS) have been developed in ABB. They are based on the Faraday Effect, whereby the precise current magnitude is deduced from the generated magnetic field measured by light.

ABB FOCS based products and systems are being adopted to meet the demand for reliable AC and DC measurement under the harsh conditions in an outdoor substation or metal smelting industrial production. Application-specific FOCS kits are developed and produced in the ABB FOCS factory in Wettingen, Switzerland. The factory’s product portfolio encompasses different FOCS kit versions for reliable current measurement, which are used both for AC and DC measurement in power transmission and distribution as well as for measurement of high DC current in industrial surroundings.

The right physics for highest accuracy, the science behind FOCS
The FOCS system utilizes the Faraday Effect to measure current. A simple coil with several turns of optical fiber is placed around some current conductor. The Faraday Effect can be observed when circularly polarized light waves are exposed to a magnetic field. As a result, the waves accumulate a phase difference.

In the FOCS system, the right and left circularly polarized light waves travel through the sensing fiber coil placed around a conductor. At the end of the fiber, the waves are reflected, their polarization direction swapped and then retrace their optical path towards the sensor electronics. If an electrical current is flowing through the conductor, the optical waves accumulate a phase difference which is proportional to the line integral of the magnetic field along the sensing fiber. This difference is therefore a direct and highly precise measure of the current.
Orthogonal linear light waves

Left and right circular light waves

Current-related phase shift

\[ \Delta \phi = 4Vl \]

\[ l = \oint H \text{d}s \]

\( V = \text{material constant (Verdet constant)} \)
\( H = \text{magnetic field} \)
\( s = \text{length of sensing fiber} \)

A FOCS kit for the HV power industry is most often designed as a redundant three-phase sensor that consists of two optoelectronic (OE) modules, and three robust, lightweight and versatile sensor heads connected by fiber optic cables.

The OE module houses the opto-electronics to interrogate the sensing fiber coils, simultaneously for all 3 phases. Each sensor head contains two sensing fiber coils in order to enable redundancy on the system level.

The opto-electronic module performs the following tasks:
  * Sends polarized light to the sensor coil.
  * Receives the reflecting polarized light from the sensor coil.
  * Compares in close-loop control the phase displacement in the polarized light caused by the magnetic field of the primary current.
  * Converts the result into current sampled values and send it over an optical IEC 61850 Ethernet output.

As an optical current sensing kit, FOCS can be incorporated into a free-standing sensor system (FOCS-FS) for 72 to 800 kV high voltage substations, embedded into live tank breakers and disconnecting circuit breakers, or added to dead tank breaker CT housings or to power transformers.
Customer benefits

- **FOCS facilitates introduction of smart grids and digital substations**: Digital interface, designed for IEC 61850-9-2LE communication for integration into digital substation automation systems.
- **“Plug & Play” solution**: Exchangeable and hot-swappable merging units.
- **Accurate**: Meets key modern performance requirements for accuracy, in a wide temperature range.
- **Technology is inherently free of magnetic saturation**: Suitable for capturing fast transient currents, short circuit currents, and alternating current (AC) with DC-offset.
- **Reduced substation footprint**: The compact design requires less space compared to traditional instrument transformers.
- **Eco-efficient**: Using no oil or SF6 gas FOCS is an eco-efficient solution.
- **Reliable**: Simple and robust design with self-diagnosis and alarm functions; different levels of redundancy available on request.
- **Safe**: As powered with low voltage, providing an optical digital output and being filled with nitrogen gas at ambient pressure, FOCS has zero risk of electrocution and explosion.
- **Compatible**: The adopted IEC61850-9-2LE protocol allows interoperability with other vendors’ equipment.
- **Simplified engineering**: Rated voltage and rated current are the main parameters that need to be specified. Projects have simplified system engineering and are delivered faster, impact of late changes in specifications is negligible.
- **Easy to install**: FOCS is lightweight, compact and flexible with reduced installation costs. Outdoor placement of the opto-electronics modules near the insulators reduces the length of sensor fiber cables to a minimum.

Final result is that FOCS based products help digital substations gain traction in the industry, with real world commercial installations, along with other NCITs and standalone merging units. Since providing saturation-free, safe inherently insulated outputs and capable to monitor current ranges not possible by conventional current transformers, the FOCS technology is valuable innovation for utility customers who search for future ready solutions.

Applications relevant for power industry

FOCS technology and FOCS based products demonstrate high level of versatility and usability for solving conventional and newly emerging protection, control and monitoring tasks in global power industry sector. New needs have emerged in the power industry active companies (e.g. imposed by novel standardization and regulatory), but also the expectation to address conventional task in a modern, more reliable and effective way.

Protection applications:

FOCS based products are offering all protection classes mentioned in modern IEC and IEEE standards. FOCS technology does not suffer from any saturation or other nonlinear effects. The system relative accuracy (defined as the maximal error vs primary current reading) is not dependent on the primary current value. Therefore the FOCS is offering the same relative error from very low currents till the maximal current for which some FOCS sensor is designed. This is typically about 160 kA, but also peak currents of close to 700 kA can be accurately measured too.
Measurement applications:
ABB FOCS is capable to deliver very accurate sampled values which are required for revenue metering applications. FOCS sensor head is containing only electrically passive, dielectric components and does not experience any excitation losses nor burden limitations. FOCS is offering IEC accuracy class 0.2S for nominal currents of 400 Arms and more. FOCS optoelectronic units are designed in a way to enable simultaneous delivery of signals which can be used for revenue metering task and the standard IEC 61850-9-2 conform signals for protection and control use. Also the FOCS sensor heads can be used for both applications. Specific for ABB’s sensor heads is the use of proprietary technology that ensures magnificent inherent temperature compensation of system output signal.

GIC application:
Geomagnetically induced currents (GIC), affecting the normal operation of long electrical conductor systems, are a manifestation at ground level of space weather. During space weather events, GIC may emerge in conductors operated on the surface of Earth. Power transformers have a magnetic circuit that is disrupted by the quasi-DC GIC: the field produced by the GIC offsets the operating point of the magnetic circuit and the transformer may go into half-cycle saturation. This produces harmonics to the AC waveform, localized heating and leads to high reactive power demands, inefficient power transmission and possible mis-operation of protective measures. FOCS measuring principle enables simultaneous measurement of 3 phase currents. FOCS is measuring current values in extremely short time intervals of less than 1 microsecond and will accurately measure all harmonics, including the DC component in arbitrary current signal. In this way the accurate values of GIC may be extracted from the FOCS output stream. Contrary to the conventional way of indicating summary value of GIC from all three phases by measuring on the grounded star points of transformers, the FOCS approach enables detailed and precise insight in the process as it measures slowly varying DC offset on each phase. This information helps utilities to perform transformer thermal impact assessments and to mitigate potential GIC effects in their transmission networks.

Open-phase detection:
Since many years the industry is looking for a solution to reliably detect open-phase events that can occur on transmission power supplies. It is difficult to detect an open-phase condition in case of auxiliary transformers when they are energized but being in standby or lightly loaded condition. This is known problem that is especially under focus in case of nuclear power stations, which may present significant threat if the open-phase condition is not noticed for longer time. It became known that this has already happened in several occasions worldwide. Owed to its capability to measure zero to maximal current with the same sensor head, FOCS can be used to reliably determine if some line is open or still closed. This decision can be made in the scope of 1-2 current cycles and FOCS may be easily programmed to issue appropriate alarms over its analogue or digital output lines. The same FOCS can still be used for conventional P&C tasks when the line is under full load. This means that FOCS may serve as a key component of a test a system used to detect an open-phase condition for all loading conditions, including standby (unloaded) and lightly loaded, for susceptible power plant transformers.
Tracking of arbitrary form of the primary current
FOCS is capable to measure arbitrary form of primary current, without any influence of the current form (amplitude, phase, frequency) to the FOCS accuracy. Further, as having significant digital calculation capability, FOCS can be programmed to directly analyze the sampled value data output for all its own three channels (phases) and produce usable information out of such data. One example of such use of FOCS is the task of improving operational safety of Pumped-Storage Waterplants (PSW) with double-infeed excitation system. New PSWs with double-infeed pump-generator machine face operational safety challenges due to emergence of low frequency stator currents having high DC-offset (5 to 15 kA), which are induced during machine starting and net synchronization process. In this situation the opening of the connected circuit breaker must be done in a very specific time window to enable successful extinguishing of the arc that is occurring at each opening of the breaker.

FOCS can be programmed in a way to precisely determine the appropriate time window for breaker opening. In this application the FOCS can be connected to the breaker control system as additional "enabling switch". Also other applications that required detection of specific current forms in broad frequency bandwidth can be envisaged and the FOCS appropriately programmed and set for this application.

Detection and precise analysis of current transients and impulses
ABB’s FOCS is acquiring digital raw sampled values of primary current with a sampling rate higher than 1 MS/s. Even the present FOCS optoelectronic unit is made to deliver output data according to relatively slow IEC 61850-9-2 process bus protocol, it may be possible to release special versions of firmware which may be done in a way to recognize and analyze main relevant parameters of current transients or/and impulses and deliver final information that is relevant for some analytic or operative task.

Travelling Wave Fault Location (TWFL)
Special form of transient signal analysis task may be the TWFL. When exploiting the high sampling data rate capability of FOCS it will be possible to use the existing FOCS hardware in combination with specific firmware (still to be developed) to determine the distance of the fault relative to the FOCS installation spot. The accuracy of the location may be even improved with future FOCS versions using specifically optimized design for TWFL.

FOCS based product variations
FOCS sensor kits can be provided in a number of configurations to facilitate its incorporation into different areas of the grid.
FOCS free standing (FOCS-FS)
The product is provided with three outdoor-rated polymer insulator housings filled with low-pressure nitrogen. Each housing can accommodate one or two sensor heads, each with redundant fiber sensing coils and is connected via robust outdoor-rated fiber optic cable to FOCS OE modules situated in a field-mountable stainless steel enclosure or in a station or bay control room. Typical enclosure contains redundant OE modules and redundant power supplies.

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<th>FOCS free standing (FOCS-FS) system voltage applications</th>
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<tr>
<td>72 kV system</td>
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<td>145 kV system</td>
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<td>245 kV system</td>
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<td>420 kV system</td>
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<td>550 kV system</td>
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<td>800 kV system</td>
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Dead Tank Breaker with FOCS sensor
A FOCS integrated with or added to a dead tank breaker needs no additional insulation medium and uses less material compared to a conventional CT. The use of standard optical Ethernet cables and process bus protocol makes it easy and fast to integrate FOCS into the control and relay part of the substation (“plug and play”).

Slip-over field application (FOCS-SO)
In this configuration, the product can be field-applied onto existing electrical equipment to help fit pilot projects or permanent installations with a digital process bus format. Specifically designed sensor heads are sized for use inside dead tank circuit breaker shrouds, or externally slipped over for quick installation around power bushings. FOCS OE modules can be assembled inside stainless steel enclosures for field mounting or alternatively placed in a station or bay control room.

Live Tank Breaker embedded (LTB/DCB with FOCS)
The FOCS is embedded into live tank or disconnecting circuit breakers from 362 kV to 800 kV with redundant sensor coils incorporated into each breaker pole. The FOCS sensor heads in the breaker poles are connected via fiber optic cables to OE modules situated in field control cubicles or in the station or bay control room.