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IEC 61850
Process Bus - It is Real!

The new international standard for substation communications IEC 61850 allows the development of a new generation of substation protection, automation and control systems that results in significant reduction of the overall cost of such systems, while at the same time improves the functionality of different applications. Non-conventional instrument transformers with digital interface based on IEC 61850-9-2 process bus eliminate some of the issues related to differences in protection and metering requirements. The data can be processed by any device to perform different protection, automation and control functions.

The IEC61850 international standard for communications in substations brings a new era in the development of substations. It affects not only the design of the substation protection, monitoring and control system, but also the design of the substation secondary circuits. High-speed peer-to-peer communications using GOOSE messages and Sampled Analog Values allow development of distributed applications based on current and voltage values communicated between devices connected to the process and substation local area networks.

Over the past few years, the market surge towards to IEC61850 has been evident for suppliers and customers alike. Much of this interest has centered on the migration from manufacturer-driven station bus implementations, towards substation automation systems that fully integrate IEDs such as protection relays on the new accepted international standard.

This approach has largely concentrated on the IEC61850-8.1 station bus, emulating and improving on the conventional SCADA approaches and the replacement of hard-wired signal exchange between substation protection and control devices with GOOSE messages. However, the station bus is only a part of the advancement that IEC61850 can offer, with IEC61850-9.2 being largely unexplored. IEC61850-9.2 is the part of the standard that brings non-conventional instrument transformer technology (NCIT) into play, breaking the shackles and constraints of conventional CTs and VTs with iron wound cores at their heart. NCIT has some relative advantages such as elimination of transients, improvements in safety and accuracy, reduction in wiring costs, and the resulting effect on substation topology. More than 15 years of advanced research and different projects around the world are proving the great potential of this technology

Non-Conventional Instrument Transformers

The successful implementation of NCIT in various applications (AIS and GIS) requires the availability of a full range of products. Laboratory type tests and field experiments have been running for more than 15 years and successfully show the technical feasibility of sensors and their implementation in high voltage networks within the ruling specifications.

All configurations require one unique secondary electronic rack, the so-called Merging-Unit (MU). This is a device that includes sensor electronics and different kinds of interface, compatible with protection and metering devices.

Technical solutions based on Optical and Hybrid sensors integrate the best advantage of the technology in AIS substations. The CTOE "Current Transformer based on Optic-Electronics sensors" and the VTCE "Voltage Transformer based on Capacitor-Electronics

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sensor" are the optimum solutions proposed. However, mainly due to interface modifications there have been a limited number of industrial applications in substations. Recent works on international standards by working groups under IEC resulted in the definition of digital communications that allow some interoperability experiments between NCIT and other equipment used by automation, opening the door to complete applications in HV and EHV substation. (Figure 3)

The solution consists in the use of following devices:

- Current Transformer based on Optical sensors and primary Electronics (CTOE)
- Voltage Transformer based on Capacitor divider and primary Electronics (VTCE)
- Merging Unit (MU)- an electronics device containing the necessary electronics for sensors and the digital interface according to IEC 61850-9-2 the Standard
- Intelligent Electronic Device (IED) with protection functions, compatible with digital interface according to the IEC standard for Sampled Values communications

The CTOE and VTCE are connected to the merging unit by optical fibers transporting digital signal according to a proprietary protocol. The MU elaborates the standardized digital frame according to an IEC 61850 implementation guideline published by the UCA International Users Group: IEC 61850-9-2-LE. An Ethernet switch allows all devices that subscribe to the sampled values to connect to the merging unit.

In order to understand better the advantages of non-conventional instrument transformers, let us consider the operating principles of this sensor technology and how they are implemented in real devices.

Optical Current Sensors and Primary Electronics

Current Transformers with Optical sensors and Primary Electronics (CTOE) are devices able to measure the current of High Voltage lines for revenue metering application, as well as for protection and redundancy features.

One phase unit includes:

- Head with a primary optical sensor (number can be up to 3 for redundancy)
- Composite insulator, comprising optical fibers
- Base, including a junction box containing optical connectors and 2 redundant electronics boards for digitalization and transmission to the merging unit
- Optical cable to the MU

IEC 61850 allows interoperability between IEDs and non-conventional sensors

The Faraday sensor:

The Faraday Effect or the magneto-optic effect describes the influence of a magnetic field on a transparent optical medium. The magnetic field alters the electron path in the medium, which acquires a circular birefringence (the phenomenon of double refraction of light wavefronts in a transparent, molecularly ordered material produced by the existence or orientation-dependent differences in refractive index) and affects the polarization state of a monochromatic light beam propagating in the same direction as the magnetic field. As a result, the light acquires a rotation of polarization state. (Figure 2)

The design of an optical sensor is a very important factor in its performance. We need to keep in mind that such devices, depending

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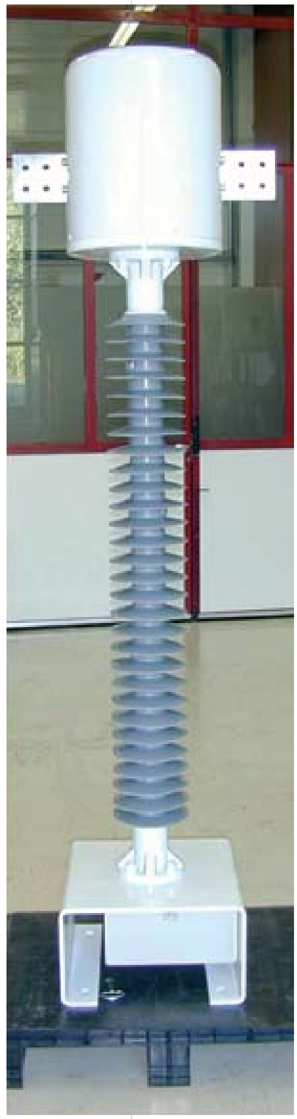
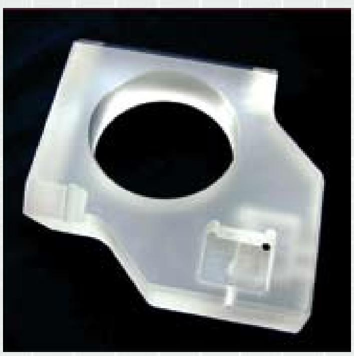


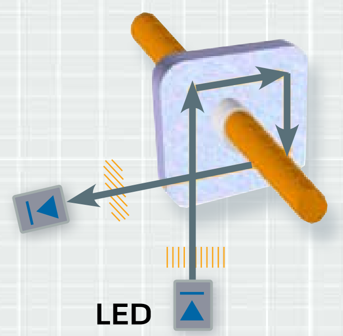
Figure 3

NCIT based solution

1 Ring glass design



2 Faraday sensor principle



Optyical current transformers are based on the Faraday effect - influence of magnetic field on transparent optical medium on where they are installed, may be exposed to some extreme weather conditions. The choice of ring glass solution that gives good temperature response and also important benefits, such as easiness of manufacture, industrialization and possible use of multimode components such as larger optical fiber core, easier connectors, LED (Light Emitting Diodes) instead of LD (Laser Diode). (Figure 1) The optical detection is used to transform the Faraday polarization modulation in a light intensity modulation by addition of a "polarimetric system", including two polarizers oriented at 45° from each other, with Faraday medium between them. Furthermore, the light intensity is a measurable value and can be converted into electric signals by special opto-electronics components called photodiodes .

Primary Converter in the base of the CTOE

A primary electronics board allows converting the light power traveling in the sensor in electronics signals transmitted digitally to the merging unit. These primary electronics includes:

LEDs that emit a quasi-monochromatic light. This light is coupled to a fiber included in the composite insulator, transmitted to a Faraday sensor, and coupled in a return fiber.

The beam light, modulated by the magnetic field, is detected by a photodiode (PD) and then converted in an electronic analogue signal.

An analogue to digital converter associated with a micro-controller of communications used to send the sampled values of the signal to the merging unit through a classical communication optical fiber.

Secondary Converter in the Merging Unit - MU:

A secondary electronics board in the merging unit performs the signal processing necessary to make available through the process bus communications the sampled values of the currents.

Optical Cable:

The optical cable, between the CTOE and the merging unit is not standardized in IEC 61850. In one implementation it packages standard communication 62.5/125 multimode optical fibers that, as well as the connectors may be chosen by the user.

CTOE Unit:

Head, including primary conductor, high voltage terminals, and a housing box containing the optical sensors:

- 2 redundant protection channels
- 1 metering channel
- Composite insulator, including optical fibres for the optical sensors
- Insulator junction
- Base with optical connection, or primary electronics, and fibre transmission.

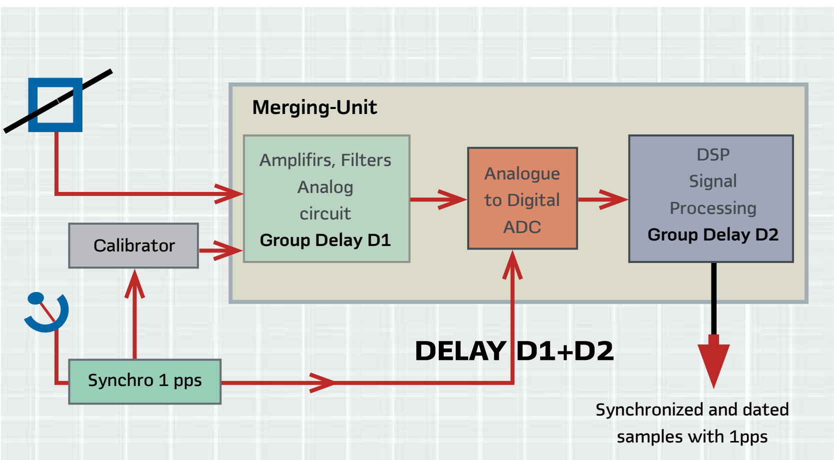
Voltage Transformer Based on Capacitor Divider and Primary Electronics (VTCE)

The Voltage Transformers based on a Capacitive Divider and Primary Electronics (VTCE) are devices able to measure the voltage of High Voltage lines for revenue metering application, as well as for protection and redundancy features.

Non-conventional instrument transformers may be exposed to extreme weather conditions

A Merging Unit can be considered as a remote analog input board of an IED

4 Simplified block diagram of a merging unit



5 Relay with station and process bus

One phase Unit includes:

- A capacitive divider, isolated with film-paper-oil, or SF6 technology represents technology that is well-known and mastered by many manufacturers
- A redundant Primary Converter, replacing the conventional transformer in the bottom of CCVTs ; these electronics are designed for digitalization and transmission to the merging unit with an optical cable.

Advantages of the VTCE solution:

This Non Conventional Capacitor divider Voltage Transformers, where the magnetic part is replaced by electronics Primary Converter, offers many advantages:

- Takes advantage of inherent low cost technology (CCVT)
- Uses standard products manufactured in several unit of production ; proven solution for capacitor divider using mixed film/ paper/oil technology

EHV-VTCE could be developed for Extra High voltage applications and improves measurement performances by offering:

- Harmonics capability
- Extended metering Class
- Digital communications to Merging Unit (MU).

The solution offers also the Power Quality capability, allowing harmonics measurements up to the 100 of the rated frequency.

The VTCE Unit:

The VTCE unit includes:

- Head, including primary conductor to high voltage terminals
- Composite insulator, including the capacitive divider
- Capacitor junction
- Base with primary electronics, and fibre transmission.

IEC 61850-9-2 Digital Interface for Sampled Values

Electronics technology has fully evolved in the last decade and the consequence is the generalization of digital hardware designs for electronics devices like Merging Units (MU) and Intelligent Electronic Devices (IED), including protection relays and meters, as well as the digital communications between them. A previous RTE experiment at Vielmoulin 400 kV substation has successfully demonstrated during more than three years the feasibility of such a digital link. Unfortunately, there was a delay of several years before receiving a standard communications protocol that is accepted worldwide. This fact has considerably slowed down the NCIT applications.

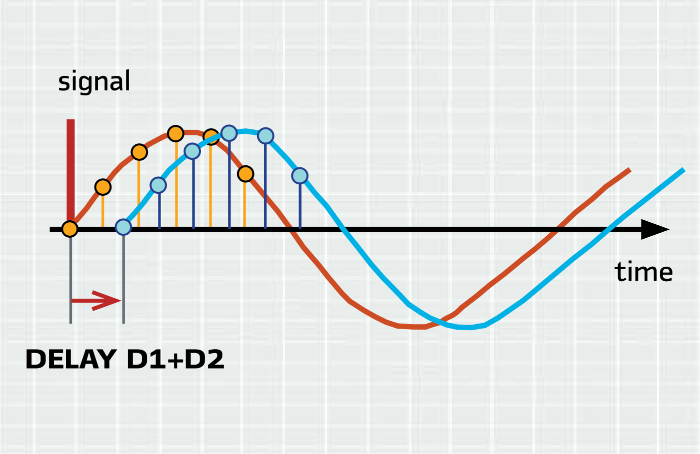
We also need to remember that the technology of optical sensors is well proven. Indeed, since the end of the nineteen's many CTO units for revenue metering and protection function have been installed at the HV terminals of IPPs (Independent Power Producers). These devices have the major advantage of extra high dynamic range for current measurement that can be achieved with conventional current transformers only by using separate CTs for protection and metering.

As already mentioned previously, the publishing of IEC 61850 creates a great opportunity because of its main objective – to ensure "Interoperability" between IEDs coming from various suppliers, to enable the unrestricted exchange and usage of data to perform their individual dedicated functionality.

This is not an easy task, especially if we consider the many different requirements for various substation and power

NCITs are successfully implemented in high voltage substations in different countries

6 Analog signal phase shift



7 La Prairie substation CTOs

system related applications. Many chapters exist in this standard that define several levels of abstract communications and their implementation in real substation communication networks - in particular Parts 8-1 and 9-2 that are respectively dedicated to defining in detail the digital protocols between the different types of substation secondary devices.

The three main types of substation communications are:

- Client (mostly an HMI or other substation level function) - Server (IED)
- Peer-to-Peer based on GOOSE (Generic Object Oriented Substation Events) between IEDs
- Instrument Transformers (Conventional or Non-Conventional) to IED – based on the sampled values produced by a Merging-Unit

Because the IEC 61850-9.2 was a protocol largely open to the future that should not restrict any possible applications, there were many parameters that are not fixed and are subjected to different technical choices. This supports the required flexibility of the standard that makes it future-proof. However, it introduces an interoperability issue that had to be resolved.

The joint efforts of several major manufacturers under the umbrella of the UCA International Users Group resulted in the publication of implementation guidelines for substation applications.

Interoperability between merging units and protection, control, monitoring or recording devices is ensured through this document. Two modes of sending sampled values between a merging unit and a device that uses the data are defined. For protection applications, the merging units send 80 samples/cycle in 80 messages/cycle; i.e each Ethernet frame has the MAC Client Data containing a single set of V and I samples. For power quality monitoring and waveform recording applications such sampling rate may not be sufficient. That is why 256 samples/cycle can be sent in groups of 8 sets of samples per Ethernet frame sent 32 times/cycle.

The information exchange for sampled values is based on a publisher/subscriber mechanism. The publisher writes the values in a local buffer, while the subscriber reads the values from a local buffer at the receiving side.

A time stamp is added to the values, so that the subscriber can check the timeliness of the values and use them to align the samples for further processing. The communication system shall be responsible to update the local buffers of the subscribers. A sampled value control (SVC) in the publisher is used to control the communication procedure.

Figure 4 shows a simplified block diagram of a merging unit including amplifiers, filters, analog to digital converter and DSP signal processing. The merging unit is synchronized using 1 PPS signal from a GPS receiver. As can be seen from the figure, there is a time delay D = D1 + D2 introduced within the device. If this time delay is not compensated, it will be seen as a phase shift (Figure 6) that will affect all functions using the sampled analog values.

The receiving devices then process the data, make decisions and take action based on their functionality. The action of protection and control devices in this case will be to operate their relay outputs or to send a high-speed peer-to-peer communication message to other IEDs in order to trip a breaker or initiate some other control action.

There is an important detail that needs to be considered when processing the data by the receiving IED. The sampling rate in the merging unit is fixed, because the samples/cycle are defined at the nominal frequency of the system. At the same time, the protection algorithms in most cases are based on frequency tracking with a fixed number of samples/cycle at the frequency of the system.

Many devices that are used both as conventional IEDs and IEDs with process bus interface capabilities have sampling rate different from the 80 samples/cycle. This will require re-sampling in order to run the different protection and other algorithms. (Figure 5)

A document itself can never convince a user that all interoperability issues are resolved. Especially protection engineers. They need to see it to believe it. That is why multiple interoperability demonstrations between major manufacturers on NCIT and protection and other IEDs were organized to show that this is not emerging, but existing technology.

The recent CIGRE 2006 DEMO presented a small part of a substation where several devices from different vendors were involved in an IEC 61850 process bus interoperability demonstration involving both merging units and protection devices. The test device injected currents and voltages into the different merging units that were interfacing with IEDs from a manufacturer different from the one that produced it.

The Demo was a real success and the perspective of using this technology excited many visitors.

Following the very successful experiment made with NCIT and distance protections interfaced by

The Process Bus information exchange is based on publisher/subscriber mechanism

a digital communication at EDF/RTE France during more than three years, several other pilot projects were launched:

- NGT (U.K.), Osbaldwick 400 kV GIB, with hybrid sensor like : Rogowski coils and capacitor electronics
- RTE (France), Saumade 245 kV GIS substation with hybrid sensors, MU and distance protections,
- HQ (Canada), La Prairie 315 KV AIS substation , with CTOs, and conventional CCVTs mixed in the Merging Unit. (Figure 7)

The first experiment is conducted with NGT on a GIL connecting two parts of a substation. Osbaldwick and Thornton substations, separated by thirty miles, are involved. A differential line protection is installed working with NCITs on one end and conventional ITs on the remote end.

The second one with RTE is Saumade GIS 245 kV substation, using NCIT based on hybrid technology (Rogowski coils and capacitors), connected on the merging-unit and interfaced digitally with two Distance protections, provided by Areva and Siemens, and a Landys+Gyr meter.

The third one is driven by Hydro Quebec and shows an application with optical Faraday sensors at 315 kV, in the substation La Prairie, near Montreal. Extreme temperature variations make a good demonstration of the technology reliability and stability in accuracy. Here again, protection devices come from different manufactures, showing interoperability. (Fig. 8)

Process Bus Benefits

Process bus based applications offer some important advantages over conventional hard wired analog circuits. The first very important one is the significant reduction in the cost of the system due to the fact that multiple copper cables are replaced with a small number of fiber optic cables.

Another result is the practical elimination of CT saturation because of the elimination of the current leads resistance RL.

In this case the CT secondary is connected to the phase current inputs of the Merging Units and RL is practically equal to zero. The knee-voltage then will be only dependent on

$$V_K = f(R_{CT}, R_{RP})$$

In this case the impedance of the merging unit current inputs RRP is very small, thus resulting in the elimination of CT saturation and all associated with it protection issues.

An additional benefit of process bus based solutions is the improvements of the safety of the substation by eliminating one of the main safety related problems - an open current circuit condition. Since the only current circuit is between the secondary of a current transformer and the input of the merging unit located right next to it, the probability for an open current circuit condition is very small. It becomes non-existent if optical current sensors are used.

Last, but not least, the process bus improves the flexibility of the protection system. Since current circuits can not be easily switched due to open circuit concerns, the application of bus differential protection, as well as some backup protection schemes becomes more complicated.

The above is not an issue with process bus, because any changes will only require modifications in the subscription of the protection IEDs receiving the sampled analog values over IEC 61850 9-2.

The Future

The process bus is a very promising technology. First experiences have proven its feasibility. The simultaneous experimentation of NCIT and process bus has first been driven by the NCIT in order to connect them to protection systems. The test of both technologies is probably one of the reason of the limited use today of the process bus. The focus on purely the process bus with conventional sensors is likely to develop the business, for instance for retrofit (replacement of cable) and voltage distribution (also in MV) applications.

The industrial optimisation phase shall now start in order to bring fully cost effective solutions and be generalized. New IEDs based on IEC61850-9-2 (protective relays, Intelligent Marging Unit, etc.) will become available progressively, while in parallel, the utilities will gain confidence in "protection over process bus".

Process bus based applications offer some important advantages over conventional analog circuits

8 Protection panel with merging unit

Merging unit interface with different protection devices