IEC 61850 – The Digital Power System

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Agenda

IEC 61850 and the Digital Substation

- What is Substation Automation?
- High-Level Review of IEC 61850 and Digital Control
- Communication
- Data Model
- Engineering and Testing Process
- Benefits/risks

Future IEC 61850 Applications
What is a substation?

“A node on the electric grid where power is transformer, flow controlled, and monitored”
What is automation?

“The use of computers and machines to control mechanisms with minimal human guidance”
What is substation automation?

“Control of substation equipment (transformers, circuit breakers, switches) through computerized system”
IEC 61850 is a standard for substation automation communication

aka – how does “the brain” communicate

Goals of IEC 61850

- A communication protocol designed to model the entire station
  “Defines the rules of engagement for communication in a substation”
- Promotion of high inter-operability between systems from different vendors
  “Vendor agnostic – same rules regardless of the manufacturer”
- A communication protocol that can be made future proof
  “Network based – similar to an office computer network”
- Define testing required to ensure equipment conforms to the standard
  “How are you sure that everyone is playing by the same rules”
IEC 61850 – Substation Automation

The Premise

- Non-propriety, secure, and reliable network communication within an electric substation

Network Based Communication

- Analog (CT/PT) and discrete signals (contacts/trip/close) are transmitted over IT-based networks

- Communication paths “wiring” and logic is defined in software in lieu of physical wiring
IEC 61850 – Substation Automation

Modern Computer System

- Digital logic made possible by common programming languages
- Wired logical connections
- Standards enable off-the-shelf products
- Custom design

Original Computer

- Wired logical connections
- Custom design

Standards enable off-the-shelf products
Conventional vs. IEC 61850 Station

Example of a recently constructed control panel

Relay panel with partial 61850 installation

CT & PT wires not necessary

4 pairs of fiber provide full redundancy for control, protection, & maintenance
Conventional Substations

![Diagram of conventional substations](image)
An IEC 61850 Approach
## Wiring Comparison

<table>
<thead>
<tr>
<th>Conventional</th>
<th>IEC 61850</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor intensive and expensive wiring</td>
<td>Simplified and cost-effective</td>
</tr>
<tr>
<td>Limited performance and data transmission capabilities</td>
<td>Enhanced performance and data transmission capabilities</td>
</tr>
</tbody>
</table>
IEC 61850 – Digital Control System

Digital Control/Protection System

- Control is performed over network through digital devices (HMIs, relays, etc.)
- Test switches are not needed in the control house as voltages and currents are converted to digital signals in the yard
- Panel reduction and therefore control house size reduction
Digital Control System Example

In-Use Digital Control System

• Breaker Control Screen

Control done via screen, relay, or control center, reducing physical control switches

Tagging done locally at screen or relay, positive confirmation provided to control center
IEC 61850 System Example

System 1 relay package for a 345 kV switching station. This control house is smaller than many medium-voltage metal-clads.

Cabling between system 1 and 2 control panels.

Hundreds/thousands of copper wires in a traditional station are replaced with a few fiber optic cables.
IEC 61850 – Substation Automation

Recently constructed 345kV control house

Same 345kV control house using IEC 61850

158’-4” x 41’

~60” x 30’
Today there are 28 separate documents under IEC 61850 alone, along with supplemental material from IEEE and CIGRE.
IEC 61850 – Substation Automation

What makes IEC 61850 different from other standards:

- Data mapping of **electric substation** equipment
- Engineering and testing processes are built into the standard
- Communication protocols
  - GOOSE - Fast Transfer
  - SMV - Sampled Data
  - MMS – Reporting
- Each packet has:
  - Quality
  - Time sync
  - Test/Simulation
Communication

Dial “61850” for help
GOOSE Messaging

- Generic Object-Oriented Substation Event
  - Device to multi-device communication
    - IED transmits message
  - Devices subscribe to message
  - Event-driven message
  - Message sent repeatedly every predetermined interval (~ms)
  - Contains a dataset
    - Think of an “Envelope” not just a “point”
GOOSE – Layer 2

- Layer 1 - Physical
- Layer 2 - Data Link
- Layer 3 - Networking
- Layer 4 - Transport

Sample Values Type 4
GOOSE Type 1A
Time SNTP Type 6
MMS Type 2, 3, 5
Publisher-Subscriber Model

- Messaging pattern to categorize and filter data
  - Publisher – sends data to a network
  - Subscriber – subscribes to a specified type of data
GOOSE – An Event-Driven Message
GOOSE on the Process Bus

Line Relay

Merging Unit

Merging Unit

Merging Unit

Process Bus

Line Relay

4ms PTRC 8ms PTRC 16ms PTRC 32ms PTRC 64ms PTRC

1s PTRC 1s PTRC 1s PTRC 1s PTRC 1s PTRC
Sampled Values

- **Time-Sampled Data** from CTs & VTs
- Sent from merging units to relays
- Multicast messages sent over Ethernet
- For protection – 80 samples per cycle with 4 currents and 4 voltages in the stream, 256 samples/cycle for metering/fault analysis
- Addressed in IEC 61850 9-2 (clarified in 9-2LE)
Sampled Values – Layer 2

Layer 1 - Physical

Layer 2 - Data Link

Layer 3 - Networking

Layer 4 - Transport

Sample Values
Type 4

GOOSE
Type 1A

Time SNTP
Type 6

MMS
Type 2,3,5
Sampled Values On The Process Bus

- Line Relay
- Ia, Ib, Ic, Va, Vb, Vc
- Merging Unit
- 9-2 LE
- Process Bus
- Merging Unit
- Merging Unit
- Merging Unit
Current Vs. Sample

The graph shows a sinusoidal relationship between Current and Sample, with the values ranging from -1.5 to 1.5.
MMS Reporting

Manufacturing Message Specification

- Client-server communication
- Real-time process data and supervisory control
- Less “critical” data compared to GOOSE and SMV
- Device-to-device communication over network
- Originated in ISO 9506, prior to IEC 61850
MMS – Layer 4
Client-Server Model

- Communication structure for a network system
- Client – the requestor/initiator
- Server – the provider/servicer
- Request/Response messaging pattern
- IEDs act as clients to other IEDs to obtain data
An Everyday Example

Client

How many feet are in a mile?

5280 feet

GOOGLE

Server
In A Substation Environment

**Substation Controller**

Client

Class 3 poll, (DNP) points, 4,5,6

115, 123, 142

**Substation LAN**

**Line Relay**

Server

4 - 115
5 - 123
6 - 142
MMS Operation

Type 1 – Fast messages
Type 1A – Trip
Type 2 – Medium speed messages
Type 3 – Low speed messages
Type 4 – Raw data messages
Type 5 – File transfer functions
Type 6 – Time synchronization messages
Data Map
IEC 61850 – Data Map

What is the IEC 61850 data map:
LN Application – Circuit Breaker Status

- The interface to a circuit breaker can be modeled as the logical node XCBR
- This Logical Node XCBR has a data object POS (breaker position)
- Within the data object, there is a data attribute called stVal (status value)
### IEC 61850 Data Mapping – XCBR Example

<table>
<thead>
<tr>
<th>Data object name</th>
<th>Common data class</th>
<th>Explanation</th>
<th>T</th>
<th>M/O/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>LName</td>
<td>DPL</td>
<td>The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2, Clause 22.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Descriptions

<table>
<thead>
<tr>
<th>Data object name</th>
<th>Common data class</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EENaName</td>
<td>DPL</td>
<td>External equipment name plate</td>
</tr>
</tbody>
</table>

#### Status Information

<table>
<thead>
<tr>
<th>Data object name</th>
<th>Common data class</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EENHealth</td>
<td>ENS</td>
<td>External equipment health</td>
</tr>
<tr>
<td>LockKey</td>
<td>SPS</td>
<td>Local or remote key (local means without substation automation communication, hardwired direct control)</td>
</tr>
<tr>
<td>Loc</td>
<td>SPS</td>
<td>Local control behaviour</td>
</tr>
<tr>
<td>OpCnt</td>
<td>INS</td>
<td>Operation counter</td>
</tr>
<tr>
<td>CBOpCap</td>
<td>ENS</td>
<td>Circuit breaker operating capability</td>
</tr>
<tr>
<td>POWCap</td>
<td>ENS</td>
<td>Point on wave switching capability</td>
</tr>
<tr>
<td>MaxOpCap</td>
<td>INS</td>
<td>Circuit breaker operating capability when fully charged</td>
</tr>
<tr>
<td>Dsc</td>
<td>SPS</td>
<td>Discrepancy</td>
</tr>
</tbody>
</table>

#### Measured and metered values

<table>
<thead>
<tr>
<th>Data object name</th>
<th>Common data class</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SumSwARs</td>
<td>BCR</td>
<td>Sum of switched amperes, resettable</td>
</tr>
</tbody>
</table>

#### Controls

<table>
<thead>
<tr>
<th>Data object name</th>
<th>Common data class</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>LocSta</td>
<td>SPC</td>
<td>Switching authority at station level</td>
</tr>
<tr>
<td>Pos</td>
<td>DPC</td>
<td>Switch position</td>
</tr>
<tr>
<td>BlkOpn</td>
<td>SPC</td>
<td>Block opening</td>
</tr>
<tr>
<td>BlkCls</td>
<td>SPC</td>
<td>Block closing</td>
</tr>
<tr>
<td>ChaMotEna</td>
<td>SPC</td>
<td>Charger motor enabled</td>
</tr>
</tbody>
</table>

#### Settings

<table>
<thead>
<tr>
<th>Data object name</th>
<th>Common data class</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBTmm</td>
<td>ING</td>
<td>Closing time of breaker</td>
</tr>
</tbody>
</table>

This is the breaker position (52a or 52b)
## IEC 61850 Data Mapping – Sample of LN

<table>
<thead>
<tr>
<th>Functionality</th>
<th>IEEE</th>
<th>LN Function</th>
<th>LN Class</th>
<th>LN class naming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transient earth fault protection</td>
<td></td>
<td>PTEF</td>
<td>PTEF</td>
<td>Transient earth fault</td>
</tr>
<tr>
<td>Sensitive directional earth fault</td>
<td>37</td>
<td>PSDE</td>
<td>PSDE</td>
<td>Sensitive directional earth fault</td>
</tr>
<tr>
<td>Thyristor protection</td>
<td></td>
<td>PTHF</td>
<td>PTHF</td>
<td>Thyristor protection</td>
</tr>
<tr>
<td>Protection trip conditioning</td>
<td></td>
<td>PTRC</td>
<td>PTRC</td>
<td>Protection trip conditioning</td>
</tr>
<tr>
<td>Checking or interlocking relay</td>
<td>3</td>
<td>CILO</td>
<td>CILO</td>
<td>Interlocking</td>
</tr>
<tr>
<td>Over speed protection</td>
<td>12</td>
<td>POVS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero speed and under speed protection</td>
<td>14</td>
<td>PZSU</td>
<td>PZSU</td>
<td>Zero speed and under speed</td>
</tr>
<tr>
<td>Distance protection</td>
<td>21</td>
<td>PDIS</td>
<td>PDIS</td>
<td>Distance protection</td>
</tr>
<tr>
<td>Volt per Hz protection</td>
<td>24</td>
<td>PVPH</td>
<td>PVPH</td>
<td>Volts per Hz</td>
</tr>
<tr>
<td>Synchronism check</td>
<td>25</td>
<td>RSYN</td>
<td>RSYN</td>
<td>Synchronism-check</td>
</tr>
<tr>
<td>Over temperature protection</td>
<td>26</td>
<td>PTTR</td>
<td>PTTR</td>
<td>Thermal overload</td>
</tr>
<tr>
<td>(Time) Under voltage protection</td>
<td>27</td>
<td>PTUV</td>
<td>PTUV</td>
<td>Under voltage</td>
</tr>
<tr>
<td>Directional power / reverse power protection</td>
<td>32</td>
<td>PDPR</td>
<td>PDOP</td>
<td>Directional over power</td>
</tr>
<tr>
<td>Undercurrent / under power protection</td>
<td>37</td>
<td>PUCP</td>
<td>PTUC</td>
<td>Under current</td>
</tr>
<tr>
<td>Loss of field / Under excitation protection</td>
<td>40</td>
<td>PUEX</td>
<td>PDUP</td>
<td>Directional under power</td>
</tr>
<tr>
<td>Reverse phase or phase balance current protection</td>
<td>46</td>
<td>PPBR</td>
<td>PTOC</td>
<td>Time overcurrent</td>
</tr>
<tr>
<td>Phase sequence or phase-balance voltage protection</td>
<td>47</td>
<td>PPBV</td>
<td>PTOV</td>
<td>Overvoltage protection</td>
</tr>
<tr>
<td>Motor start-up protection</td>
<td>48, 49, 51LR66</td>
<td>PMSU</td>
<td>PMRI</td>
<td>Motor restart inhibition</td>
</tr>
<tr>
<td>Thermal overload protection</td>
<td>49</td>
<td>PTTR</td>
<td>PTTR</td>
<td>Thermal overload</td>
</tr>
<tr>
<td>Rotor thermal overload protection</td>
<td>49R</td>
<td>PROL</td>
<td>PTTR</td>
<td>Thermal overload</td>
</tr>
<tr>
<td>Rotor protection</td>
<td>49R</td>
<td>PROT</td>
<td>PTTR</td>
<td>Thermal overload</td>
</tr>
</tbody>
</table>
The only value which is typically available in a conventional station.
IEC 61850 Data Mapping - Example
IEC 61850 Testing - Example
IEC 61850 Testing Process

Station Controller

HMI

Station bus Ethernet network

GOOSE sent over network

GOOSE now marked with 'test bit'

Test device can be inserted to sniff/inject GOOSE / MMS

Test device can be inserted to sniff/inject GOOSE / Sampled Values

Redundant Process Bus Ethernet network

Placed in Test Mode

Relay
## IEC 61850 – Benefits

<table>
<thead>
<tr>
<th>Interoperability</th>
<th>Non-propriety common communication language</th>
</tr>
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<tr>
<td></td>
<td>Common platform for protection, control, asset management systems</td>
</tr>
<tr>
<td>Design Standardization</td>
<td>Shorter construction window as <em>system can be designed, modeled, and tested in advance</em></td>
</tr>
<tr>
<td></td>
<td>Designs are easily reproducible</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Data is available over the network, modifications can be done via settings rather than physical changes</td>
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<tr>
<td></td>
<td>System can be easily expanded</td>
</tr>
<tr>
<td>Digital Control System</td>
<td>Reduced control building size</td>
</tr>
<tr>
<td></td>
<td>Reduced physical wiring</td>
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<tr>
<td>Increased System Visibility</td>
<td>Optimizing on-site maintenance</td>
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<td></td>
<td>Easier access to more asset data</td>
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<tr>
<td>Safety</td>
<td>Electrical hazards are remote from operator terminals</td>
</tr>
<tr>
<td></td>
<td>Enhanced tagging control</td>
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</table>
The logic that used to be constructed with devices wired in parallel or series is now done via digital programming.

There are various file types, a couple examples:

- **ICD** – IED Configuration Database
  - Configuration for a single relay or merging unit
- **SCD** – Substation Configuration Database
  - Configured file for entire substation
- **SSD** – Substation Specification Database
  - Generic configuration file for the entire substation, can include logic, communication, protection elements, etc.
Engineering Process

- What is a top-down approach?
- Focus on the system objectives not equipment limitations
- Possible because IEC 61850 defines the data map for a substation
Engineering Process

Top-Down vs. Bottom-Up Engineering

- Goal of using a Top-Down design:
  1. Standardized engineering process
  2. Repeatability
  3. Vendor inter-operability

- Reality:
  1. Mix of top-down and bottom-up
  2. Standards based on top-down approach, but of the system will need to be customized based on equipment limitations
Standard and Portable Design

- National Grid’s goal is to create general standards around IEC 61850
- The design will be tailored for specific installations

Engineering Process

- Grid Planning
- Engineering Specification
- Device Selection
- System Configuration
- Testing
- As-Built
- System can be tested in the lab while still in engineering
- Factory acceptance testing minimizes field work

Standard SSD file is created for the project “Conceptual Engineering File”

Configuration file is updated for the specific equipment “Preliminary Engineering”

Final ICD and SCD files are created “Final Engineering”
IEC 61850 – Substation Automation

Why would we want to change the status quo?
- Decreased capital cost
- Smaller footprint
- Increased flexibility and visibility
- Proactive condition-based maintenance and remote access
## IEC 61850 – Benefits

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## IEC 61850 – Risks

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyber-Security</td>
<td>Network connectivity, all devices connected to the network are potentially accessible</td>
</tr>
<tr>
<td></td>
<td>The network can be a single point of failure if not properly designed</td>
</tr>
<tr>
<td></td>
<td>Patch management requirements are greatly increased</td>
</tr>
<tr>
<td>New Technology</td>
<td>Some concepts are not fully proven in the field</td>
</tr>
<tr>
<td></td>
<td>Not all vendors offer compatible products</td>
</tr>
<tr>
<td></td>
<td>Limited available workforce</td>
</tr>
<tr>
<td>Engineering &amp; Operational Learning</td>
<td>New standards and work methods are required</td>
</tr>
<tr>
<td></td>
<td>Cross discipline skillsets are not available for example, most protection engineers are not familiar with VLANS or MAC addresses</td>
</tr>
</tbody>
</table>
IEC 61850 – Substation Automation

In Summary…

- Packet-based network communication for electric power systems
- Reduced control house size, reduced wiring, standardized design, reduced operational costs
- IEC 61850 considers the entire system lifecycle; engineering, construction, operations
- Potential new challenges that have to be addressed
  - Coordination between engineers and operations is critical
1.) What were the standard committee’s goals in the development of the IEC 61850 standard?

- Data mapping of the entire substation;
- Future-proof communication;
- Vendor interoperability;
- A common means of storing data,
- Defining testing for conformance to the standard
2.) What are some of the advantages in transitioning to an IEC 61850 digital substation?

**Answer:**
- Interoperability
- Design standardization
- System flexibility
- Reduced capital costs
- Reduced operational costs
- Increased system visibility
- Enhanced safety
3.) What are the risks with digital substations?

- **Answer:**
  - Cyber-security
  - New technology
  - Engineering and operational learning curve
IEC 61850 – Substation Automation

A couple questions

4.) How are the potential risks with digital substations being mitigated?

Answer:
- Design with security in mind
- Compartmentalized networks
- Extensive collaboration between engineering and operations
IEC 61850 – Substation Automation

A couple questions

5.) Does IEC 61850 have a technical, commercial, or organizational impact?

Answer:

- All of the above! To fully realize the benefits, transitioning to a digital substation requires complete organizational buy-in.
Transmission Innovation – Future of IEC 61850

Enhanced System Monitoring & Visibility

Increasing Levels of Variable Generation

Increasingly competitive marketplace

System Stability

Optimizing Maintenance & Operation
IEC 61850 and the Future

- Flexibility to support the rapidly changing power industry
  - More than one utility is using IEC 61850 to support dynamic relay settings
    - Settings will adjust based on system conditions

- Automatically generated HMI screens

- Software based design
Thank You

1. Ethernet-based communication on IEC 61850
2. Digitalization of analog protection elements
3. Asset management support
4. Integrated engineering
5. Cyber Security - Prerequisite of any digital substation
6. Network control support

The first GOOSE caught on our network analyzer
IEC 61850 – Terminology

HMI

Gateway

Relay

Bay Controller

Merging Unit