Practical Applications of Peer-to-Peer Messaging in Industrial Facilities

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Agenda

- Fundamentals of IEC61850 Protocol
- Network Requirements
- Applications of Peer-to-Peer Messaging
- Conclusions
Overview of IEC61850 Protocol

- Evolving since 1997
- Uses Ethernet Network
- Communications between Different Manufacturers
  - **Station Bus** – Digital I/O & Analog Data Between IEDs (GOOSE Messaging)
  - **Process Bus** – Inst. Sampled Values, Status and Control
  - Client (SCADA/HMI/DCS) to Server ("IED") coms
  - Common Database Naming Format and Structure
Peer-to-Peer Communications Using IEC61850 GOOSE Messaging

Generic Object Oriented Substation Event (GOOSE)

- Ethernet LAN Required
- "Publisher-Subscriber"
- Reliable Message Delivery from One to Multiple Devices
  
  Reliability by Message Repeat

- Fast Delivery (1-2ms)
- Sent Periodically for Self-Test
- Multicast Message – Sent on Change of State
  - Binary I/O Values - False-to-True or True-to-False Transition
  - Analog Measurements - Value Changes Greater than Configured Deadband

- Typical GOOSE Message is About 300 bytes long or 2400 bits
  - Time on the Wire is 2400 bits ÷ 100,000,000 bits/sec = 24 μsec
  - Primary Limitation of Message Transmission and Reception is Change Detection in IED
Peer-to-Peer Communications Using IEC61850 GOOSE Messaging

**Generic Object Oriented Substation Event (GOOSE)**

**GOOSE Header:**
- Multicast Address
- GOOSE NAME and Its Controls (User Setting)
- Number of Data Items in GOOSE Message
- Time Until Next GOOSE
- Number of Times GOOSE Message Changed
- Number of Times GOOSE Message was Repeated
- Number of Times Configuration of GOOSE Changed
- TEST Flag

**User-Defined Dataset:**
- Status Information (I/O)
- Analog Values
- Data Quality
- Time

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IEC61850 GOOSE

Ethernet LAN

Relay Relay Relay Relay Relay
Reduced Wiring to IEC61850 IEDs

Standard Wiring to All Devices/IEDs

- 3 Phase & Ground Currents
- 3 Phase Bus Voltages
- 1-3 Phase Line Voltages for Synchrocheck Function
- 52a Breaker Contact
- TOC Contact (is breaker racked in?)
- Trip/Open Output
- Close Output
- Relay Control Power
- Ethernet Communications

*Exchange Logical I/O & Analog Info using Ethernet communications (Device I/O, Protective Element Statuses, Analog Values, Programmable Logic States)*
Network Requirements

- Topology of Network is Critical for GOOSE Messaging
- Redundancy of Ethernet LAN is Recommended
- Self-Healing Ring Configuration (Desired)
- Virtual Local Area Networks (VLAN)
- Quality of Service (QoS)
Network Requirements

Virtual Local Area Networks (VLANs)

- Handles Bandwidth More Efficiently (Separation of Traffic)
- Provides Additional Network Security
- Multiple “Virtual” Networks on Same Ethernet Switch or Spanning Multiple Ethernet Switches

VLAN Types:
- Port Based VLANs – Specific Port or Group of Ports to VLAN
- Tag Based VLANs, - VLAN Identifier Tag Sent as Part of Message

Tagged VLANs Used within IEC61850 GOOSE Messaging

Up to 32 VLANS Defined per Ethernet Switch (Depending on Manufacturer)
Network Requirements
Priority using Quality of Service (QoS)

- IEC61850 GOOSE Messaging uses Priority
- Quality of Service (QoS) Prioritizes Traffic on Ethernet Network – Eight Levels (Setting of 0-7)
- Not all Network Traffic Requires Same Priority
- Prioritizing Traffic into Different Classes Ensures Critical Data is Processed First (i.e. Protection Traffic, Data, Voice or Video)
- Allows Traffic to Accelerate Through Network – Improves Performance
Networking Topologies

Ring Architecture

- By Design, Provides Network Redundancy
- Unique Requirements for Protection and Control Industry is “Quick” Recover from Network Problems
- By using RSTP Techniques, Failure Recovery Time of 5 milliseconds per Ethernet Switch or Hop
- RSTP Sends Messages to Various Nodes in Network to Detect Broken Paths and Perform Re-configuration
Networking Topologies
Redundant Networks or Redundant IED Ports
Considerations

Per IEEE Power System Relaying Committee Working Group WG119 report, the following recommendations are made when using IEC61850 for critical applications:

“1. Connect multiple switches in a ring, so that there are at least two paths from any switch port used by a relay to any other such switch port. Ethernet switches include the failover service called rapid spanning tree protocol (RSTP) by which the switches discover and use a normal or default message path without circulating messages forever in a loop – one link in the loop is blocked to achieve this. If the ring suffers a break or if one switch fails, the switches can detect the path loss and immediately set up new routing of messages by unblocking the spare path to maintain communications.

2. Many GOOSE-capable relays have primary and failover communications ports. Provide two switches or switch groups within the redundant Set A, and also in Set B. Connect the relay’s primary port to one switch or switch group, and connect the relay’s failover port to the other switch group.”
GOOSE Messaging Application 1
Bus Zone Interlocking Protection Scheme

- Arc Flash Energy Expressed in $I^2t$
  - Decrease $I$ or Decrease $t$ to Lessen Incident Energy

- Protective Relays can Lower $t$ by Optimizing Sensitivity and Decreasing Clearing Time

- Low Impedance Bus Protection, High Impedance Bus Protection and Bus Zone Interlocking are Protective Methods Decrease Clearing Time

- Traditionally Coordinate between Main and Feeder Relays with Time Overcurrent Relays (ANSI 51)
  - Coordination Time Interval of 200ms or 12 cycles

**Bus Zone Interlocking Protection Scheme:**
- Main Relay - Definite Time Overcurrent
- Feeder Relay - Time Overcurrent
- Main Relay Tripped or Blocked Depending Fault Location Identified by Feeders Relays
GOOSE Messaging Application 1
Bus Zone Interlocking Protection Scheme

"Out-of-Zone Fault"

Block GOOSE Message Sent to Main Relay
GOOSE Messaging Application 1
Bus Zone Interlocking Protection Scheme

Main Trip Delay:

20ms  Main 50 Operate
20ms  Feeder 51 Pickup
2-4ms  Network Delay
8-16ms  Margin
50-60ms  Main Trip Delay

“In-Zone Fault”

Ethernet Switch

GOOSE Messaging

50/62

Main Breaker Trips after 3-4 Cycles

No Block GOOSE Message Sent to Main Relay
GOOSE Messaging Application 1
Bus Zone Interlocking Protection Scheme

Benefits
- Arc Flash Hazard Reduction
- Eliminates Need for Discrete Bus Differential Relay
- Easily Implemented in Retrofit Applications vs. Traditional Low or High Impedance Methods
- Transmitting and Receiving IEC61850 GOOSE Messages between Protective Relays at High-Speed via Ethernet
- Ease of Relay Coordination
- No Hard Wiring between Devices
- Easy Setup and Configuration
- Scheme Alarms when Protective IEDs are “Off-line” or not Communicating
GOOSE Messaging Application 2
Main-Tie-Main Bus Transfer with (2) IEDs
GOOSE Messaging Application 2
Main-Tie-Main Bus Transfer with (2) IEDs

- Peer-to-Peer Relay Communications between Relay 1 and Relay 2
- Bus Transfer Logic and Protection Implemented using Relay 1 (and/or Relay 2)
- Relay 1 Controls Main 1 and Tie Breakers
- Relay 1 Provides Phase & Ground Overcurrent Protection for Main 1
- Relay 2 Provides Phase & Ground Overcurrent Protection and Transfer Control for Main 2
GOOSE Messaging Application 2
Main-Tie-Main Bus Transfer with (2) IEDs

Digital/Analog Data Exchanged Between IEDs

Feeder Protection Relay 1

52A racked in & closed
Source A undervoltage
52T racked in
Transfer enabled
Transfer in AUTO
Source A downstream fault
52T closed

3-Phase Voltages
(for Synchrocheck)

Source B undervoltage
Transfer enabled
Close Tie from B transfer
Source B downstream fault
52B racked in & closed

Feeder Protection Relay 2
GOOSE Messaging Application 2
Main-Tie-Main Bus Transfer with (2) IEDs

**Benefits**
- Significant Reduction in Hardwiring
- Transmitting and Receiving IEC61850 GOOSE Messages between Protective Relays at High-Speed via Ethernet
- Easy Setup and Configuration
- Programmable Logic (Timers and Control Logic) within Protective Relays Provides Flexible / Custom Bus Transfer Scheme
- Selector Switch Functions (Select to Trip, Auto Transfer On/Off) via Protective Relay Faceplate Programmable Pushbuttons
- Zone Interlocking (Bus Protection) Easily Implemented
- Scheme Alarms when IEDs are “Off-line” or not Communicating
- Reconfiguration of Scheme without Time and Expense of Additional Wiring
- Easily Duplicate Additional M-T-M Systems by Changing IEC61850 Device Names
GOOSE Messaging Application 3
Fast Load Shedding

• Rapidly Sheds Load in Large Industrial Facility for Loss of Incoming Sources to Avoid Complete System Collapse while Maintaining Power to as Much of the Process as Possible

• Fast Initiation of Load Shedding before System Frequency/Voltage Declines, which Maintains System Stability – Unlike Undervoltage, Underfrequency, or Rate of Frequency Decay Load Shedding Schemes

• Scheme uses IEC61850 Based Relays on Ethernet Network to Calculate/Transmit Power at Locations Throughout Facility (Generation, Mains, Feeders/Loads)

• Analog Power Values are Sent via Analog GOOSE Messaging

• Open & Close Commands are Sent via Digital GOOSE Messages
GOOSE Messaging Application 3

Fast Load Shedding

- Aggregators Combine Load Information from Multiple IEDs into a Single IEC61850 Message – Extends Number of Loads Fast Load Shedding Scheme can Control
- Aggregators Retransmit up to Next Level (Master Controller)
- Generation or Power Sources are Connected to Master Controller
- Master Controller Determines Loads to Shed Based on User Configuration, Shed Groups and Priorities – Real Time Decisions (within milliseconds)
- Scheme Issues/Sends Load Shed Commands within 2 cycles of Loss of Generation
- This IEC61850 Based Architecture Can Shed over 2500 Loads
How fast is it in a typical system?

17 milliseconds

End device detects a change

GOOSE message is created

GOOSE message is parsed in the controller

Shed command composed and sent

Shed command goes through 20 Ethernet switches

Shed command parsed by end device

Trip command is sent to contact

Load trip contact closes

GOOSE Messaging Application 3
Fast Load Shedding
GOOSE Messaging Application 3
Fast Load Shedding
GOOSE Messaging Application 3
Fast Load Shedding

External computer (optional)

32 load group powers
32 infeed powers
32 reserve powers

Priorities or trip masks

GOOSE
Modbus over TCP/IP

Fast Load Shed Controller (FLSC)

E-switch

Aggregator

FLSC

End device

End device

Load data units (power, unavailable)

Infeed data units (power, offline)

Lacks, infeeds

Lacks, infeeds

Aggregator data message (32 load power groups)

Shed commands

Lacks

Lacks
GOOSE Messaging Application 3
Fast Load Shedding

Benefits

- Efficient Use of Protective IEDs for Protection and Control without External devices or PLCs
- Transmitting and Receiving IEC61850 GOOSE Messages (Both Digital and Analog) between Protective Relays at High-Speed via Ethernet
- Easy Setup and Configuration
- Scheme Alarms when IEDs are “Off-line” or not Communicating
- Reconfiguration of Scheme without Time and Expense of Additional Wiring
- Load Aggregation provides Large Number of Shedable Loads
- This type of scheme is impossible without IEC61850 because no other protocol has the capability of sending analog and digital messages with the speed required.
GOOSE Messaging Application 4
IEC61850 Process Bus – Transformer Protection
GOOSE Messaging Application 5
IEC61850 Process Bus – Generator Protection
GOOSE Messaging Application 6
IEC61850 Process Bus – Motor Protection
GOOSE Messaging Application 7
Device Tripping and Resetting Applications

- Transformer faults detected by and initiates **hardwire** trip to utility source breaker and **GOOSE** trip message to Motor Relays to trip each motor breaker.

- Target Reset of Transformer Relay used to send **GOOSE** target reset message to all Motor Relays to reset their targets.
GOOSE Messaging Application 7
Device Tripping and Resetting Applications

- Bus faults detected by Bus Relay initiates GOOSE trip to utility source breaker via Transformer Relay and GOOSE trip message to Motor Relays to trip each motor breaker

- Target Reset of Bus Relay used to send GOOSE target reset message to all Motor Relays and Transformer Relay to reset their targets
GOOSE Messaging Application 8
IED Measurement Verifications - IEC61850 Analog GOOSE

Current Comparisons:

- Bus Relay <-> Fdr1, Mtr1, Fdr2, Mtr2
- Low-Side: Bus Relay to Transformer Relay
- Time delay on alarms to ride through normal operating and fault conditions
- Continuous Verification of IED Health and Instrument Transformer
IEC61850 “Peer-to-Peer” GOOSE Applications

- Breaker Failure Initiate
- Breaker Failure Operate
- Broadcast Trip/Open Message
- Broadcast Close Message
- Main-Tie-Main Bus Transfer
- Ultra Fast Load Shedding
- Zone Interlock Bus Protection
- Remote Start/Stop Commands
- Remote I/O

- Remote Trip & Close
- Oscillography Cross Triggering
- Remote Device Target Reset
- IED Analog Cross Verification
- Arc Flash Mitigation (2nd Settings Level)
- Station Lockout Relay
- Process Bus Applications (Transmission, Generation, Feeder, Motor, Bus, Transformer)

Significant Cost Savings (Less Control Wire)
High Degree of Flexibility
Conclusions

- One GOOSE Message can Replace Hundreds of Wires Normally Used for Inter-Device Functionality
- IEC61850 Allows Standard Device Wiring
- IEC61850 Allows GOOSE Messages with Both Digital and Analog Information
- We Know when It is Broke – Alarms when IED(s) go off-line or No Communications
- Common Database Naming Format and Structure (“Self-Describing” IED, OPC Compatible)
- Simple Configuration and RE-Configuration
- Capability to Send High-Speed Process Data to IEC61850 IEDs
- Many Practical Industrial Applications of IEC61850 (Bus Zone Interlocking, Main-Tie-Main Bus Transfer, Fast Load Shedding, Device Tripping and Resetting, IED Measurement Verifications, etc.)

When Selecting New Devices Please Consider IEC61850
Questions?