Digital Switchgear concepts for MV Applications

Take full advantage of IEC 61850 and enable digital switchgear

Daniel Vettraino & Vincent Duong

About the presenter

Daniel Vettraino
Regional Business Development Manager / Field Application Engineering
Electrification Products Division

Daniel Vettraino has been working within ABB group for 10 years and currently holds a Regional Business Development Manager / Field Application Engineering position in Electrification Products Division. He received his BSEE degree with Electrical & Computer Engineering specialization from Northeastern University; and his MSEE degree in with Electrical & Computer Engineering specialization from Northeastern University.

Daniel has spent most of his career in electrical distribution, power and control, including one-line distribution design, 480V to 38KV application technical support and complete system solutions. He is also actively involved in customer training and electrical distribution instruction. He is an IEEE member, EIT certified of Massachusetts. He has over 25 years of related experience with Schneider Electric, RG Vanderweil Engineers, Russelectric and the US Army National Guard.
About the presenter

Vincent Duong
Product Market Specialist for Mega Projects
Electrification Products
Division | Medium Voltage Business Unit

Vincent G. Duong, P.E., PMP has been working within ABB group for 6 years and currently holds a Mega Project Account Development Manager position in Medium Voltage Distribution Automation group. He received his BSEE degree with Power System Specialization from the University of Alberta in Edmonton, Canada; and both MBA and MS in Operations and Project Management degrees from Southern New Hampshire University in Manchester, New Hampshire. Vincent has spent most of his career in distribution and transmission protection and controls engineering, including system modeling, study, design, relay settings, and system disturbance analysis. He is also actively involved in customer training and power system protection-coordination instruction. He is an IEEE member, a registered Professional Engineer of New Hampshire, and Project Management Professional of Project Management Institute (PMI).

Available CEU / PDH Session Topics

1. Session 1: IEC 61850 GOOSE enabled digital
2. Session 2: Leveraging the Internet of Things advances in monitoring and diagnostics of distribution system assets
3. Session 3: Improvements in capacitive switching technologies
4. Session 4: Arc Mitigation - passive and active techniques and practices
5. Session 5: Considerations for the application of MV high-speed grounding switch for arc flash mitigation of LV equipment
6. Session 6: LV Connectivity - Grounding and Bonding for LV Systems
7. Session 7: Extending the Life of an Electrical System – Corrosion & Harsh Environments
Why digital switchgear?
What is digital switchgear?
IEC 61850 enabled relays
Key digital switchgear components:
  - Current and voltage sensors
  - Protection & control relays with LEA inputs
Innovative bus protection with digital switchgear
Major benefits with examples
**ANSI medium voltage switchgear**

What do customers want?

- Distribution networks have evolved and become more complex.
- Industry trends want MV switchgear that is:
  - more efficient
  - safe
  - smart
  - reliable
  - environmentally friendly
  - easy to engineer, install and operate
- MV Switchgear has a more important role as part of the grid than before

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**Digital Switchgear (Low or Medium Voltage) Defined**

An enclosure for circuit switching, interruption and control devices where all measurement, device status information and commands are reliably transferred on a common communication [IEC 61850] Ethernet bus using remote digital sensors (current and voltage).
## Digital Switchgear - the next evolutionary step

<table>
<thead>
<tr>
<th>1890-1920</th>
<th>1921-1940</th>
<th>1940-1970</th>
<th>1970-present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early years of power</td>
<td>Moving into enclosures</td>
<td>Going from oil to air</td>
<td>Modern standards and switchgear construction</td>
</tr>
</tbody>
</table>

- 1921: Merlin Gerin produced the first oil circuit breaker
- Electro-mechanical protective relays introduced
- First circuit breaker performance std issued in 1919
- 1924: 1919 Performance Standard was revised
  - Prohibits flame during interruption
  - Requires the condition after an interruption to be "...substantially the same as before"
- Metal-enclosed concept was carried over to MV levels
- 1938: 2500-5000 V metal-enclosed switchgear with interrupting capacity up to 150,000 kVA
- Units featured an enclosed, insulated bus

- 1927: A patent for the first arc-chute design filed
- 1940: Most oil tank breakers phased out for the preferred minimum oil breaker design
  - Produced up to the mid 1970’s
- 1940: First air-blast circuit breaker offered commercially
- 1945: C37.6 introduced preferred ratings for indoor, oil circuit breakers up to 34.5kV
- Switchgear construction was still basically the same (metal-enclosed) until 1960, metal-clad construction became popular
- Protective Relays
  - 1943: FlexiTest relay cases became available
  - 1960s: Continual improvement of electro-mechanical relays
  - 1965: First solid state relay introduced
- Breaker standards became fully developed
  - C37.04, C37.06 & C37.09
- Switchgear standards adapted to changing technology and addressed construction differences
  - C37.20.1: Metal-Enclosed Low-Voltage Switchgear
  - C37.20.2: Metal-Clad Switchgear
  - C37.20.3: Metal-Enclosed Interrupter Switchgear (1-38 kV)
- Emergence & increased adoption of vacuum technology
  - Development began as early as the 1920s
  - Commercial products appeared in the late 1960s
  - Dominant by the early 1980s at medium voltage
  - Provided advantages in size, interruption capability and maintenance over oil
- SF6 & GIS Technology enter the market in late 1970s.
- Protective Relays
  - 1980s: Microprocessor relays developed
  - 1990s: Microprocessor relays replace solid state devices
IEC61850 Enabled Relays

Basics:
- Fast Ethernet (100 MBps to 1 GBps)
- MMS
- Station Bus 61850 8-1
- Process Bus 61850 9-2
- Data Model
- Substation Configuration Language

Much more than a protocol:
- Modularization and structuring of data
- On-line meaningful information
- Free allocation of functions in IEDs
- Complete description of configuration
- Structured engineering & services
- Testing, validation, and certification

IEC61850 Based Substation Automation Systems

Modbus RTU...
DNP...
TCP/IP...
IEC 62271...

“Combining the best properties in a new way...”
Relays for digital switchgear
Future proof solution based on IEC 61850

- Based on worldwide accepted IEC 61850 standard ensuring long-term sustainability
- Ready to be connected to remote control (SCADA) systems
- GOOSE messaging configured with software setting
- Available IEC 61850 Edition 2 features:
  - Vertical communication
  - Horizontal GOOSE communication (peer to peer)
  - Process bus
  - LEA (low energy analog) inputs

What is a GOOSE message?

Generic Object Oriented Substation Event
Ethernet multicast message
Fast and reliable distribution of information
- Status (breaker position, trip, pickup, alarms, etc.)
- Analog (counter values, etc.)

Performance
- Fast messages Type 1A (Class P2/P3) received within 3ms.
- Includes transmission time into the other IEDs
- Similar to an output to input connection between 2 relays
- Broadcast capable to all relays simultaneously
- Messaging: 1-to-1 / 1-to-many / many-to-many
- Interoperability among different vendors
- Non propriety

- GOOSE messages are based on change event
- Includes diagnostic functions
- A heart beat to all devices subscribed is sent periodically
- Managed by GOOSE control blocks inside IEDs
- Send data sets upon changes of state
- Number of connections equal to number of devices
What is Process Bus?

Conventional connections to CT/VT and drives
Process bus to merging units for current and voltage sensors
Process bus to merging units for current, voltage and binary signals

MU = Merging Unit
NCIT = Non Conventional Instrument Transformer
SAMU = Stand-alone Merging Unit
BIED = Breaker IED

Digitized Copper (8-1 and 9-2)

Station level
Bay level
Process level

Station bus (8-1)
GOOSE
Client / Server
SMV
Process Interface

Engineering/ Monitoring
Gateway
Control
Protection & Control
Control
Protection
Process Interface

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IEC61850 Enabled Relay
Protection and control

IEC61850 Edition 2
- The relays support the IEC 61850 standard for communication and interoperability of substation automation devices according to Edition 2.
- Edition 2 offers the best possible interoperability for modern substations.
- Edition 1 is still supported as Edition 2 and Edition 1 are selectable modes during the engineering phase.
- Edition 2 offers:
  - Full relay functionality modelling for substation applications
  - Zero-loss Ethernet redundancy with HSR and PRP
  - Improved device mode handling for relay testing
  - Advanced and safe station control authority

Network Redundancy

IEC61850 Ethernet redundancy - HSR
- Optional second fiber-optic or galvanic port (only fiber-optic for RED615)
- Enables redundant Ethernet communication controlled by a managed switch with IEC 61850 HSR protocol support
- Avoids single point of failure without any delay
- Secures highly critical communication between devices
  - Communication downtime is eliminated.
  - If the ring is broken, messages will still arrive over the intact path.
  - A broken ring is easily detected since duplicate messages are no longer received
Network Redundancy

IEC 61850 Ethernet redundancy - PRP

- Optional second fiber-optic or galvanic port (only fiber-optic for RED615)
- Enables redundant Ethernet communication controlled by a managed switch with IEC 61850 standard PRP support
- Avoids single point of failure without any delay
- Secures highly critical communication between devices
  - Communication downtime is eliminated.
  - The communication network is fully duplicated.
  - If only one packet is received, the receiver knows the other path is broken.

Time Synchronization

IEEE 1588 time synchronization

- The relay supports IEEE 1588 V2 Precision Time Protocol (PTP) with Power Profile.
  - Provides high-accuracy time synchronization of 1 μs
- Required especially in process bus applications with sampled values using protocol IEC 61850-9-2 LE
  - Time stamp resolution of the relay: < 4 μs
- IEEE 1588 support is included in variants having a redundant Ethernet communication module and with the following protocols:
  - IEC 61850
  - Modbus®
  - DNP
IEEE 1588 time synchronization example using HSR

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**Time Synchronization**

IEEE 1588 time synchronization example using HSR

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**ANSI medium voltage switchgear**

Levels of digitalization

<table>
<thead>
<tr>
<th>Digital switchgear</th>
<th>Description</th>
<th>Main switchgear value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong></td>
<td>Simply replace CTs &amp; PTs with Current &amp; Voltage Sensors</td>
<td>1. Reduced weight&lt;br&gt;2. Space saving (primarily due to elimination of PT compartment)&lt;br&gt;3. Eliminates problems of saturation and Ferroresonance&lt;br&gt;4. Safety-no possibility of open CT circuits</td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td>Above + IEC61850-8-1 &amp; GOOSE messaging Ethernet cabling between Protective Relays.</td>
<td>Above +&lt;br&gt;5. Significant reduction in wiring between frames&lt;br&gt;6. Late customization</td>
</tr>
<tr>
<td><strong>Level 3</strong></td>
<td>Above + Process bus (61850-9-2LE) requires use of Merging Units (MUs), time synchronization devices &amp; Ethernet switches. Fiber optic connection from bay (switchgear) to substation.</td>
<td>Above +&lt;br&gt;7. Improved flexibility - changes in protection only require IED level changes.</td>
</tr>
</tbody>
</table>
ANSI medium voltage digital switchgear
Next phase in the evolution of switchgear

Digital Switchgear is not only new products, it is also a new concept in protection, control, and automation.

SAFETY & SIMPLICITY are the most significant benefits, but there are many more.
What standards are applicable to sensors?

Background

- The latest version of the metal-clad switchgear standard, IEEE C37.20.2-2015, addresses the use of sensors in ANSI metal-clad switchgear
- There are two IEC standards applicable to sensors:
  - IEC 60044-7 Electronic voltage transformers
  - IEC 60044-8 Electronic current transformers
- These standards are being replaced by the IEC 61869 family:
  - IEC 61869-6: General requirements for Low Power Instrument Transformers
  - IEC 61869-7-8: Electronic Instrument Transformers
  - IEC 61869-10-11-12: Low Power Stand-alone Sensors
- Currently no ANSI/IEEE standard that applies to current & voltage sensors. Power System Instrumentation and Measurements (PSIM) Committee of IEEE has formed a working group to develop standards for the use of sensors in ANSI equipment. The intent is to reference the relevant IEC standards for the sensors. This activity is expected to continue for several months before a standard will be published.
- Working on UL: C37.20.2 annex to allow voltage sensors although it references the wrong IEC standard, this requires correction (which could take up to a year)...

How is a current sensor selected for an application?

Current Sensors

- What three (3) parameters are needed?
  - Primary current, Primary voltage and Short-circuit current
- Why are CT calculations not needed?
  - Sensors do not have any iron core which might saturate, therefore their characteristic is linear in the whole operating range. Load characteristics are addressed through the IED. Due to this fact, it is not necessary to check parameters of sensors as it is done with the conventional CTs.
Is Digital Switchgear Constructed Differently?  
Form factor permits switchgear space savings

Voltage sensors
More flexibility in placement of voltage sensors as compared to PTs.
Major space savings possible if we use them as bus supports.
Located in bus/cable compartment to remove the necessity for a dedicated drawer.

<table>
<thead>
<tr>
<th>MV sensors</th>
<th>Standards</th>
</tr>
</thead>
</table>
- IEC 61869-10 (NEW)  
- IEEE PSIM Working Group  
- CSA Available|
| Electronic current transformers |
| Voltage sensors | - IEC 60044-7 (1999)  
- IEC 61869-11 (NEW)  
- IEEE PSIM Working Group  
- CSA Available|
| Electronic voltage transformers |

Latest version of IEEE C37.20.7-2015 address the use of sensors in ANSI metal-clad switchgear

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Sensors - ideal for critical applications  
Concerns better addressed by sensors

- 20+yr old technology in switchgear with over 150,000 units in operation
- Use solid state components and little or no ferromagnetic material in circuit
- Lack of magnetic core → very low energy output → cannot typically transfer power to secondary
- Numerous form factors for indoor and outdoor application (voltage only, current only, combination)
- Wide variety of outputs – from ~100 mV / mA to 120 V / 1 Amp

BENEFITS
- Increased safety
- Reduced footprint
- More linear response
- Simplified installations – less wiring, smaller footprint, lighter weight
- Digital implementation (on board A/D) with present and future advantages
- Reduced energy use, esp. in tight compartments
Current sensors
Current sensors are safer than conventional CTs

Digital switchgear
Rogowski coil sensor
- Us=150 mV for 50 Hz --- 80 A Primary
- Us=180 mV for 60 Hz --- 80 A Primary
Proven technology which brings many benefits in various applications >5 years
Low Power CT, output is voltage rather than current
Output voltage is proportional to the derivative of primary current
Output voltage is integrated by protective relay
Accuracy up to class 0.5
Complies with IEC 60044-8
FOCs (Fiber Optic Current Sensor) mainly used in high voltage applications due to higher cost

No saturation (air core)
Open CT hazard eliminated

Rated short-time thermal current: up to 50KA/3s

Current sensors
Increased performance in differential protection

Rogowski Coil
Improved sensitivity for “in zone” faults
Speed of response
High security for “out of zone” faults
Multiple slopes not required (transformer)
Current sensors

Combined accuracy class 0.5/5P630

- Current sensors, thanks to their linear characteristic, guarantee wide range of primary current.
- The sensor standard, IEC 60044-8, defines accuracy characteristic as combination of metering and protection class into one.
- Thus, current sensors transmit currents from couple of Amps up to short circuit, therefore accuracy class is defined as 5P630, where 630 is not an error but a real number calculated out of maximal current to be transmitted via sensor to secondary side.

Accuracy of sensor is improved by utilizing correction factors in the protection relays.

Voltage sensors

Voltage sensors are safer than conventional PTs

Voltage sensors
- Resistive voltage divider sensor
- Non-saturable and linear over the whole measuring range
- 10,000:1 transformation ratio
- Accuracy up to class 0.5
- Passive element
- No fuses required
- Complies with IEC 60044-7

Gas Insulated Switchgear (GIS) uses Capacitive Voltage Divider (CVD) sensors.

No ferroresonance (non-inductive)
**Voltage sensors**

Combined accuracy class 0.5/3P

- For voltage sensors, the sensor standard IEC 60044-7 defines the accuracy class combining metering and protection class into one.
- Thus voltage sensors have accuracy class of 0.5.

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**How is a current sensor selected for an application?**

**Current Sensors**

- How is the grounding accomplished on a current sensor?
  - The current sensors have metal plated cover to properly ground the sensor in the switchgear frame.
- Is it possible to change polarity of the current sensor?
  - Yes, for ABB relays polarity can be changed in the protection relay setting: false or true
- What would you do for a zero sequence/ground sensor current transformer (GSCT)?
  - Physical dimensions required would necessitate using 3 sensors – one per phase – rather than a single large zero sequence CT. It would not have the sensitivity needed to accurately compute the residual current in the IED. It is recommended to use a conventional zero-sequence/ground current transformer. Relion IEDs used for digital switchgear have one input for conventional CT secondary signal (0.2/1A) that can be used for such instances. A strength of ABB IED solutions for Digital MV switchgear is the possibility to mix sensor and traditional solutions.
Current and voltage sensor connections to IED
Point-to-point wiring eliminated with RJ-45 ports and CAT5E cables

SENSORS
- Error free connections:
  - Directly to the protection relay for current/voltage measurements.

PROTECTION RELAY
- 3 combined sensor inputs per an analog input board.
  - Combines current and voltage measurement in one RJ45 port.
  - Point-to-point wiring eliminated with CAT5E cables

Almost no analog wiring in the switchgear - increases reliability

Current and voltage sensor connections to IED
Testing Operation

SENSORS
- FT Switch Digital per 3 Phase

PROTECTION RELAY
- FT-14 Switch Digital
- Test set

Protective relays must have LEA (Low Energy Analog) inputs compatible with the Rogowski coil and RVD sensors.

Almost no analog wiring in the switchgear - increases reliability
**Digital Solution Innovation**
Smart and efficient: Full utilization of 61850 GOOSE

<table>
<thead>
<tr>
<th>Traditional</th>
<th>61850 GOOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Traditional Image" /></td>
<td><img src="image2" alt="61850 GOOSE Image" /></td>
</tr>
<tr>
<td>E.g. Automatic Transfer Scheme (ATS)</td>
<td>E.g. Automatic Transfer Scheme (ATS)</td>
</tr>
<tr>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
<tr>
<td>- Single wire pulling &amp; testing one-by-one</td>
<td>✓ Factory pre-tested</td>
</tr>
<tr>
<td>- No loss of communication detection</td>
<td>✓ More than 2x the speed</td>
</tr>
<tr>
<td></td>
<td>✓ Increased reliability</td>
</tr>
<tr>
<td></td>
<td>✓ Reduced time &amp; costs</td>
</tr>
<tr>
<td></td>
<td>✓ GOOSE always monitored</td>
</tr>
</tbody>
</table>

Enhanced performance - time & cost saving during installation & commissioning

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**IEC 61850-9-2LE process bus & GOOSE messaging**
Footprint, copper wires, safety, reliability and cost

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How is a sensor tested?
Current & Voltage Sensors

- How do you test protection relays and sensors in the switchgear?
  
  * Sensor testing consists of primary injection testing only; the methods and tools are quite similar to CT and PT primary injection testing methods.

- How do you perform secondary injection testing on protection relays with sensor inputs?
  
  * The only difference is in the testing equipment. If the protection relays have sensor inputs, the secondary injection test set must support low power analog signals. Test switches are available in two styles, ABB and FT Digital type. For secondary testing a test block adapter is required.

- Is it necessary to disconnect the sensors when performing a HiPot (dielectric withstand) test of the switchgear?
  
  * No, the sensors can remain connected.
Bus protection
Benefits versus conventional schemes

Bus protection
- Safer to handle relays on energized switchgear due to digitized CTs and PTs
- Can be applied to either AIS or GIS switchgear
- Adaptable towards increases in system fault levels without the need to upgrade system components
- Flexible to bus expansion without labor intensive scheme changes versus conventional schemes.
- Reduction of wiring versus conventional schemes that removes the requirements for dedicated bus CTs
- Improved scheme security by being immune to the effects of CT saturation
- Low or no cost of bus protection scheme
- Communication redundancy
- Simpler

IEC 61850-9-2LE process bus & GOOSE messaging
System example of utilizing process bus
**Bus protection**  
Novel method using GOOSE messaging - overview

**Bus protection**
- Utilization of directional overcurrent elements of feeder protection relays.
- Dedicated bus protection relay and associated current transformers are not required (reduces footprint)

- **Reliable**: operates only upon a fault on the protected bus
  - All contributing breakers are tripped and block-closed
  - Acceptable operating speed ~3.16 cycles (50.5 ms)
- **Secure**: able to distinguish between internal and external (through) faults
  - Allows the individual breaker to trip first to maximize system reliability

**Bus protection**

Unique features

**Bus protection**
- Flexible to multiple incoming/contributing sources
- The bus protection is accomplished by each breaker's associated protection relay, existing hardware
- A master relay is assigned to perform the bus protection scheme with a backup relay automatically assuming the master relays operation during relay failure
- All contributing relays communicate to the master and backup relays via Ethernet based IEC61850 GOOSE communication
**Bus protection**

Scheme development

**Bus protection**

- IEC61850 compliant and capable of GOOSE communication
- If the constant integrity/quality check of the GOOSE communication is bad, the scheme shall be disabled and an alarm is issued immediately
- Two phase and ground directional overcurrent elements:
  - 67P/67N as reverse direction (REV) for detecting fault current flow into the bus
  - 67P/67N as forward direction (FWD) for both detecting and tripping fault current flow out of the bus (through) fault

**Bus protection**

Principle of operation (internal bus fault)

**Bus protection**

- Bus fault occurs
- At least one reverse direction (REV) element is detected
- Not any forward direction (FWD) element is pending
- The "master" relay trips and block-closes all contributing breaker via GOOSE

**Bus protection**

Note 1: IEC61850 9-2LE capable relay publishes voltage SMV to the remaining relays.
**Bus protection**

Principle of operation (external through fault)

**Bus protection**

- An external/through fault occurs, i.e., on Feeder #2
- Feeder #2 relay FWD detected
- The rest of relays either see REV or not FWD
- Feeder #2 breaker trips

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**Bus protection**

Communication redundancy

- IEC 61850 Ethernet Redundancy – HSR
  High-availability Seamless Redundancy (self-healing ring)
- IEC 61850 Ethernet Redundancy – PRP
  Parallel Redundancy Protocol (double star network).
- Supports IEEE 1588 V2 precision time protocol (PTP) high-accuracy time sync of 1 µs
How to select a sensor?

Configuring

- Do you need fusing with the voltage sensor?
- IEEE C37.20.2 does not require fusing on the primary of voltage dividers or other voltage sensing devices, due to no possibility of shorting of primary parts causing an arc to any live parts in the switchgear. If they meet one of the following standards, then they will not need primary fuses (no faults can be made):
  - IEC 61243-5 (Capacitive dividers)
  - IEC 62271-206 (Voltage dividers)
  - C37.20.2-2015 (Annex D)
  - C37.20.9 (Annex D) (to be released in 2017)
- Fusing for PTs was addressed in the C37.20.9 committee meeting (2016). The committee, driven by UL, decided to not remove the requirement for PT fusing on Voltage Transformer (VT/PT) primaries since it is still a requirement in NEC. The fuse is there to protect the network, not the Voltage Transformer.

- How far can the sensors be from the relay?
- The solution is <10m cable length and the distance of the sensor from the relay will fall within the cable length restriction. Higher lengths <100m are possible and a 100m length has been tested. It is not recommended to extend the cable length >10m without first contacting ABB. The sensor can be designed for required cable length, but proper grounding on site needs to be ensured (critical).
Space and Weight Reduction - Example

Conventional 15kV (36in wide) metal-clad switchgear

<table>
<thead>
<tr>
<th></th>
<th>Estimated Weight (lbs)</th>
<th>CT and PT Wiring (ft)</th>
<th>CT and PT # of Wire Terminations</th>
<th>A/W/T Hours</th>
<th>Number of Shipping Splits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional 15kV (36in wide)</td>
<td>33625</td>
<td>2500</td>
<td>910</td>
<td>135</td>
<td>3</td>
</tr>
</tbody>
</table>

- 324" (27')

15kV (26" wide) metal-clad switchgear with same functionality

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<td>29100</td>
<td>2500</td>
<td>910</td>
<td>135</td>
<td>3</td>
</tr>
</tbody>
</table>

- 234" (19.5')

- 27.8%

- 13.5%

Same ratings
smaller footprint
Space and Weight Reduction - Example
15kV 26” wide digital switchgear with same functionality

<table>
<thead>
<tr>
<th>Estimated Weight (lbs)</th>
<th>Sensor Wiring (ft)</th>
<th>Sensor # of Wire Terminations</th>
<th>A/W/T Hours</th>
<th>Number of Shipping Splits</th>
</tr>
</thead>
<tbody>
<tr>
<td>25182</td>
<td>289</td>
<td>76</td>
<td>24</td>
<td>2</td>
</tr>
</tbody>
</table>

- 25.1% - 88.4%
- 91.6% - 82.6%
- 88.4% - 82.6%
- 33.3%

~5 business day reduction assuming 3 workers

Digital switchgear benefits
Reference project: Typical MTM arrangement

- Typical applications involving Main-Tie-Main arrangements require transfer schemes which can only be achieved by having both current and voltage measurements.
- Frames need to house breakers, PTs/CTs, and bus tie transition. Therefore, 3 frame M-T-M configuration has become very common.
- PT compartments take up crucial space. When replaced by a voltage sensor this space becomes available.
The use of non-conventional instrument transformers (NCITs) like sensors in place of current and voltage transformers will allow for a reduction from 3 to 2 frames for M-T-M arrangements. In addition, the use of sensors makes the 2-frames more flexible since current and voltage sensors are not dependent on ratios/ratings (they are programed in the IED). Therefore, regardless of load variances, the same lineup can now be used for the following schemes:

- Open Transition
- Closed Transition
- Fast Transfer
- Zone Selective Interlocking
Digital switchgear benefits
Reference project: ANSI switchgear at a US polymer chemicals complex

Footprint reduced (3 frames): -25%, costs: -8.9%
Digital switchgear benefits
Reference project: IEC switchgear on an offshore platform in Europe

Footprint (reduced 13 frames): -6.5%, costs: -3%
Case Study Savings

Conventional Metal-Clad Switchgear 3000A @ 40KA MTM configuration with 18 frames

Base Bid- $952,000  Competitor’s relays with IEC 61850 communication

Option 1- $920,050  Replace competitors’ relays with ABB Relion Relays using native IEC 61850 language.

Option 2- $881,680  Remove bus differential relays and associated CT’s to accomplish Bus diff digitally through IEC 61850.

Option 3- $864,680  replace remaining CT’s and PT’s with digital sensors.

9.5% cost savings plus digital benefits

Digital Switchgear Benefits - Savings

Reduced total cost of ownership

- Reduced losses during operation
  - Sensor losses are low
  - Saving potential of up to 250 MWh over 30 years (sample switchgear with 14 frames & 42 CTs or Sensors)
- Improved equipment reliability
  - Fewer live parts, fewer failure opportunities reducing outage potential and troubleshooting costs
- Reduced inventory need
- Lower initial price due to fewer frames needed. This solution requires less space
  - Complete PT compartments can be eliminated
  - Reduced space means lower costs for housing
## Digital Switchgear Benefits - Savings

### Energy savings

<table>
<thead>
<tr>
<th>Feeder</th>
<th>CTs</th>
<th>Number of panels</th>
<th>Number of CTs</th>
<th>Power consumption</th>
<th>Energy consumption in 30 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incoming</td>
<td>1000/1/1A</td>
<td>2</td>
<td>6</td>
<td>130 VA</td>
<td>36 698 kWh</td>
</tr>
<tr>
<td>Outgoing 1</td>
<td>200/1/1A</td>
<td>8</td>
<td>24</td>
<td>448 VA</td>
<td>117 776 kWh</td>
</tr>
<tr>
<td>Outgoing 2</td>
<td>100/1/1A</td>
<td>4</td>
<td>12</td>
<td>102 VA</td>
<td>26 724 kWh</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>14</td>
<td>42</td>
<td>690 VA</td>
<td>181 198 kWh</td>
</tr>
<tr>
<td>Incoming</td>
<td>1000/5/5A</td>
<td>2</td>
<td>6</td>
<td>172 VA</td>
<td>45 244 kWh</td>
</tr>
<tr>
<td>Outgoing 1</td>
<td>200/5/5A</td>
<td>8</td>
<td>24</td>
<td>629 VA</td>
<td>165 208 kWh</td>
</tr>
<tr>
<td>Outgoing 2</td>
<td>100/5/5A</td>
<td>4</td>
<td>12</td>
<td>179 VA</td>
<td>47 124 kWh</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>14</td>
<td>42</td>
<td>980 VA</td>
<td>257 576 kWh</td>
</tr>
<tr>
<td>Incoming</td>
<td>-</td>
<td>6</td>
<td></td>
<td>0.0000 VA</td>
<td>0.0000 kWh</td>
</tr>
<tr>
<td>Outgoing 1</td>
<td>-</td>
<td>8</td>
<td></td>
<td>0.0000 VA</td>
<td>0.0000 kWh</td>
</tr>
<tr>
<td>Outgoing 2</td>
<td>-</td>
<td>4</td>
<td></td>
<td>0.0000 VA</td>
<td>0.0000 kWh</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>14</td>
<td>42</td>
<td>0.0000 VA</td>
<td>0.0001 kWh</td>
</tr>
</tbody>
</table>

### Huge Inventory Savings

- **Voltage transformers**: 10's
- **Current transformers**: 100's
- **Sensors**: 2

**Full range**: up to 4000 A, 63 kA at 15kV
Digital Switchgear Benefits - Sustainability

Lower environmental impact

- Late changes / late customization
- Flexibility for varying applications (via IED)
- Quicker Delivery Time – from order to completion
- Substation availability and personnel safety
- Space saving solution / reduced weight up to 15%
- Solution uses less material
  - Less steel, less copper, less insulation, …
- Solution with reduced losses
  - Less energy required to operate the gear as there reduced losses in the sensors
- Solution can save significant level of CO₂

Sustainability of a sensor?

Reliability

- What is the failure rate of the sensors out in the field? Alternatively, what about the reliability of the sensors?
  - (This question has added relevance because RVDs are used as bus supports and would be harder to replace than a PT in a PT draw-out design, or when remote mounted from the bus). In the whole sensor family, there have been no field failures since their release over 25 years ago. The sensors are designed for a 30-year lifetime. Furthermore, the low failure rate is because of the following:
    - Current Sensors: The output levels are very low power/voltage compared to the insulation levels, e.g., the wire used in sensors is capable of withstanding several kV but is stressed only in mV.
    - Voltage Sensors: ABB design allows very low thermal burdens (Power) on RVDs allowing RVDs to perform for several decades. Our voltage sensors with 1/10th to 1/100th the output of traditional ITs pass IEEE type and routine tests including BIL and Power Frequency Withstand tests.
- How do the sensors respond to harmonics in the system, harmonic distortion of signal from sensors?
  - The sensors will simply transfer the harmonics. In fact, the high frequency components can be more accurately transferred. Most relays will filter out higher than the 25th harmonic.
  - Rogowski coil transmits true signals including harmonics (it is the feature of Rogowski coil) up to the limit frequency (it depends on sensor type, it is in range from units of kHz up to tens of kHz) and then there is attenuation.
ANSI medium voltage digital switchgear
The Five Ss

**Safety**
- Low energy analog output eliminates hazard associated with open CT secondary
- Fewer wires to install makes switchgear easier to maintain
- Solution is continuously self-supervising with maximized error detection

**Savings**
- Form factor of voltage sensors = switchgear space savings
- Size of current & voltage sensors = weight savings
- Broad application range of the sensors = inventory savings
- Significant energy savings during operation
- Savings on total cost of ownership

**Speed**
- Concept allows for compression of time from order to delivery
- Late customization possible

**Simplicity**
- Fewer wires to install, commission & maintain
- Fewer parts to fail leads to increased reliability

**Sustainability**
- Universal standards (IEC61850) enable future system expansion
- Handle future load changes without mechanical reconfiguration of system
- Lower lifetime environmental impact

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ANSI medium voltage digital switchgear
Designed to meet the needs of the future (and today)

- **Be simple!**
- **Be reliable!**
- **Be efficient!**
- **Be future proof!**
- **Be “smart”!**
- **Be on time!**
- **Be flexible!**
- **Be safe!**
- **Be easy!**
- **Minimal variation > Low inventory needed**
- **Simplified wiring**
- **Possibility of late customization**
- **Significant energy savings**
- **Space & weight saving**
- **Measurement devices with high accuracy over an extended range. Can deal with varying load flows.**