Digital Substation
Overview of Technology, Industry Trends and Standardization Efforts

4th International Scientific & Technical Conference
Actual Trends in Development of Power System Protection and Automation
3 – 7 June, 2013, Yekaterinburg, Russia
What is a Digital Substation?

It is a high voltage installation that:

- uses IEC 61850 Process Bus to implement digital measurement in the form of Sampled Values protocol, between the primary and the secondary equipment, either by means of NCITs with a digital output interface, or by digitizing analogue measurements from Conventional Instrument Transformers using Stand Alone Merging Units (SAMU), and

- uses IEC 61850 Station Bus as communications network with GOOSE and MMS messages for all information and signal exchange at the bay and station level
IEC 61850 Substation Architecture

Future use of IEC 61850:
- Substation-to-Substation
- Substation-to-Dispatch Center
- Synchrophasors over 61850

IEC 61850 Station Bus
Digital relays & control system

IEC 61850-9-2LE capable Protection Relays, Bay Controllers,

IEC 61850-9-2LE Process Bus
Digitization of signals from primary plant

Merging Unit
Remote Digital IO Module
Standalone Merging Unit
Remote Digital IO Module

Switchyard
Non Conventional Current Transformer
Non Conventional Voltage Transformer
AIS Switchgear
Non Conventional GIS/CVTs
GIS Switchgear

Dispatch Center
Corporate or Public WAN Network
Router and Cyber Security Gateway
Substation Gateway
IEC 61850 Process Bus Overview

Description

- The Process Bus enables transmission of digitized sampled measured values by NCITs (Non-Conventional Instrument Transformers) such as Optical Current Transformer, Electronic Voltage Transformers, Rogowski Coils, etc. for protection and metering application
- It also permits connection of intelligent switchgear devices such as circuit breakers, disconnectors or earthing switches

Key Benefits

- Reduction of primary copper wiring
- Cost optimization
- Better measuring accuracy
- Increased safety
NON-CONVENTIONAL INSTRUMENT TRANSFORMERS AND PROCESS BUS
NCITs – Non-conventional Instrument Transformers

Description
- Several technical and economical advantages over conventional transformers
- Development started more than two decades ago
- Defined in IEC 60044-7, IEC 60044-8 and IEC 61869
- Multiple technologies:
  - Fiber optic sensors
  - Electronic sensors
  - Rogowski Coils
  - Low energy sensors (capacitive dividers, etc.)

Main characteristics
- Don’t use magnetic cores
- Don’t provide high energy analogue output signals
- Facilitate standard digital output either natively or via converters (SAMU or equivalent)
Key Benefits of NCITs

• Highly accurate sensing for protection & metering, IEC class 0.2S
• Broad measurement bandwidth and unlimited dynamic range
• Eliminate CT saturation and ferro-resonance issue
• Prevents from explosive CT failure modes or open secondaries
• No active components in the field allowing long distances between primary sensor and secondary systems
Key Benefits of NCITs

• Reduced size, weight and cost
• Free maintenance insulator
• Environmental friendly design, no oil, SF6 or other gases
• Shorter lead times and easy spare parts management due to universal sensor head design for all voltage levels
• Digital output interoperable with modern protection devices that implement IEC 61850-9-2
Definition of the NCIT and Merging Unit in IEC 61869 Standard
Definition of the NCIT and Merging Unit

The Merging Unit is an integral part of NCIT and may contain proprietary communication links to acquire measured signals from primary sensors.

Merging Unit implements standard digital interface of IEC 61850-9-2 or IEC 61869-9.
**Definition of the NCIT and Merging Unit**

SAMU is a separate product and by definition an independent device, it can only have standard type of input interfaces to instrument transformers (digital interface, low power analogues, conventional analogues, etc.).

SAMU is standardized digital interface to different kind of instrument transformers defined in IEC 61869 series of standards.
Process Bus is a Fiber Optic Digital Switchyard

- MU is the digital interface and part of NCITs
- SAMU and RIO are standardized digital interfaces for CTs, VTs, Circuit Breakers, Switchgear, Sensors at Power Transformers, etc.
- SAMU and RIO ideally located at direct proximity to primary equipment
- Protection relays can be reduced to a CPU with Ethernet port only, no conventional IO modules
IEC 61850 Sampled Values

- Specified in IEC 61850-9-2
- Encapsulated directly in Ethernet layer
- High priority, critical, synchronous and unsolicited
- MAC Multicast, uses VLAN tag for prioritization & traffic segregation
- Multiple SV streams need to be synchronized
- Time synch via dedicated 1PPS wiring or via network (IEEE 1588)
- Multicast traffic needs to be filtered either by physical network separation of logical separation (VLAN, Multicast MAC filters)
- Network engineering is strongly recommended
• 61850-9-2LE called “Lite Edition” is the implementation agreement and a subset of IEC 61850-9-2
• 61850-9-2LE has fixed data set “PhsMeas1”:
  – 8 elements always being 4 currents and 4 voltages
• Two available sampling rates:
  – 80 samples per cycle - protection
  – 256 samples per cycle – metering and power quality monitoring
• 9-2LE SV frame at 80 samples/cycle has approx. 160 bytes
• At 50Hz and 80 samples/cycle a single Merging Unit consumes a bandwidth of approx. 5Mbit/s
• At 60Hz and 256 samples/cycle it consumes >15Mbit/s
PRACTICAL IMPLEMENTATION OF FIBER OPTIC CURRENT TRANSFORMER
Optical Fiber Current Sensing

- Suitable for AC and DC metering and protection in HV transmission systems
- Faraday Effect is the interaction between light and a magnetic field in a medium
- Polarization state of a linearly polarized optical signal is rotated as it travels through a magnetic field
- The angle rotation is proportional to the current enclosed by the path: \[ \theta = \int \frac{V}{s} \cdot d\vec{l} = VI \]
SPOF Sensing Fiber
(Spun Polarising Optical Fiber)

- Employed to avoid the large linear birefringence due to curvatures
- Local linear birefringence and the spinning combine to produce a fiber with a large circular birefringence

Cross section

Stress Region
Core
Cladding

Sectional drawing of Spun HiBi fibre structure
Faraday Effect – Measurement Dynamic Range

- Metering accuracy limit
- Operating zone
- Conventional protection accuracy limit

Values:
- 5%In
- 20%In
- In
- 120%In
SDO OCT – Practical Implementation of Optical Current Transformer

The product includes three components:

• **Sensor head**
  – Fiber sensor, based on Faraday effect
  – Fully passive optical multiplexing network including Sagnac interferometer
  – Accuracy Class IEC 0.2S

• **Insulator**
  – Post type insulator or suspension type flexible HV link
  – Connectorized fiber link inside allow easy interchangeability of insulator/sensor head

• **Merging Unit**
  – 61850-9-2LE or IEC 61869-9 digital output via dual ports
  – Up to 128\(^{th}\) harmonic
  – Optional 4xVT analogue inputs class 0.2/3P for conventional
  – Optional 1xCT inputs for conventional CT (neutral current)
  – Optional LEA (Low Energy Analogues) outputs
Merging Unit – Practical Implementation

- Optical links to OCT
- Voltage analog inputs
- 2 x Digital interface Duplex LC connector
- Relay contact outputs
- Power supply 88 – 270 Vac/Vdc
EXPERIENCE FROM PROJECTS
COPEL, Brazil, Paranagua 138kV SS Metering and Protection
CFE, México, Chihuasen 420kV SS Metering and Protection
Transition of Albany-Henderson 110kV Overhead-Underground Circuit, New Zealand
Rio Tinto, Gladstone, 132kV Harmonic Filter
CONCLUSIONS
Digital Substation - Market Trends

Market Situation
• Some utilities have been testing NCIT for over 8-10 years and still have not decided to go for commercial deployments
• Currently only pilot projects (except China), however growing interest
• In the next 3-4 years the number of pilot projects will increase as utilities want to validate and compare various technologies
• Large scale commercial deployment not earlier than in 2016
• The evolution towards fully digital substations based on digital measurement transformers and new generation of intelligent switchgear seems unstoppable

Main Reasons
• IEC 60044 & IEC 61850-9-2 - existing standards not covering all aspects of digital acquisition chain
• IEC 61869 - the new standard not finalized yet, expected by 2014-2015
• Not enough field experience and limited results available
• Not enough commercial products available and price not yet competitive compared to conventional ITs

Utilities are slow to adopt a technology that has not be sufficiently tested and does not bring short-term clear economical benefits
Thank You!