# IEC 61850 Representation of Switchgear, Switch Controller and Interlocking Functions

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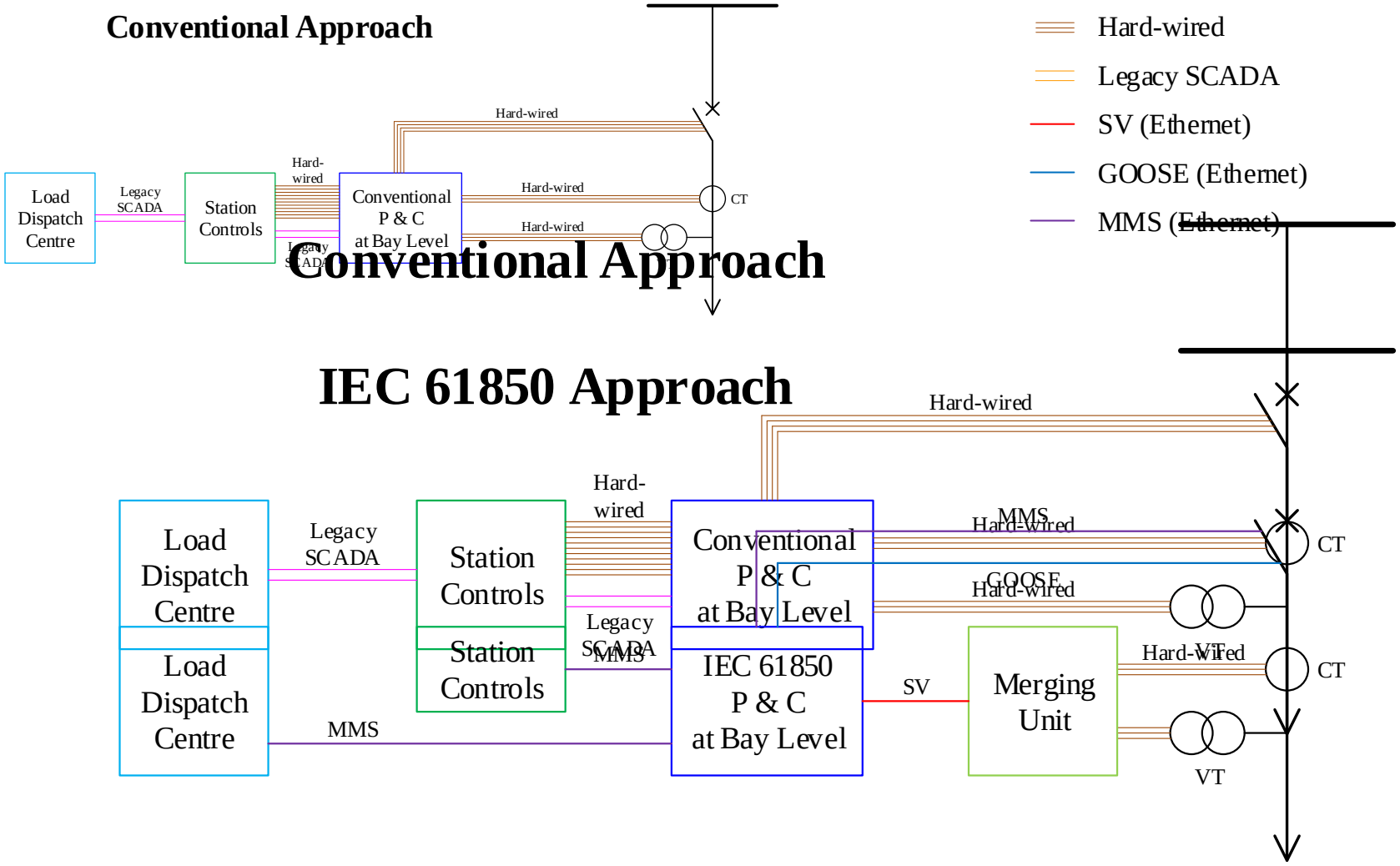
# Outline

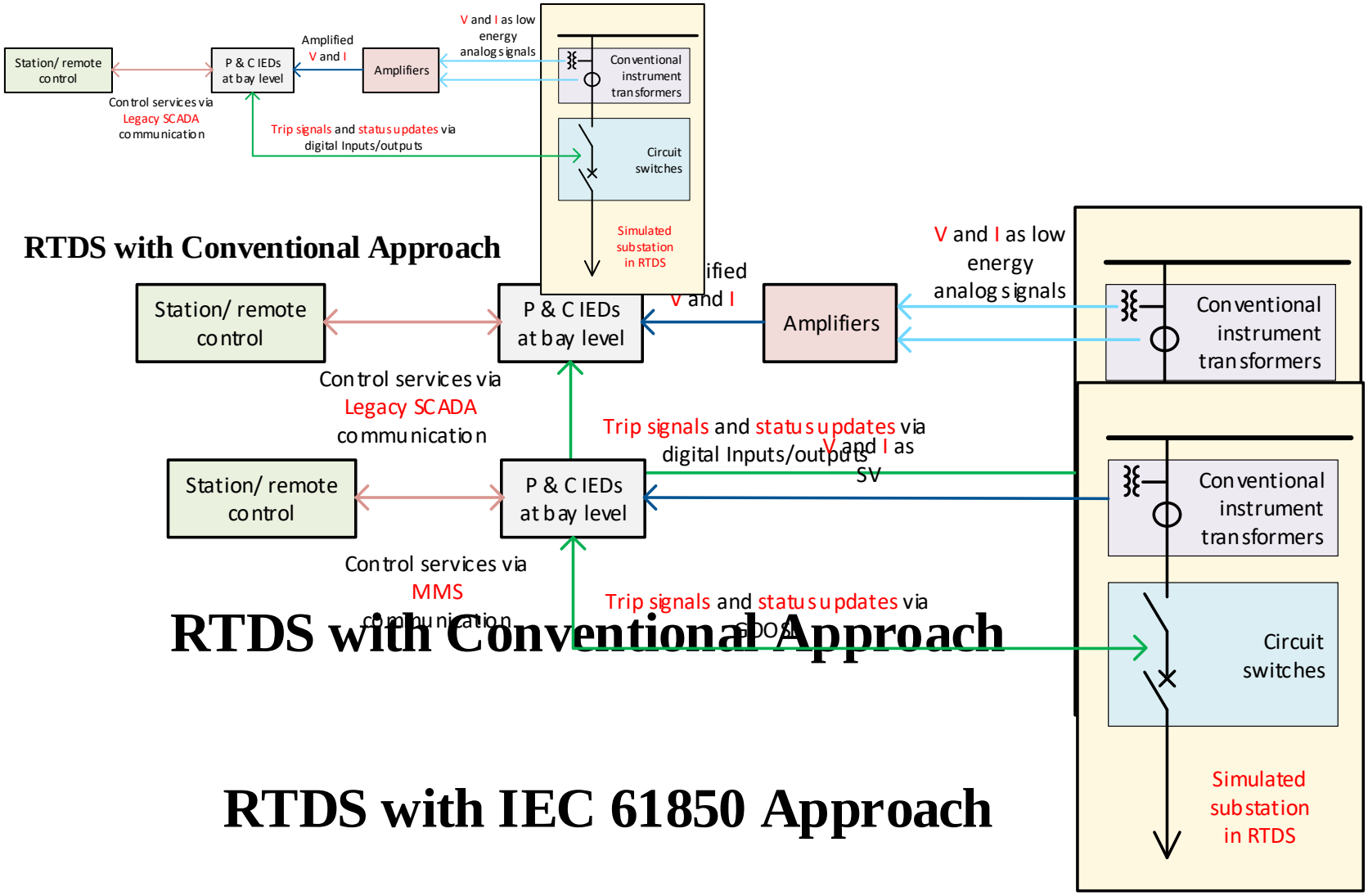
- Introduction
- Switchgear Modelling in IEC 61850
- Implementations in GTNET-GSE
- Test Procedure
- Results
- GOOSE Analyzer
- Conclusions

# Introduction

## Substation Protection, Control & Automation



# Introduction



# Switchgear Control

- **High voltage switchgear** in an electrical substation operates in response to either a **trip** or a **switch** (opening and closing) command
- Typically, only protection and control intelligent electronic devices (IEDs) at **bay level** can trip circuit breakers
- A circuit breaker can either be switched **locally with manual** control or by a command from **bay**, **station** or/and **remote levels**
- **IEC 61850** Standard defines **data models** for representing switchgear and their associated controls
- These data models can be read and controlled by communication protocols such as **MMS** and **GOOSE**

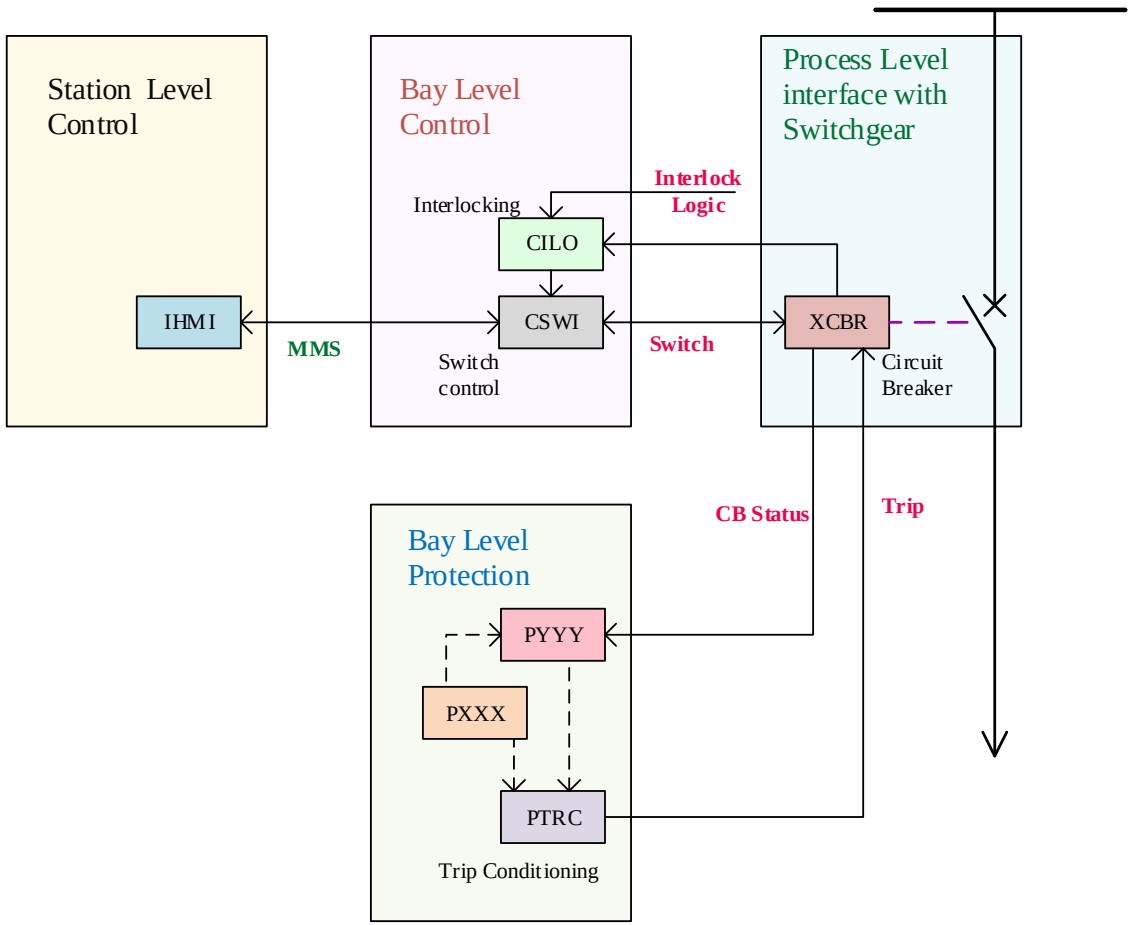
# Logical Node Classes for Switchgear

- IEC 61850-7-4 defines **logical node** (LN) classes for representing switchgear and their associated controls

| LN Class (IEC 61850-7-4) | Description |
|---|---|
| XCBR | Circuit Breakers - Switches with short circuit breaking capability |
| XSWI | Circuit Switches - Switches without short circuit breaking capability |
| CSWI | Switch Controller - Control all switching conditions above process level |
| CILO | Interlocking Function - Enable a switching operation if interlocking conditions are fulfilled |

# Switchgear Modelling in IEC 61850

- **Information flow** between logical nodes associated with switchgear operations



# Control Models in IEC 61850

- A **MMS client** is capable of changing the state of data object instances of controllable **common data classes** (CDC)
- A control model facilitates this functionality
- As different applications require different control behaviours, IEC 61850 defines **four** control models;
  - Direct control with normal security
  - SBO (select before operate) control with normal security
  - Direct control with enhanced security
  - SBO control with enhanced security

# Control Models in IEC 61850 (cont.)

## Direct control vs SBO control

- Direct control model : Does not prevent multiple clients from trying to perform conflicting control actions
- Select before operate model : A client has to “select” the control object prior to operation. Once selected, the client is the only one allowed to perform control actions on the object

## Normal security vs Enhanced security

- Normal security : No additional supervision of the status value by the control object
- Enhanced security : An additional supervision of the status value by the control object

# Originator Category

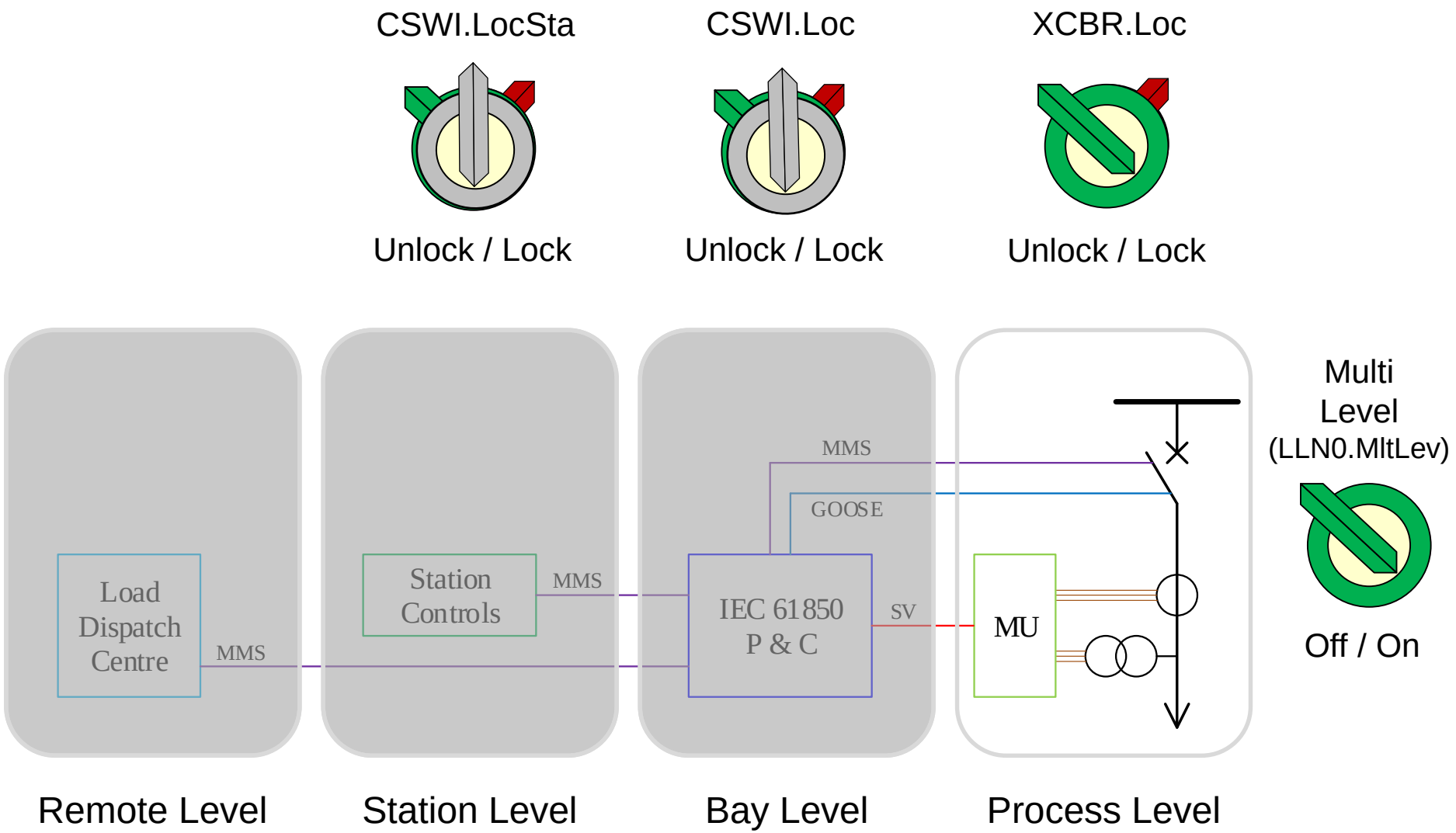
- Originator category indicates who/what requested the change of state of a controllable value. Originator categories defined are;
  - **not-supported :** value shall not be used
  - **bay-control :** Control operation issued from an operator using a client located at bay level
  - **station-control :** Control operation issued from an operator using a client located at station level
  - **remote-control :** Control operation from a remote operator outside the substation
  - **automatic-bay :** Control operation issued from an automatic function at bay level
  - **automatic-station :** Control operation issued from an automatic function at station level
  - **automatic-remote :** Control operation issued from an automatic function outside of the substation
  - **maintenance :** Control operation issued from a maintenance/service tool
  - **process :** Status change occurred without control action

# Control Parameters

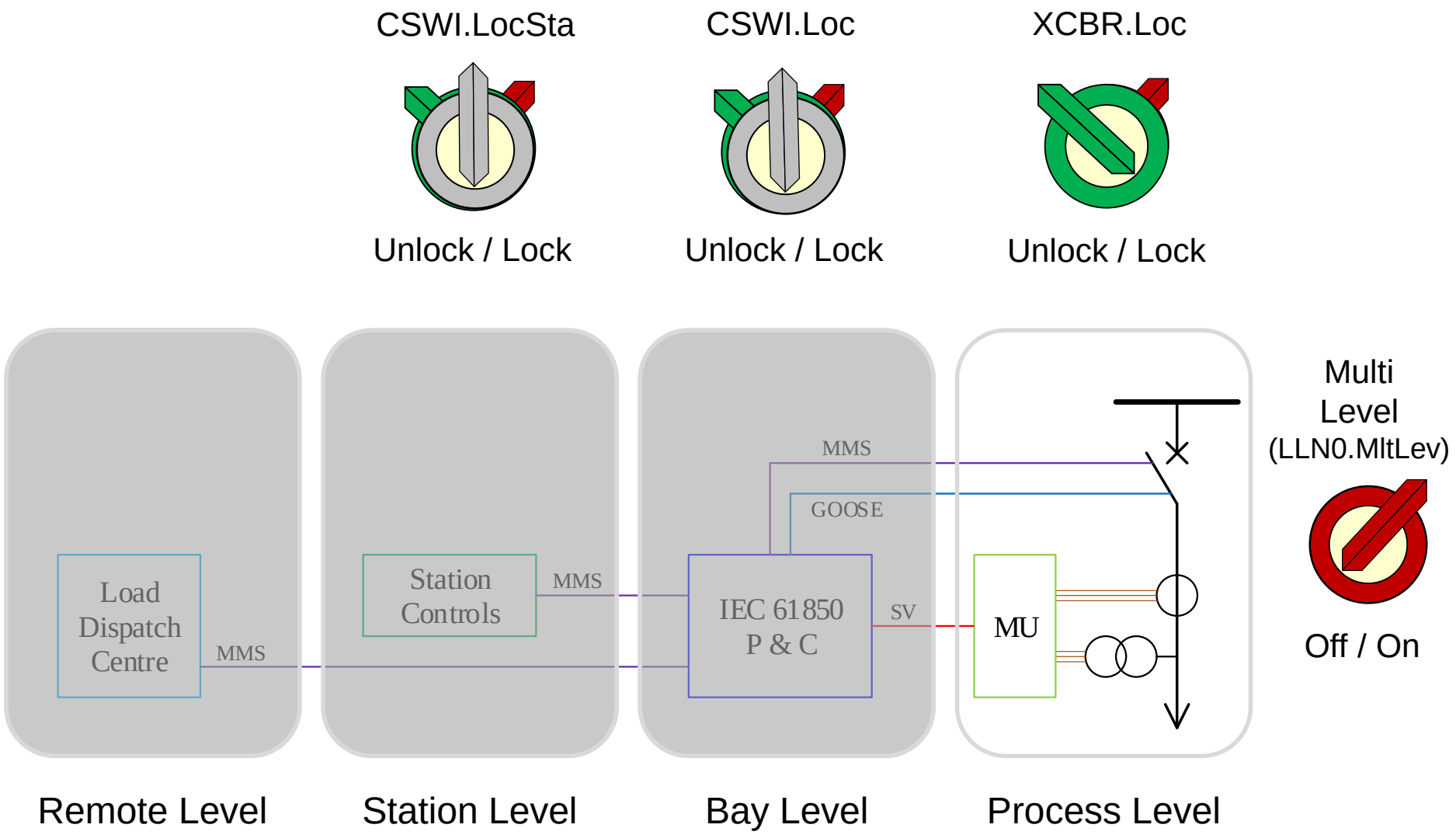
- Control authority for switching can be varied using following parameters

| Control parameter | Description (as per IEC 61850-7-4) |
|---|---|
| XCBR/XSWI.Loc | represents the status of an actual switch at the process and allows taking over the manual control authority |
| LLNO.MltLev | enables for more than one originator to hold control authority at the same time |
| CSWI.Loc | shows the control behaviour of the logical node (bay level) |
| CSWI.LocSta | shows the switching authority at station level |

# Control Authority – Single level



# Control Authority – Multi level



# Control Authority

- Annex B of IEC 61850-7-4 describes the relationship between control parameters and Control authority

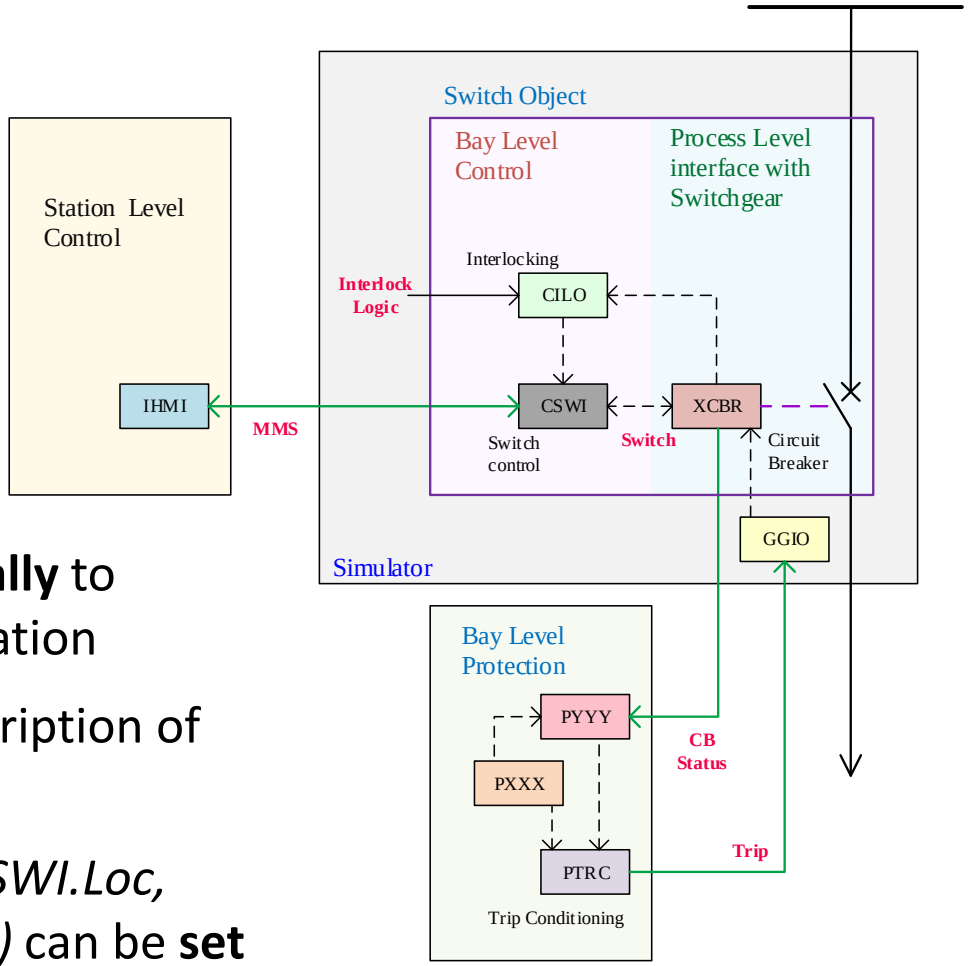
| Switch | Bay control | | | Manual control at switch (process) | Command from | | |
|---|---|---|---|---|---|---|---|
| | | | | | Bay | Station | NCC |
| | Mode of switching for local control | Local control behavior | Control authority at station level | | Originator Category (OrCat) | | |
| XCBR.Loc XSWI.Loc | LLN0.MltLev | CSWI.Loc | CSWI.LocSta | | Local Ctl (Bay) | Station | Remote |
| T | F | n.a. | n.a. | AA | NA | NA | NA |
| F | F | T | n.a. | AA | AA | NA | NA |
| F | F | F | T | AA | NA | AA | NA |
| F | F | F | F | AA | NA | NA | AA |
| T | T | n.a. | n.a. | AA | NA | NA | NA |
| F | T | T | n.a. | AA | AA | NA | NA |
| F | T | F | T | AA | AA | AA | NA |
| F | T | F | F | AA | AA | AA | AA |

**Loc Status**
T = True
F = False
n.a. = not applicable

**Command**
AA = Always Allowed
NA = Not Allowed

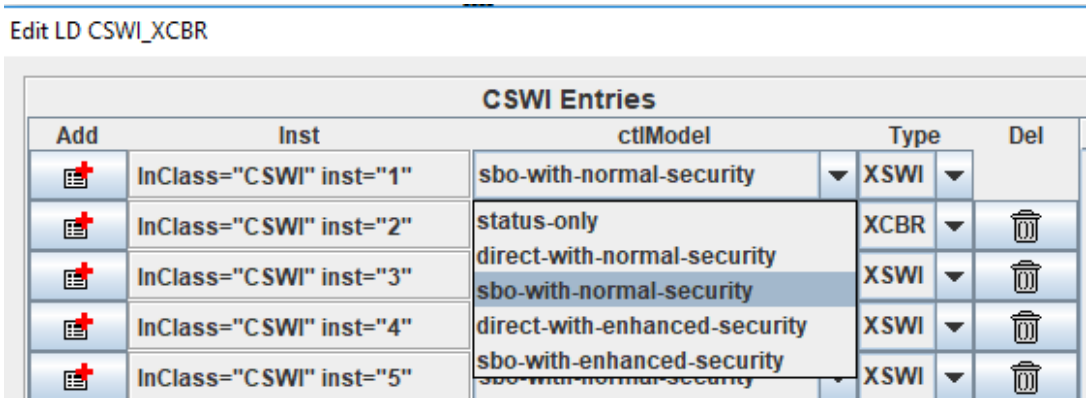
# Implementations in GTNET-GSE

- An instance each of **CSWI** and **CILO** LNs exist for every **XCBR/XSWI** LN instance
- This combination is considered as a **switch object**
- Information flow between XCBR/XSWI, CSWI, CILO LNs are internal
- XCBR/ XSWI LNs are **mapped internally** to corresponding switches in the simulation
- A GGIO LN instance is used for subscription of trip signals
- All four control parameters *(XCBR/XSWI.Loc, LLNO.MltLev, CSWI.Loc, CSWI.LocSta)* can be **set dynamically** in the simulation



# Initialization of Switch Objects

- All four control models are implemented with an added **“status only”** option in GTNET-GSE version 6
- Control model type is chosen when LN instances are first created using the **SCD Editor** (the IED configurator for GTNET-GSE)
- Type of the switch (XCBR or XSWI) is also chosen at this point
- All **three LN instances** (XCBR/XSWI, CSWI, CILO) are locally interlinked and created simultaneously



# Available Information

- Each GTNET-GSE v6 component can model a maximum of **32 independent circuit switches**
- All related LN instances are grouped in to a separate **Logical Device** (LD)
- A **dataset** each for **MMS** and **GOOSE** communication, with the following information available for a single switch object

| MMS Dataset | GOOSE Dataset |
|---|---|
| CSWI.Pos.StVal | XCBR/XSWI.Pos.StVal |
| CSWI.Loc.StVal | XCBR/XSWI.Pos.q |
| CSWI.LocSta.StVal | |
| CILO.EnaOpn.StVal | |
| CILO.EnaCls.StVal | |
| XCBR/XSWI.Pos.StVal | |
| XCBR/XSWI.OpCnt.StVal | |

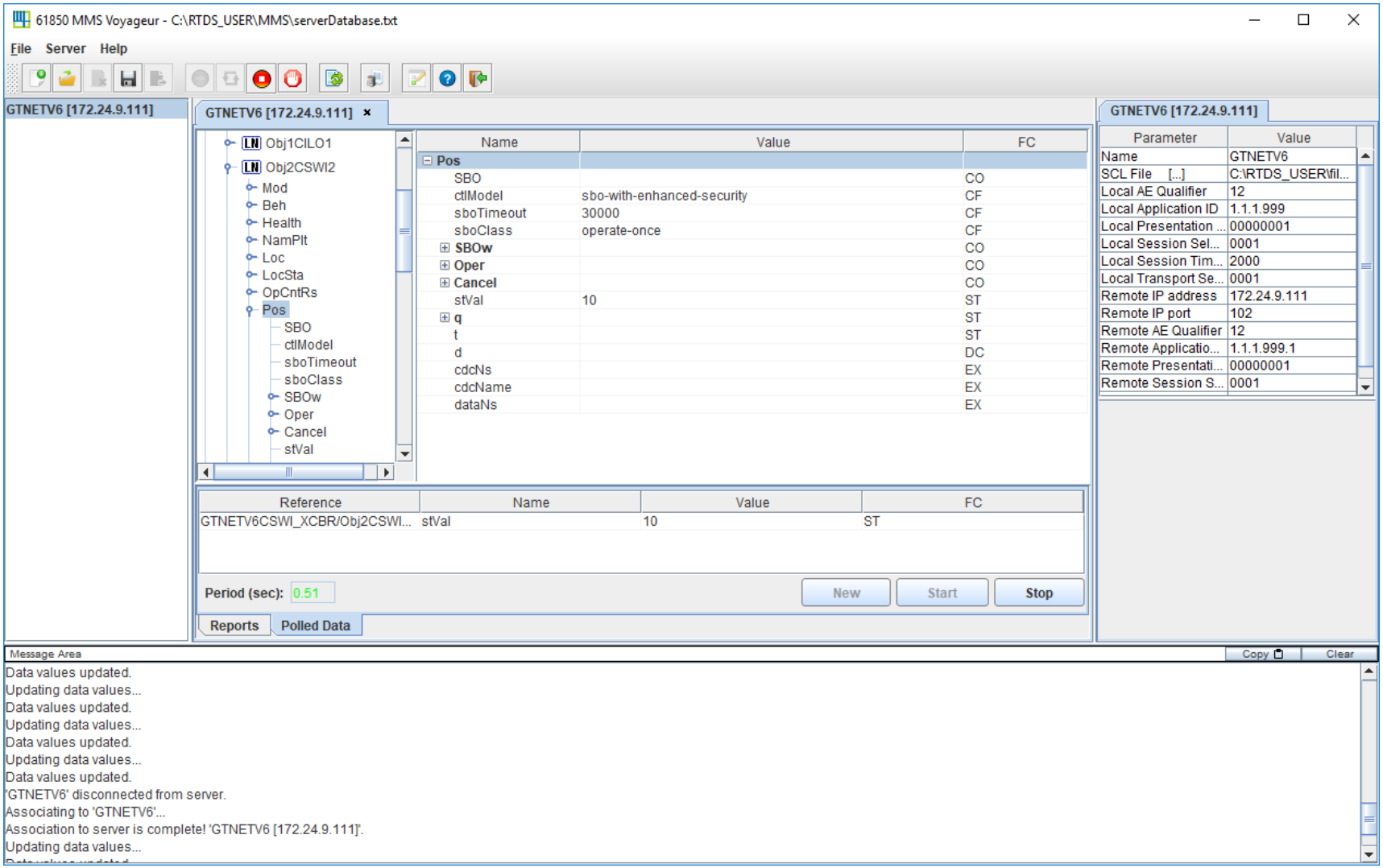
# Related Configurations

- All configurable parameters related to the **“XCBR/XSWI logical device”** can be set in the SCD editor
- These include the names of the **LD instance**, **GOOSE control block** and **GOOSE dataset** as well as the multicast MAC address, appID, VLAN ID and VLAN priority
- The IP address of the **MMS server** will be the one that is assigned to Ethernet port of the corresponding GTNET hardware module
- This IP address must be correctly configured in the **.scd file** for MMS communication to commence
- A correctly configured **MMS client** should then be able to connect and communicate with the GTNET-GSE MMS server

# MMS Client in RSCAD

- RSCAD provides a standalone IEC 61850 client program named the **“61850 MMS Voyageur”**
- It is capable to connect with a server using IEC 61850 MMS communication
- Once connected with a server, the MMS client can;
  - **test** the connection setup with the server device
  - **browse** the data model of the server device
  - **read and write** server data
  - **perform** control operations

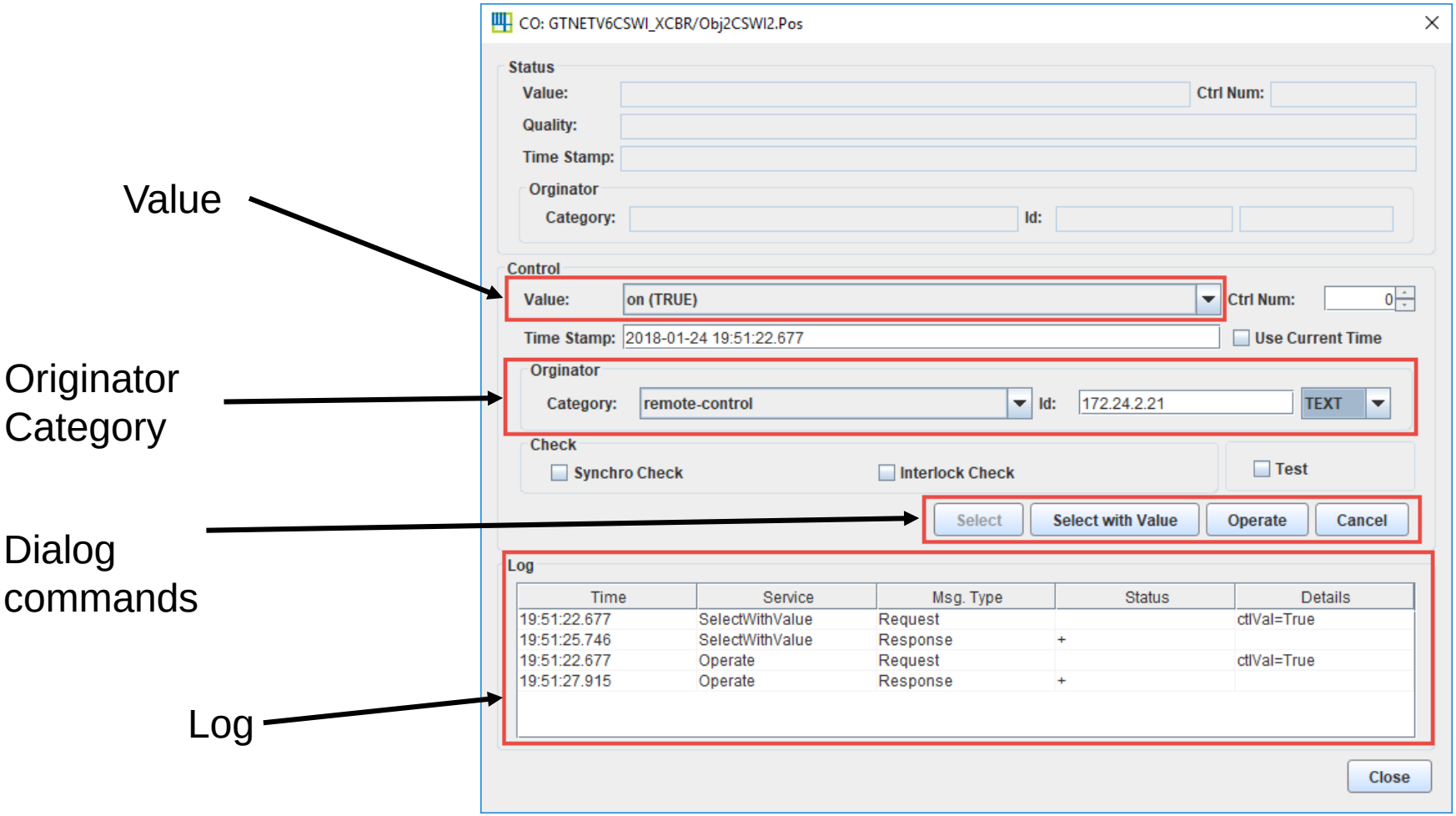
# MMS Client in RSCAD (cont.)



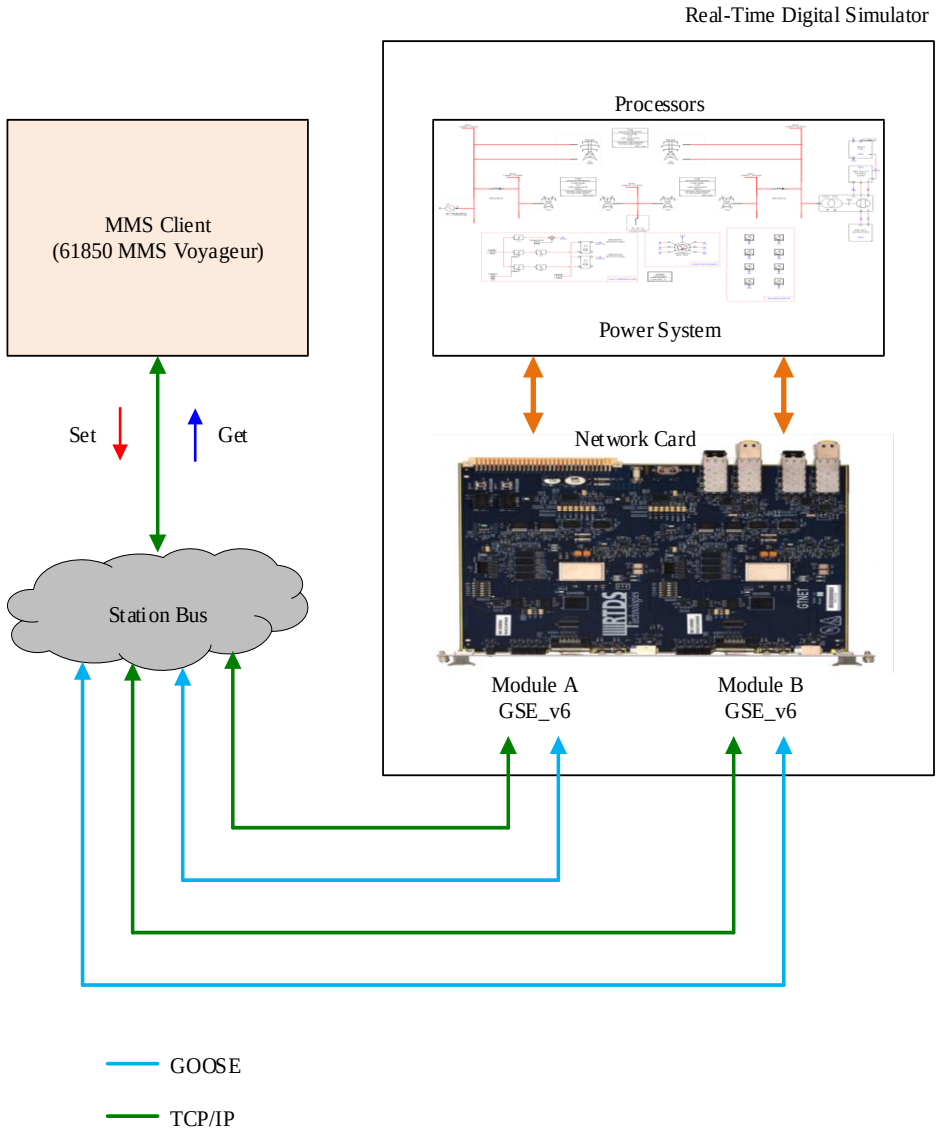
# MMS Client in RSCAD (cont.)

- In this work, the focus is only on **performing control operations** on the server device
- Control operations enable the client to **change the state** of an internal or external process of the server device
- A **“Command Control Dialog”** can be opened for a selected **“control object”**
- Parameters such as the **control value**, **originator category** and **command (service) type** can be chosen from this window
- It **supports** all standard originator categories therefore, can emulate any originator in a test
- The **logging area** displays a summary of the information exchanged between the client and the server

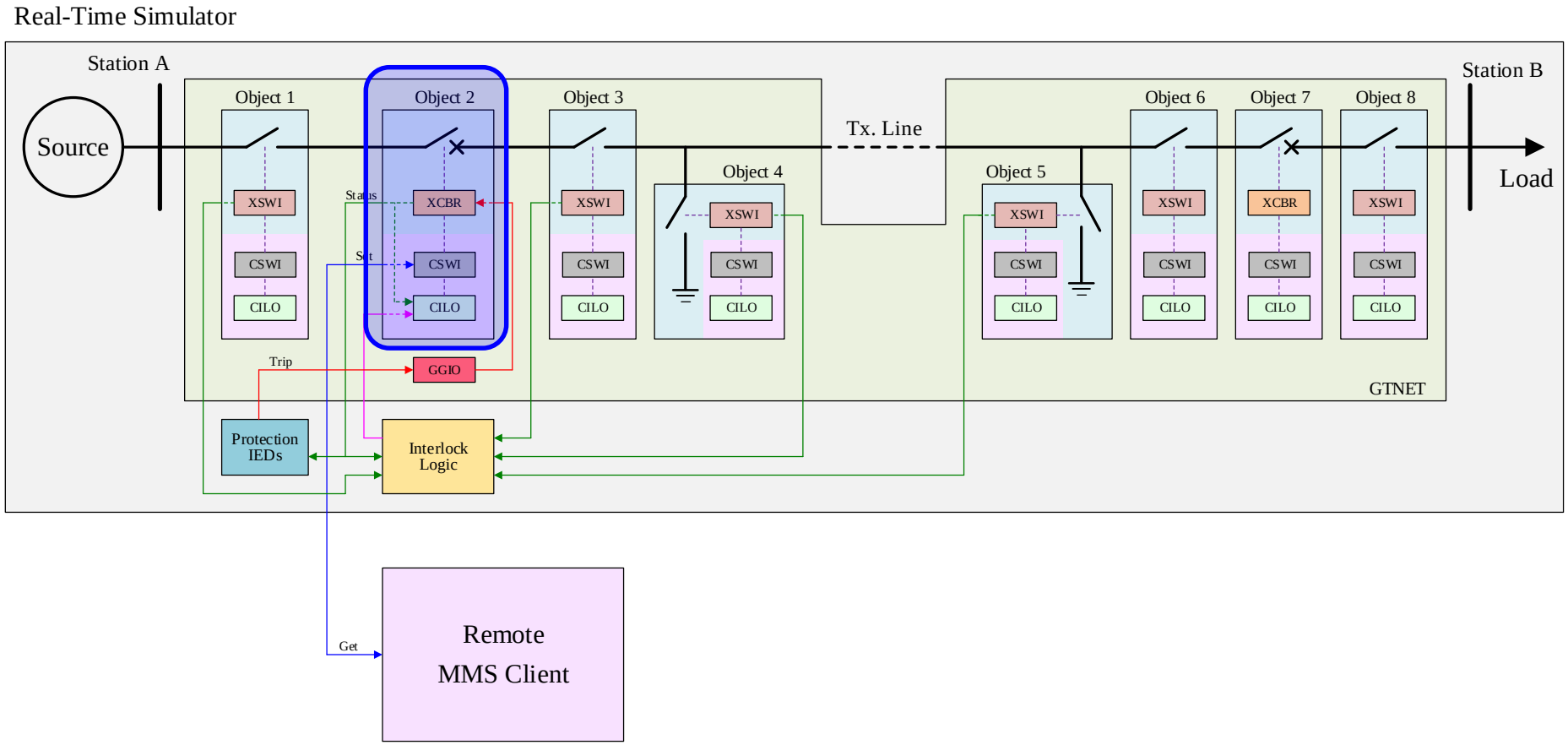
# Command Control Dialog



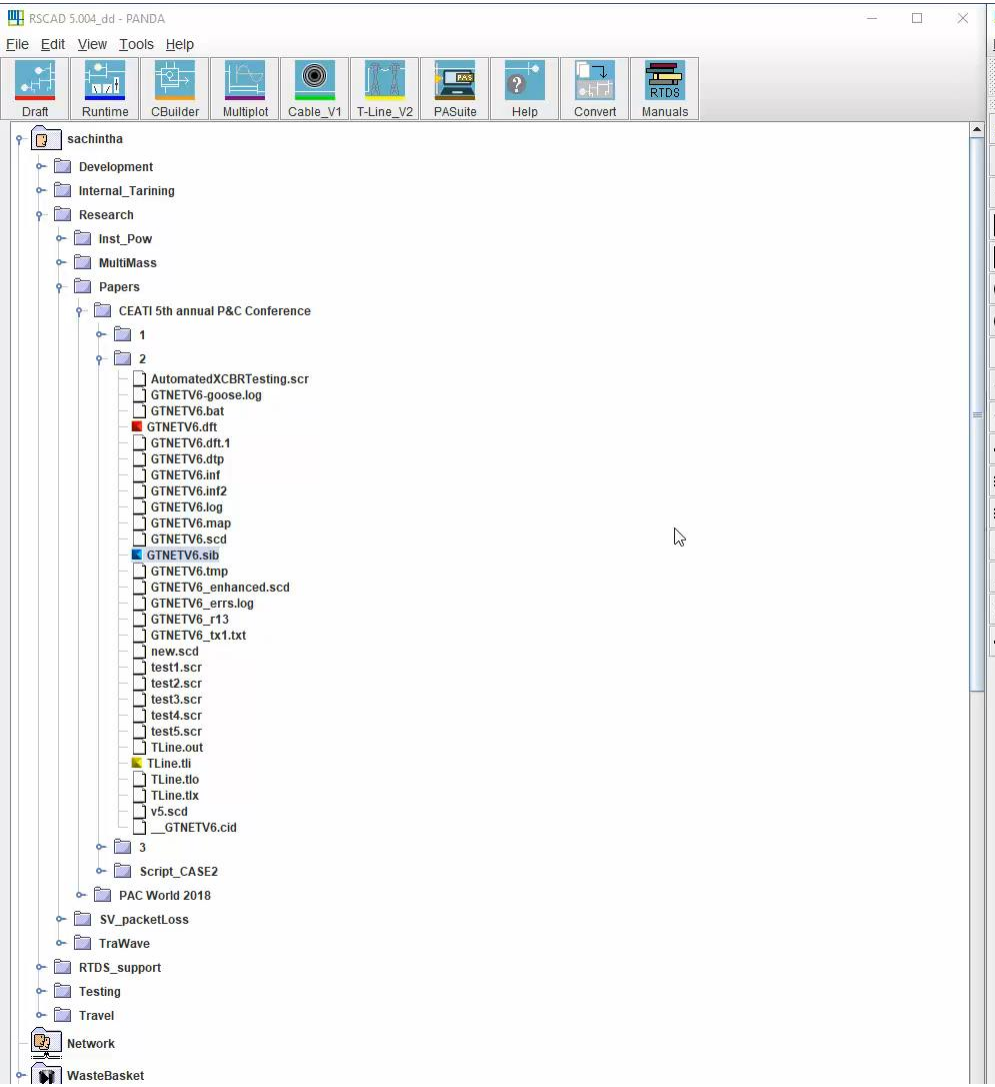
# Test Setup

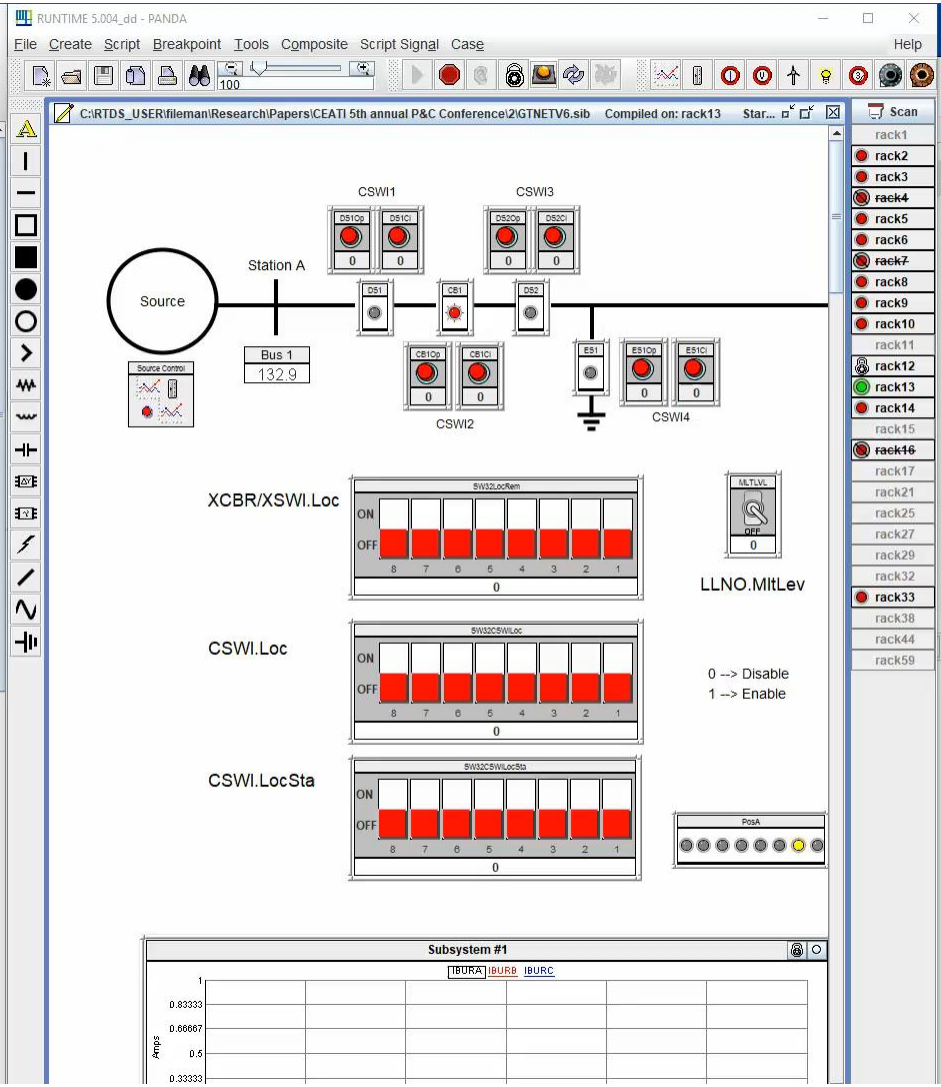

Real-Time Digital Simulator
Processors
Power System
MMS Client
(61850 MMS Voyageur)
Set
Get
Network Card
Station Bus
Module A
GSE_v6
Module B
GSE_v6
GOOSE
TCP/IP

# Example Test Case



# Manual Testing

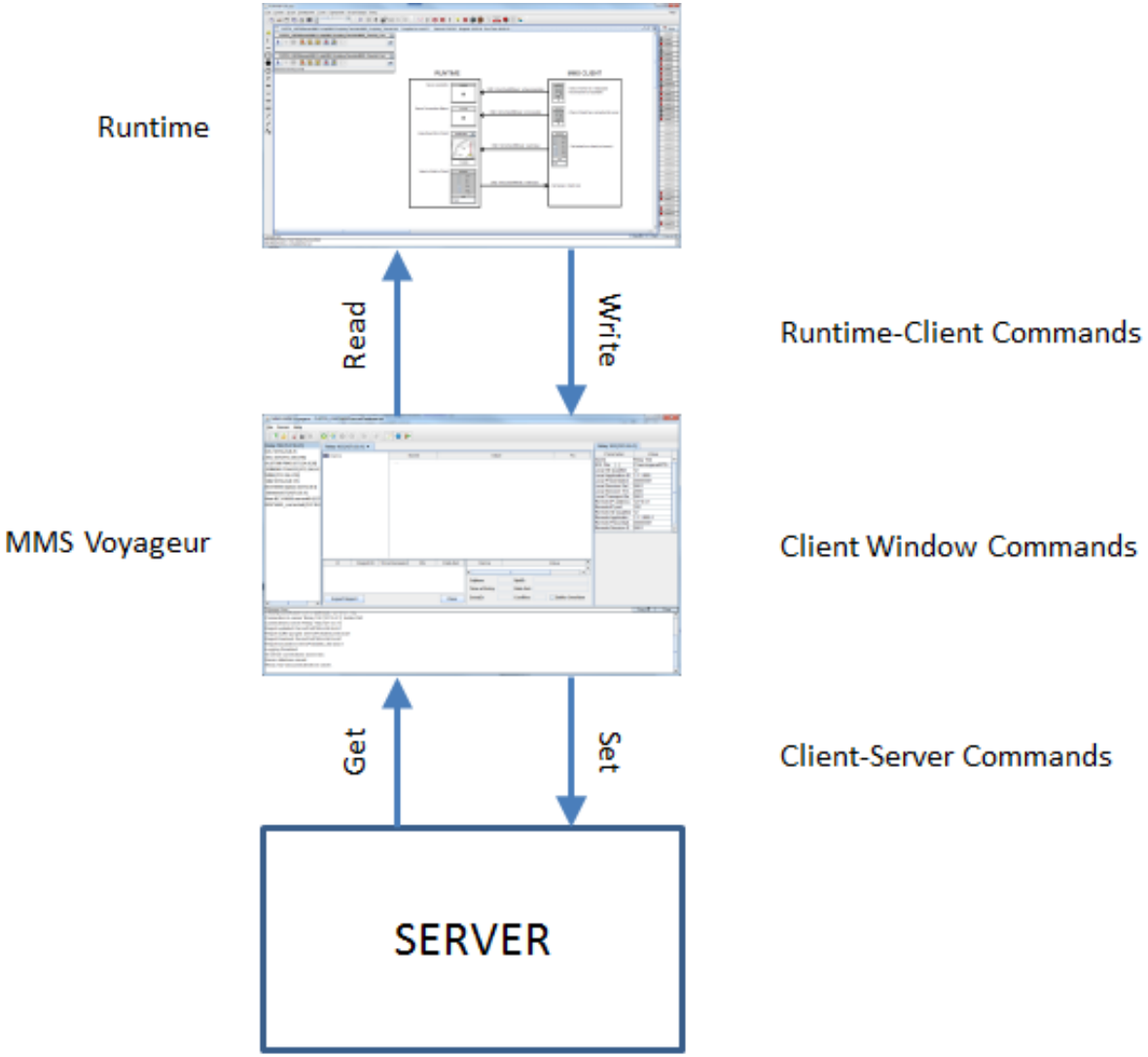


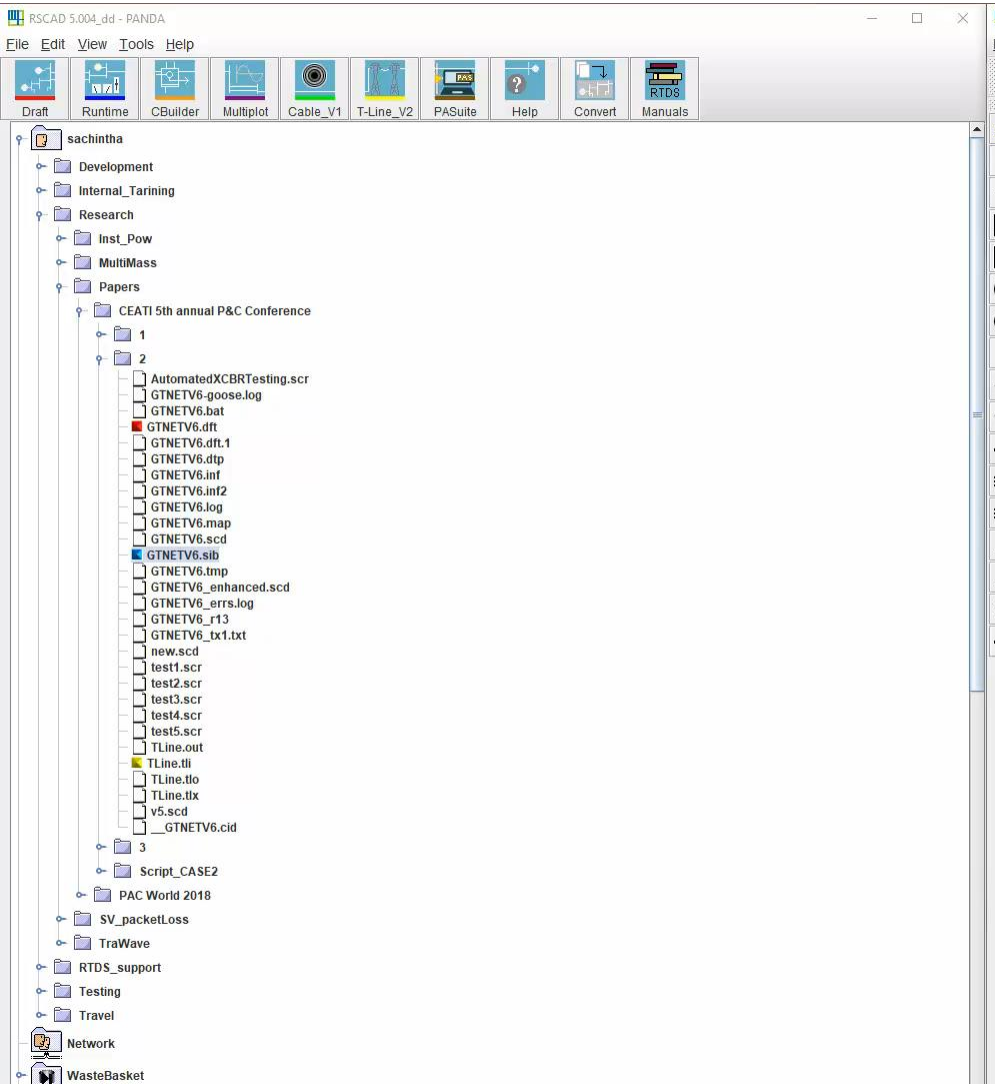
# Automated Testing with Scripting

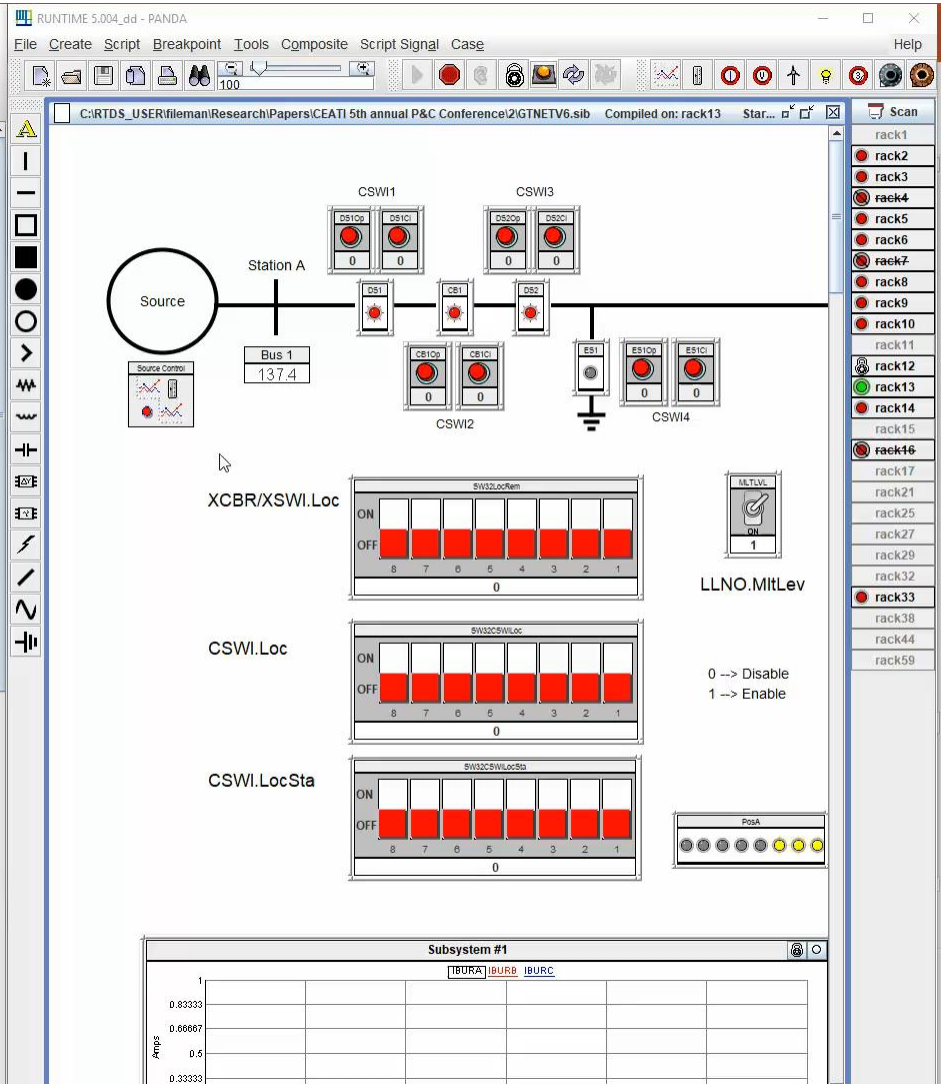
- MMS Voyageur supports the **scripting capability** of “RSCAD Runtime”
- This enables users to **automate testing** and effectively test a large number of scenarios with different settings
- Here, all cases described in IEC 61850-7-4 are tested for three scenarios,
  - With interlock check bypassed
  - With interlocks checked, but violated
  - With interlocks checked, and satisfied
- In total, **24 cases** and **72 switching operations** are performed

# Automated Testing with Scripting (cont.)



# Automated Testing






MMS Client in RSCAD
Test Procedure
Results

Test Procedure

# Test Results

- Above script only tests a **single circuit breaker**
- Its control model is **SBO with enhanced security**
- Operations for all 4 control models are tested in a similar manner
- Then, 72 x 4 = **288** control operations are performed for a single switch object

# Test Results

Scenario 1: With interlock check **bypassed**

| | Switch | Bay control parameters | | | Command from (OrCat) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Bay | | Station | | NCC | |
| Case | XCBR.Loc XSWI.Loc | LLN0.MltLev | CSWI.Loc | CSWI.LocSta | Intended operation | Result | Intended operation | Result | Intended operation | Result |
| 1 | T | F | n.a. | n.a. | NA | ✓ | NA | ✓ | NA | ✓ |
| 2 | F | F | T | n.a. | AA | ✓ | NA | ✓ | NA | ✓ |
| 3 | F | F | F | T | NA | ✓ | AA | ✓ | NA | ✓ |
| 4 | F | F | F | F | NA | ✓ | NA | ✓ | AA | ✓ |
| 5 | T | T | n.a. | n.a. | NA | ✓ | NA | ✓ | NA | ✓ |
| 6 | F | T | T | n.a. | AA | ✓ | NA | ✓ | NA | ✓ |
| 7 | F | T | F | T | AA | ✓ | AA | ✓ | NA | ✓ |
| 8 | F | T | F | F | AA | ✓ | AA | ✓ | AA | ✓ |

**Loc Status**
T = True
F = False
n.a. = not applicable

**Command**
AA = Always Allowed
NA = Not Allowed

**Result**
✓ - Expected Result
× - Unexpected Result

# Test Results (cont.)

Scenario 2: With interlocks checked, but **violated**

| | Switch | Bay control parameters | | | Command from (OrCat) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Bay | | Station | | NCC | |
| Case | XCBR.Loc XSWI.Loc | LLN0.MltLev | CSWI.Loc | CSWI.LocSta | Intended operation | Result | Intended operation | Result | Intended operation | Result |
| 1 | T | F | n.a. | n.a. | NA | ✓ | NA | ✓ | NA | ✓ |
| 2 | F | F | T | n.a. | NA | ✓ | NA | ✓ | NA | ✓ |
| 3 | F | F | F | T | NA | ✓ | NA | ✓ | NA | ✓ |
| 4 | F | F | F | F | NA | ✓ | NA | ✓ | NA | ✓ |
| 5 | T | T | n.a. | n.a. | NA | ✓ | NA | ✓ | NA | ✓ |
| 6 | F | T | T | n.a. | NA | ✓ | NA | ✓ | NA | ✓ |
| 7 | F | T | F | T | NA | ✓ | NA | ✓ | NA | ✓ |
| 8 | F | T | F | F | NA | ✓ | NA | ✓ | NA | ✓ |

**Loc Status**
T = True
F = False
n.a. = not applicable

**Command**
AA = Always Allowed
NA = Not Allowed

**Result**
✓ - Expected Result
× - Unexpected Result

# Test Results

Scenario 3: With interlocks checked, and **satisfied**

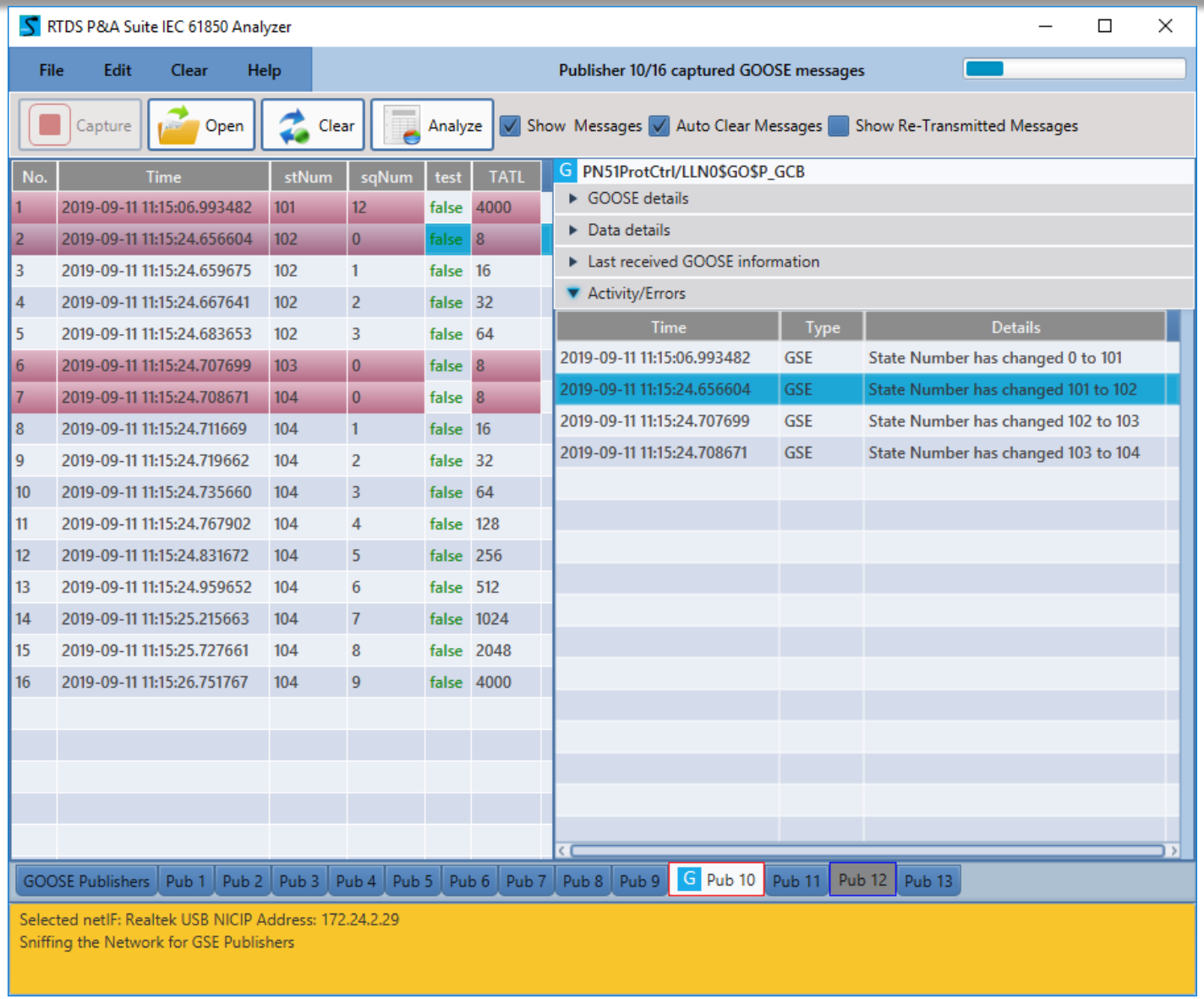
| | Switch | Bay control parameters | | | Command from (OrCat) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Bay | | Station | | NCC | |
| Case | XCBR.Loc XSWI.Loc | LLN0.MltLev | CSWI.Loc | CSWI.LocSta | Intended operation | Result | Intended operation | Result | Intended operation | Result |
| 1 | T | F | n.a. | n.a. | NA | ✓ | NA | ✓ | NA | ✓ |
| 2 | F | F | T | n.a. | AA | ✓ | NA | ✓ | NA | ✓ |
| 3 | F | F | F | T | NA | ✓ | AA | ✓ | NA | ✓ |
| 4 | F | F | F | F | NA | ✓ | NA | ✓ | AA | ✓ |
| 5 | T | T | n.a. | n.a. | NA | ✓ | NA | ✓ | NA | ✓ |
| 6 | F | T | T | n.a. | AA | ✓ | NA | ✓ | NA | ✓ |
| 7 | F | T | F | T | AA | ✓ | AA | ✓ | NA | ✓ |
| 8 | F | T | F | F | AA | ✓ | AA | ✓ | AA | ✓ |

**Loc Status**
T = True
F = False
n.a. = not applicable

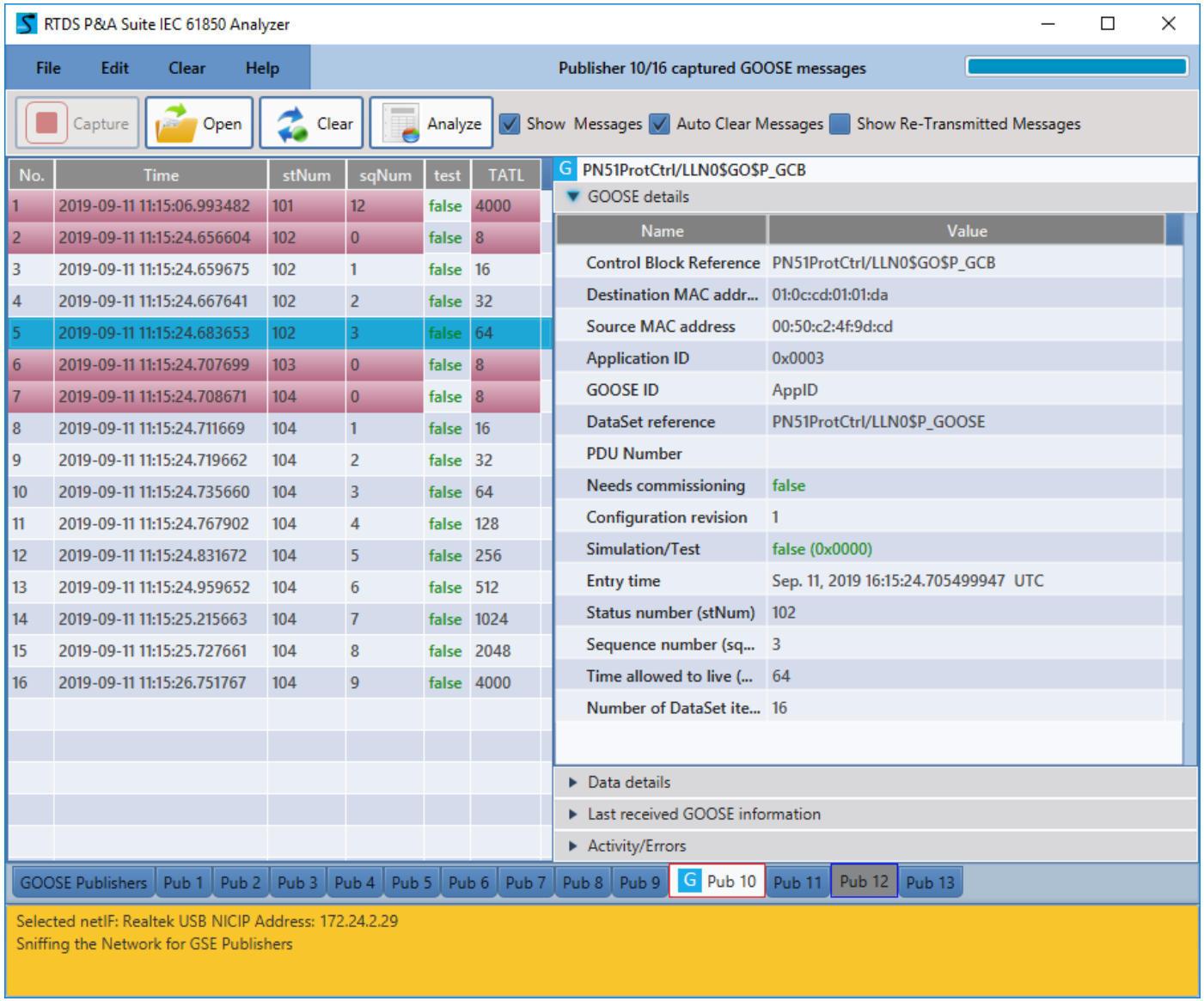
**Command**
AA = Always Allowed
NA = Not Allowed

**Result**
✓ - Expected Result
× - Unexpected Result

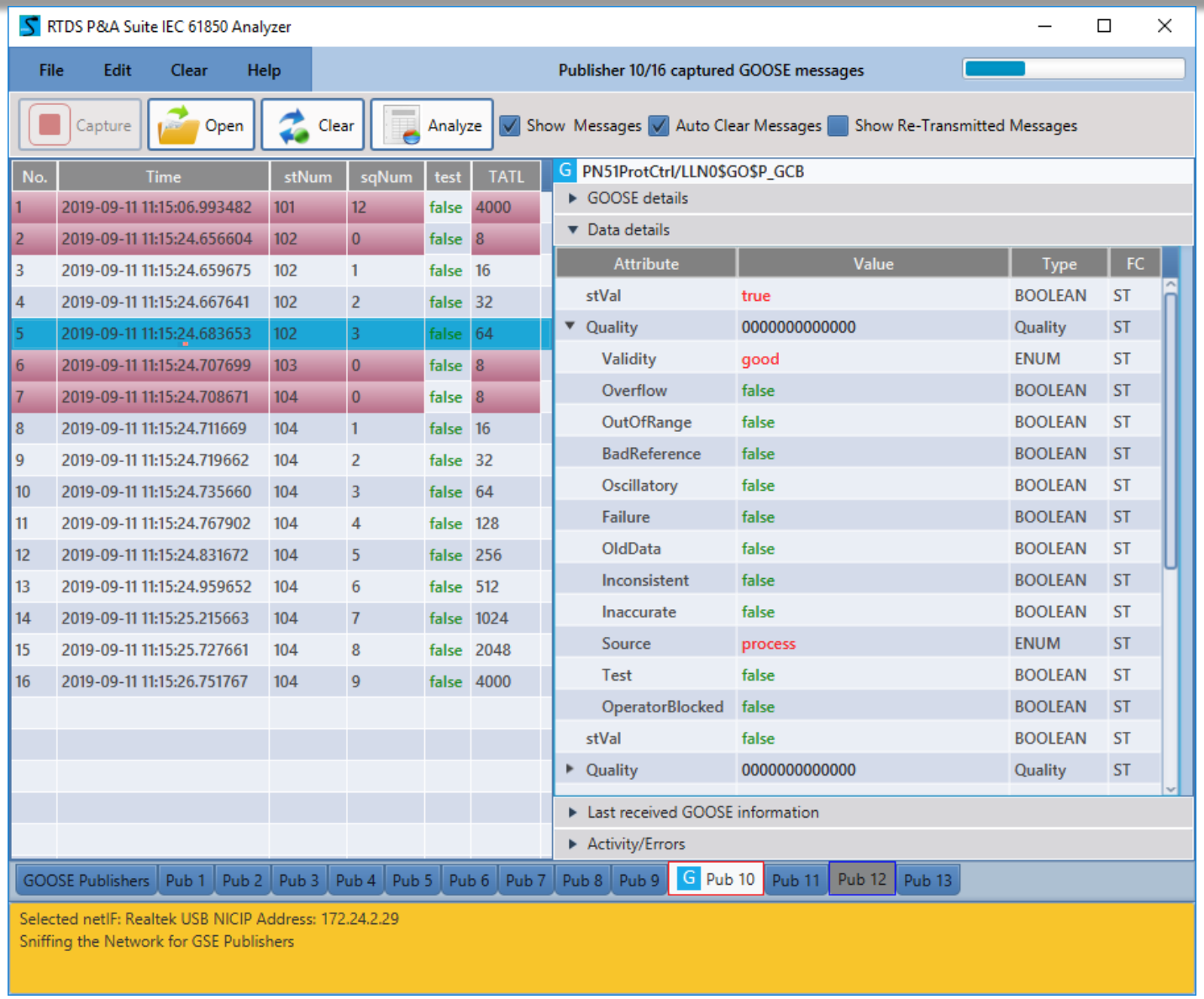
# RTDS P&A Suite IEC 61850 Analyzer



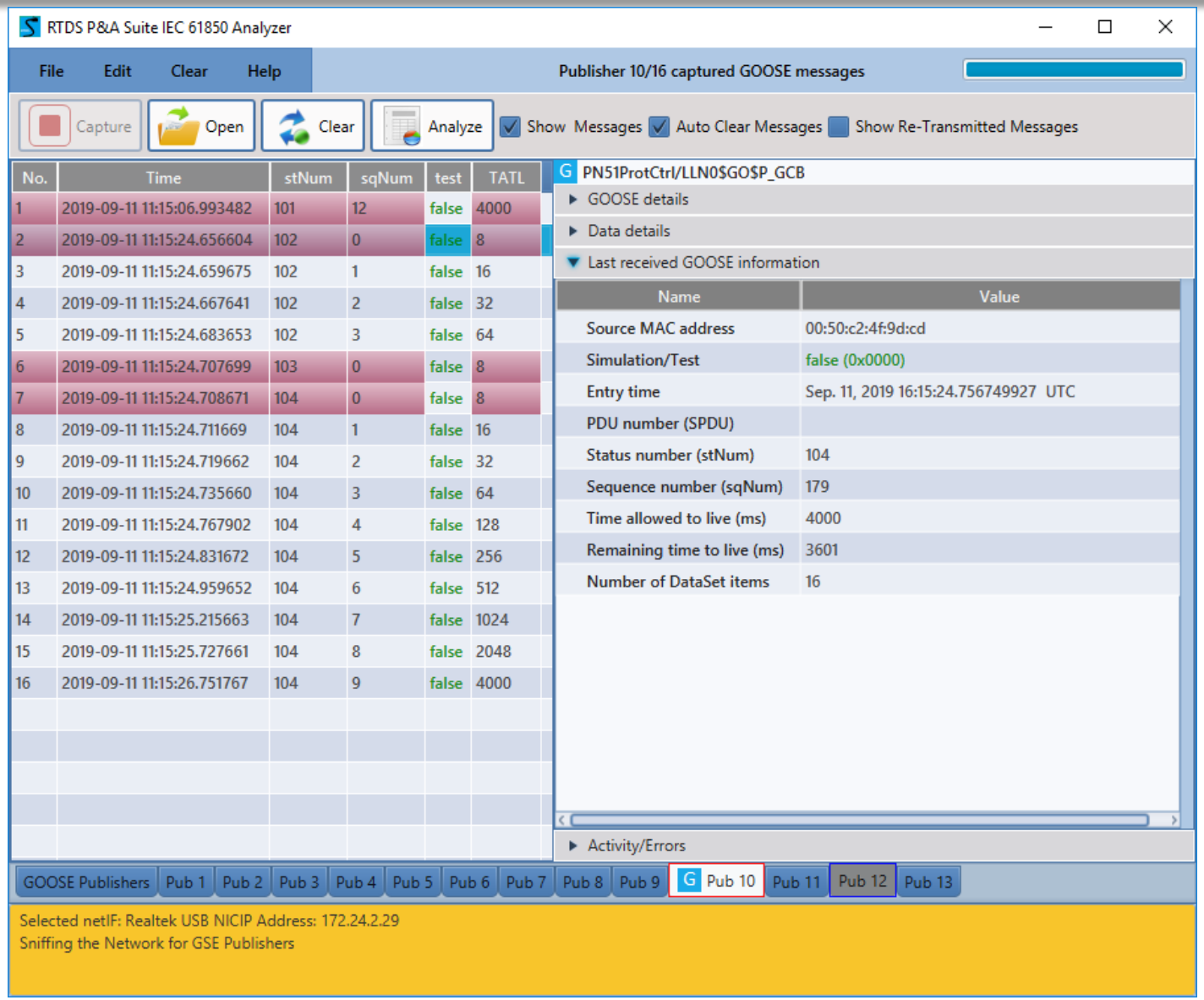
# GOOSE details



# GOOOSE data details



# GOOSE last received message



# Conclusions

- Standard IEC 61850 models are created to represent switchgear in real-time simulations
- Related implementation details and configuration procedures are explained
- A standalone client program is used to validate the MMS server operations related to switchgear implementations
- A number of scenarios are tested and results are presented

# Thank you

Q & A