Substation Automation Systems: from Engineering to Automated Testing

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Outline

> Motivation
> IEC 61850 SCL Engineering Process
> Test Method for Substation Automation System
> Engineering Requirements for Optimal Testing
> Test Case Examples
> Conclusion
Protection Testing:
- Tools for Automated Testing
- Standardized Test Plans reduced efforts dramatically

But what happened in the...

Testing Automation and Control:
- Functional drawings and interfaces
- Logics, Interlockings
- SCADA, Gateways, RTUs (signal lists)

Manual procedures so far... How to test it efficiently?
IEC 61850 Substations

- Data Models
- Client/Server (Reports), GOOSE, Sampled Values
- System Configuration Language (SCL)
Engineering of IEC 61850 with SCL

- IEC 61850-6
- Configuration of overall communication system
- Interoperability between Engineering Tools

**System Specification Description**

**IED Capability Description**

**SSD**

**System Configuration Tool (SCT)**

**SCD**

**ICT**

**SID**

**CID**

**Substation Configuration Description**

**Configured IED Description**
SCL Scope

- SCL uses XML-based files
- An SCL file contains the following information:
  - IEDs: Data Models and Configuration of Reports, GOOSE, SV
  - Correlation between Switchgear and Functions to IED Logical Nodes
  - Communication links between IEDs
New Test Approach

> Based on SCL Information

> Visualize and Test entire Substation Automation System
New Test Approach

#1 Monitor and Test Communication

#2 Identify errors

#3 Test Logic

#4 Simulation (e.g. FAT)
New Test Approach

#5 Testing the SAS during its entire Lifecycle

#6 Test Plans

[Diagram showing testing process]

IED Features + Quality SCL File = Efficient Testing

Requirements??
Test Mode and Simulation Flag

> Test Mode: what are the DUT

<table>
<thead>
<tr>
<th>GOOSE data</th>
<th>IED</th>
</tr>
</thead>
<tbody>
<tr>
<td>q.test = FALSE</td>
<td></td>
</tr>
<tr>
<td>Beh = ON</td>
<td></td>
</tr>
<tr>
<td>Beh = TEST</td>
<td></td>
</tr>
</tbody>
</table>

Output to process
- processed
- not processed

> Simulating Messages with Test Set

<table>
<thead>
<tr>
<th>Test Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>GoID=1</td>
</tr>
<tr>
<td>Simulation = FALSE</td>
</tr>
<tr>
<td>Simulation = TRUE</td>
</tr>
</tbody>
</table>

| IED |
| LPHD.Sim = FALSE |
| LPHD.Sim = TRUE |

Subscribe GoID=1
SCD Substation Section

> Substation Topology in SCD

```xml
<Substation desc="Munich" name="AAL" sxy:x="1" sxy:y="5">
  <PowerTransformer name="TA1" sxy:y="9" type="PTR">
    <PowerTransformer name="TA2" sxy:x="15" sxy:y="9" type="PTR">

  </PowerTransformer>

</Substation>

<VoltageLevel name="D1">
  <Voltage multiplier="k" unit="V">380</Voltage>

  <Bay desc="TF1" name="Q01" sxy:x="1" sxy:y="2">
    <LNode iedName="AA1D1Q01Q1" ldInst="C1Q01F1" lnClass="PDIS" lnInst="1"/>
    <LNode iedName="AA1D1Q01Q1" ldInst="C1Q01F1" lnClass="PTOC" lnInst="1"/>
    <LNode iedName="AA1D1Q01Q1" ldInst="T3S1S1" lnClass="ATCC" lnInst="1"/>
    <LNode iedName="AA1D1Q01Q1" ldInst="T3T1F1" lnClass="YLTC" lnInst="1"/>
    <LNode iedName="AA1D1Q01Q1" ldInst="T3T1F1" lnClass="YPTR" lnInst="1"/>
    <LNode iedName="AA1D1Q01Q1" ldInst="C1Q01F1" lnClass="PTRG"/>
    <LNode iedName="AA1D1Q01Q1" ldInst="C1Q01F1" lnClass="RBRF"/>
    <LNode lnClass="M2XU" lnInst="1"/>
    <ConductingEquipment name="BC1" sxy:y="4" type="CTR">

  </Bay>

<ConductingEquipment name="Q1A" sxy:y="5" type="CBR">
  <LNode iedName="AA1D1Q01Q1" ldInst="C1Q02QA1" lnClass="C"/>
  <LNode iedName="AA1D1Q01Q1" ldInst="C1Q02QA1" lnClass="X"/>
  <LNode iedName="AA1D1Q01Q1" ldInst="C1Q02QA1" lnClass="C"/>
  <Terminal bayName="Q01" cNodeName="L11" name="L11" subst/>
  <Terminal bayName="Q01" cNodeName="L12" name="L12" subst/>
</ConductingEquipment>
```

Substation
Voltage Level
Bay

IED
Breaker

Testing Tool
SCD Substation Section

> Association between Switchgear and LNs

<ConductingEquipment name="QA1" sxy:y="5" type="CBR">
  <LNode iedName="AA1D1Q01Q1" ldInst="C1Q02QA1" lnClass="CILO" lnInst="3"/>
  <LNode iedName="AA1D1Q01Q1" ldInst="C1Q02QA1" lnClass="XCBR" lnInst="1"/>
  <LNode iedName="AA1D1Q01Q1" ldInst="C1Q02QA1" lnClass="CSWI" lnInst="3"/>
  <Terminal bayName="Q01" cNodeName="L11" name="L11" substationName="AA1" vo/>
  <Terminal bayName="Q01" cNodeName="L12" name="L12" substationName="AA1" vo/>
</ConductingEquipment>
SCD: Signal Descriptions

> “desc” attribute of Data Objects should be present in SCD file
> IEC 61850 allows to hide 61850
> Instead of Complex Addresses, use signal names from Engineering
> If unavailable, use smart names from Standard
Describing GOOSE connections

> 2 ways to define subscriptions in SCD:
  > Subscribers in GOOSE Control Block of Publisher
  > ExtRef in Subscribers

```xml
<GSEControl name="GCB_switchgear" type="GOOSE"
  <IEDName>BB_PROTECTOR</IEDName>
  <IEDName>AA1D1002Q1</IEDName>
  <IEDName>AA1D1003Q1</IEDName>
  <IEDName>AA1D1004Q1</IEDName>
  <IEDName>AA1D1005Q1</IEDName>
</GSEControl>
```

> Use of LGOS
  > Logical Node for GOOSE Subscription
  > One per Subscription
  > Enable Monitoring of Receive Status

> Benefit → Check of GOOSE links:
  > Verify Publisher
  > Verify mismatches by comparing traffic with SCD
  > Verify Reception with Subscribers LGOS
Report Configuration

- Reports used for SCADA Communication
- One-to-one connections between IED and Clients
- Reports can be reserved
  - "Owner" attribute
  - Described in SCD

Benefit → Check Report links:
  - Verify “Owner” is the Client defined in the SCD
Network Design Considerations

> Testing Requirements should be considered for Network Design

> Clear Access Points for Testing considering:
  > Topology: Station Bus and Process Bus
  > Traffic Control: VLAN and Multicast Filtering
  > Redundancy: RedBox
Example: Testing Interlocking Logics

> CILO LN shows interlocking logic result for each switch
Example: Troubleshooting

> Tracing Signals through the SAS
Example: Re-testing after Security Updates

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</tr>
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<td>Reporting</td>
<td>passed</td>
</tr>
<tr>
<td>Test modes</td>
<td>passed</td>
</tr>
<tr>
<td>Interlocking</td>
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Before firmware update

Firmware update

After firmware update

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Conclusion

> SCL is a very powerful aspect of IEC 61850

> Challenges:
  > Some features are Optional
  > Lack of Tools

> Requirements to be considered during System Design and Engineering

> Benefits go beyond engineering:
  > Testing / Monitoring
  > Cybersecurity
  > Documentation

> Save Time and Increase Efficiency Using what SCL Offers
Questions?

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