Case Studies of IEC 61850 Process Bus Systems Using GOOSE and Sampled Values: Recent Installations and Research

John Bettler
Commonwealth Edison Company

Jesse Silva
Southern California Edison

Dan Morman
Puget Sound Energy

Ricardo Abboud, David Bowen, Ed Cenzon, and David Dolezilek
Schweitzer Engineering Laboratories, Inc.

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NERC definition of protection system

Current definition includes station bus communications
Proposed new definition adds process bus communications.
### Device performance criteria defined by international standards

<table>
<thead>
<tr>
<th>Category</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal dependability and security requirements</td>
<td>IEC 61850 and IEC 60834</td>
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<tr>
<td>Device availability requirements</td>
<td>IEC 61850, IEC 60834, and IEEE 802.1</td>
</tr>
<tr>
<td>System reliability metrics</td>
<td>IEC 61850, IEEE 1613, and IEC 60870</td>
</tr>
</tbody>
</table>
Signal exchange criteria defined by international standards

Packet dependability and security requirements
IEC 61850, IEC 60834, IEC 15802, and IEEE 802.1

Packet latency specifications
IEC 61850, IEC 60834, IEC 15802, and IEEE 802.1

Signal speed
IEC 61850, IEEE 1646, and IEC 61869
Internationally standardized definitions
Centralized protection and control (CPC) system

Is a high-performance computing platform
Collects data via high-speed, time-synchronized measurements
Performs protection, control, monitoring, communication, and asset management

Working Group K15
Substation Protection Subcommittee of the IEEE Power System Relaying and Control Committee
ANSI C37.2 Device 11 multifunction device
Protection, automation, and control (PAC)
Replace traditional hardwired signals with digital messages

Copper conductors  Fiber connectors
Momentary outage <5 s
H2M SCADA, engineering access, synchrophasors
M2M time synchronization
Substation automation system

Momentary outage <15 ms
Station bus client-server H2M
M2M communications-assisted automation

Digital
Analog
Level 0
Physical

Level 1
Protection

Level 2
Automation

Level 5
Perimeter

Enterprise network

Ethernet gateway

SDN switch

CPC relay

CPC

IMU

SU

Controller

Relay

Ethernet gateway

STA switch

HMI

Computer

SIEM

Configuration
Communications-assisted interlocking

Momentary outage <15 ms

M2M interlocking, automation, and Boolean protection

Boolean MU
Station bus connection to process bus devices

Momentary outage <5 s

M2M time synchronization
Momentary outage <417 µs
M2M interlocking, automation, and Boolean and streaming analog protection
Communications supervising and auditing

Monitor and report behavior of H2M and M2M exchanges
Block controls that will create unwanted grid state

Detect, stop, alarm, and quarantine invalid packets
Capture LAN traffic for forensic review

Level 5 Perimeter
Clock
Ethernet gateway
Enterprise network

Level 4 Perimeter
STA switch
Ethernet gateway

Level 3 Access
SDN switch
Ethernet gateway

Level 2 Automation
Clock
SDN switch
CPC

Level 1 Protection
CPC relay
SDN switch
CPC relay

Level 0 Physical
IMU
MU
IMU
MU

Digital
Analog
6H2M-OT
M2M

Communications supervising and auditing

Monitor and report behavior of H2M and M2M exchanges
Block controls that will create unwanted grid state

Detect, stop, alarm, and quarantine invalid packets
Capture LAN traffic for forensic review
Internationally standardized definitions

Merging unit (MU)
Remote input / output module (RIO)
Process interface unit or device (PIU / PID)
Intelligent merging unit (IMU)

Working Group K15
Substation Protection Subcommittee of the IEEE Power System Relaying and Control Committee
Internationally standardized definitions

Class a
Minimal services to transmit MU data using SV

Class b
Class a plus GOOSE messages

Class c
Class b plus information model based on logical nodes with self-description

Class d
Class c plus buffered and unbuffered reporting and file transfer

IEC 61850 and IEC 61869 MUs
SV, GOOSE, and MMS
Internationally standardized definitions

**Class a**
Minimal services to operate switchgear (GOOSE)

**Class b**
Class a plus information model based on logical nodes with self-description

**Class c**
Class b plus buffered and unbuffered reporting and file transfer

**IEC 62271 switchgear MUs**
GOOSE and MMS
MUs in yard
Modular PACs centralized in building
Centralized modular and monolithic PACs

Control house

<table>
<thead>
<tr>
<th>A/D termination panel</th>
<th>Line PAC</th>
<th>Fast bus / transformer PAC</th>
<th>Relay</th>
<th>Computer</th>
<th>Battery kiosk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feeder PAC</td>
<td>Feeder PAC</td>
<td>Automation controller</td>
<td>Switch</td>
<td></td>
</tr>
</tbody>
</table>

Control kiosk

<table>
<thead>
<tr>
<th>Precise time</th>
<th>Computer</th>
<th>Automation controller</th>
<th>Battery kiosk</th>
<th>Switch</th>
</tr>
</thead>
</table>
IEEE IMU, IEC 61850, or IEC 61869 MUs in yard
SV, GOOSE, and MMS with 0 wires and 1 cable
Relays or IMUs in yard – best method to reduce copper instrumentation wiring
Traditional, distributed, and modular PACs
IEC 62271 switchgear MUs with GOOSE and MMS in yard
24 wires and 1 cable
MUs in yard – modular PACs centralized in building
Monolithic CPC – distributed MU and IMU

Control kiosk

Battery kiosk

Precise time
Computer
Automation controller
Switch

Relays 11 21
Relays 11 87
Relays 11 51
Relays 11 51
Relays 11 51
Relays 11 51
Relays 11 51
Relays 11 51

Control kiosk
Monolithic

Modular
Centralized monolithic

Centralized modular
Centralized monolithic

Centralized modular

Direct action buttons

HMI buttons
IEC TR 61850-90-4 network engineering guidelines – switched Ethernet connections

SAMU Part 7.3.2.2.2

NCIT Part 7.3.2.2.3

Dual-primary SAMU and relay Part 7.3.2.2.4

Dual-primary NCIT and relay Part 7.3.2.3.3

Switch-centric topology
IEC TR 61850-90-4 network engineering guidelines – point-to-point connections

Point-to-point
Part 7.3.2.3.5

Point-to-multipoint
Parts 7.3.2.3.6 and 7.3.3.2

Relay-centric topology
Networked solution considerations

- Communications engineering
- Dependence on external time
- Workforce development
- Cybersecurity
Process bus topology comparison

**Scenario A**
IEC 61850 IMU and IEC 61850 relay

Switch-centric topology
Process bus topology comparison

**Scenario B**
IEC 61158 MU and IEC 61850 relay

**Scenario C**
IEC 61850 relay (standalone in yard)
## Cost
Relative aggregate of equipment and labor

<table>
<thead>
<tr>
<th>Scenario comparison</th>
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</thead>
<tbody>
<tr>
<td><strong>Item / solution</strong></td>
</tr>
<tr>
<td>Protection and control relay</td>
</tr>
<tr>
<td>IMU or MU</td>
</tr>
<tr>
<td>Switch</td>
</tr>
<tr>
<td>GPS</td>
</tr>
<tr>
<td>Ethernet fiber interface</td>
</tr>
<tr>
<td>Relay panel design</td>
</tr>
<tr>
<td>Project panel MU</td>
</tr>
<tr>
<td>Automation panel design</td>
</tr>
<tr>
<td>Fiber launch</td>
</tr>
<tr>
<td>Relay configuration</td>
</tr>
<tr>
<td>MU configuration</td>
</tr>
<tr>
<td>Network configuration</td>
</tr>
</tbody>
</table>
## Complexity

Comparison of required knowledge and tools

<table>
<thead>
<tr>
<th>Item</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relay software</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MU software</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switch</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>GPS software</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional test enclosure</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SV test enclosure</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network analyzer</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Protection engineering</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SV network engineering</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
Unavailability
IEC 60870 fault tree
Speed – protecting and tripping line after applied fault
Speed – protecting and tripping line after applied fault

ADC and filtering → Transmit packet → Receive packet → Protection logic → Transmit packet

I/O logic → Receive packet → Fiber

Fiber
Speed – protecting and tripping line after applied fault

- ADC and filtering
- Transmit packet
- Fiber
- Receive packet
- Protection logic
- I/O logic
- Receive packet
- Fiber
- Transmit packet
### International scenario comparison

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cost</th>
<th>Complexity</th>
<th>Unavailability</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario A</td>
<td>Highest</td>
<td>Highest</td>
<td>Highest</td>
<td>Slowest</td>
</tr>
<tr>
<td>IEC 61850 IMU and IEC 61850 relay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario B</td>
<td>Middle</td>
<td>Middle</td>
<td>Middle</td>
<td>Middle</td>
</tr>
<tr>
<td>IEC 61158 MU and IEC 61850 relay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario C</td>
<td>Lowest</td>
<td>Lowest</td>
<td>Lowest</td>
<td>Fastest</td>
</tr>
<tr>
<td>IEC 61850 relay (standalone in yard)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
New IMU case studies

- Provide GOOSE trip continuity among stations
- Use IMU and NCIT
- Add process bus to existing relays

PSE
Algona, WA

SCE
Irvine, CA

ComEd
Chicago, IL
Advice from early adopters

- Previous experience
- Reason / desired benefits
- Topology
- Technology choices
- Metrics
- New technology in workplace
- Lessons learned
SCE NCIT optical sensing with process bus demonstration

- Limited to single subtransmission line and distance protection
- First field implementation of IEC 61850 process bus technology at SCE
Lessons learned

Monitoring device to compare SV with analog values proved valuable.
Lessons learned

Single point to EMS for process bus – alarms were “OR’d” to minimize alarms to operations
Lessons learned

Circuit breaker with built-in MUs provides efficient means of installation

Circuit breaker redesign is required for full station, since distribution voltages contain extremely small form-factor circuit breakers

Future full station design requires careful redesign of fiber-optic cable runs back to control room

Circuit breaker factory MU testing is valuable FAT testing

Firmware lockdown is required prior to installation
Questions?