System-Based Protection Testing in Digital Substations

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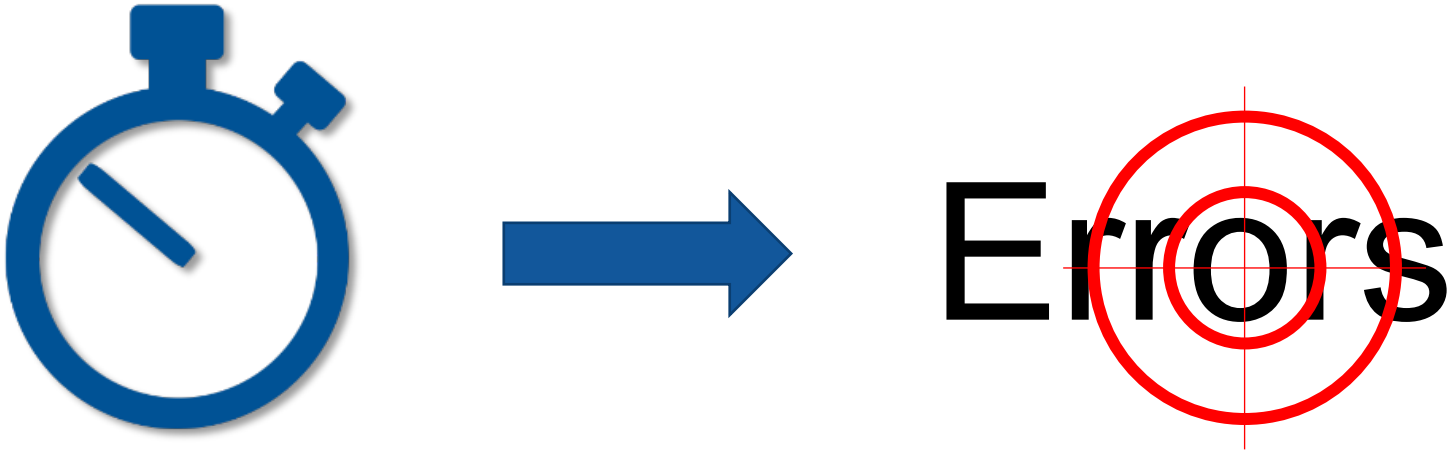
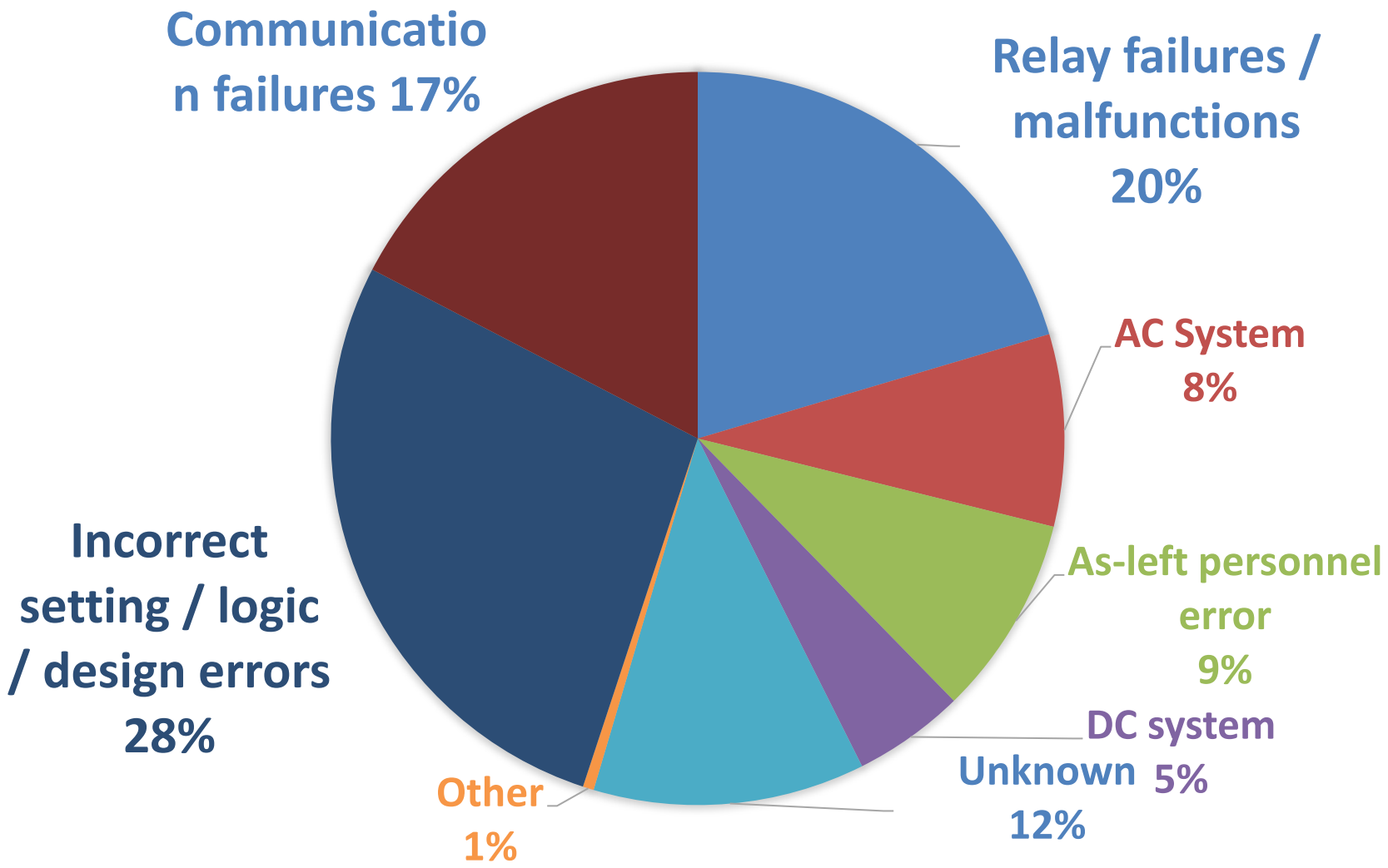
System-Based Testing

Testing strategy: Focus on the Errors

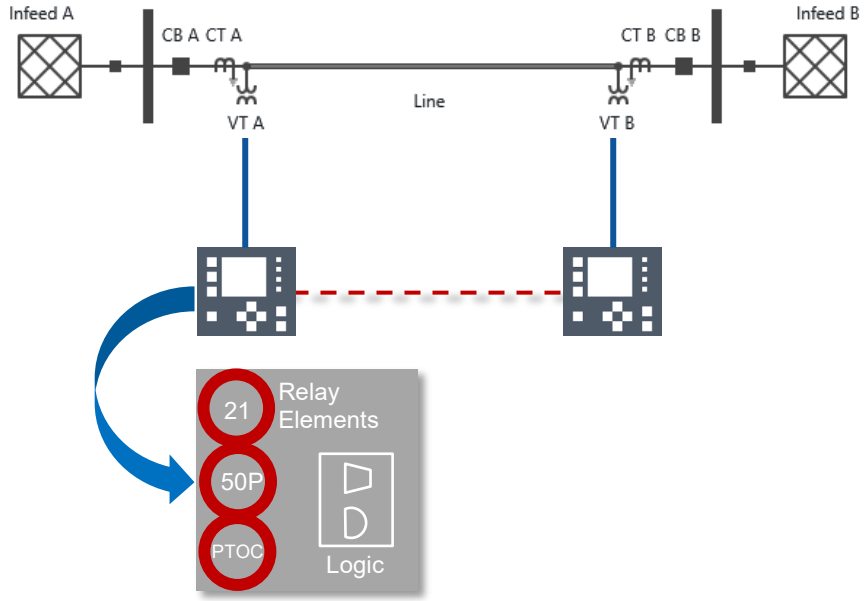


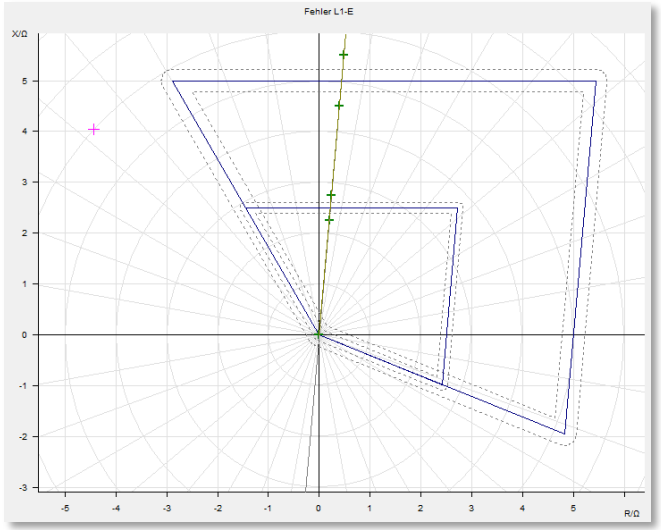
Cause For Misoperations: NERC Report

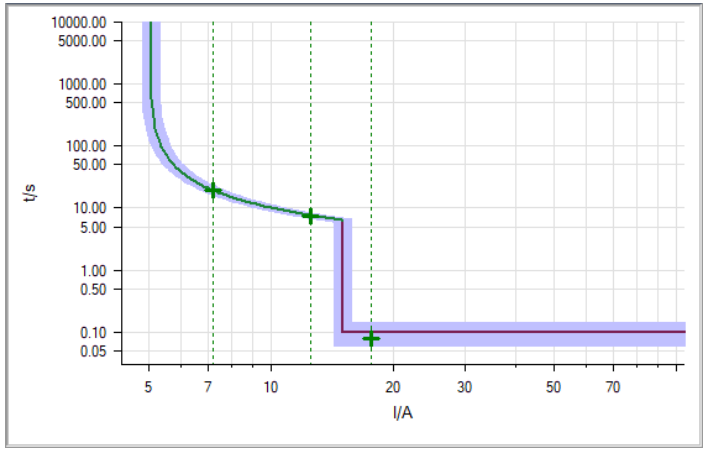


Testing Against Relay Settings

- The relay is working with given settings!
- **What if the settings, logic or design are wrong?**
- **Do the settings across a protection scheme work together?**

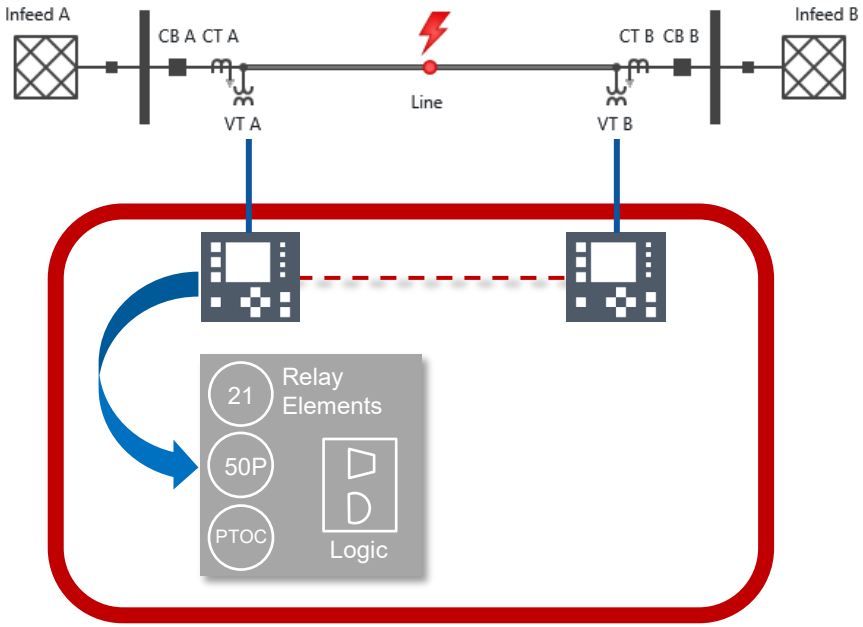






Testing Against System Requirements

- Starting with real-world scenario
- Not compromised by process error
- Very simple to define

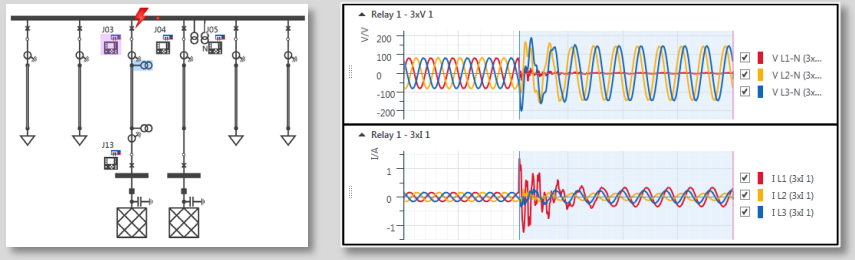


1. Fault on protected line must trip instantaneously.
2. If a breaker fails during a fault, the local busbar must be tripped.
3. …

System-Based Testing Solution For Field Testing

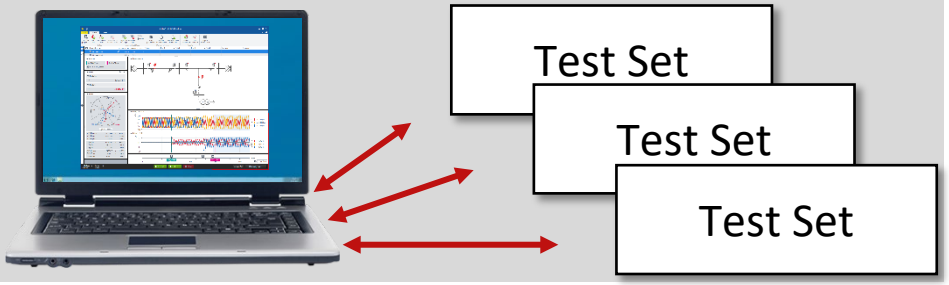
1.

Real world scenario



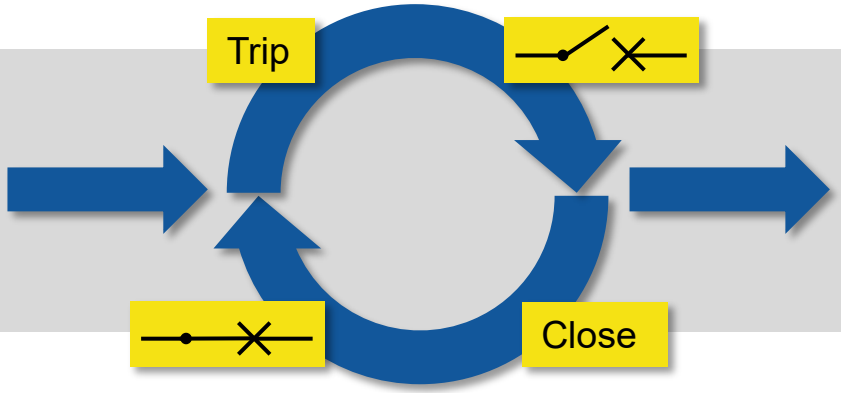
2.

Test protection system
(instead of elements)



3.

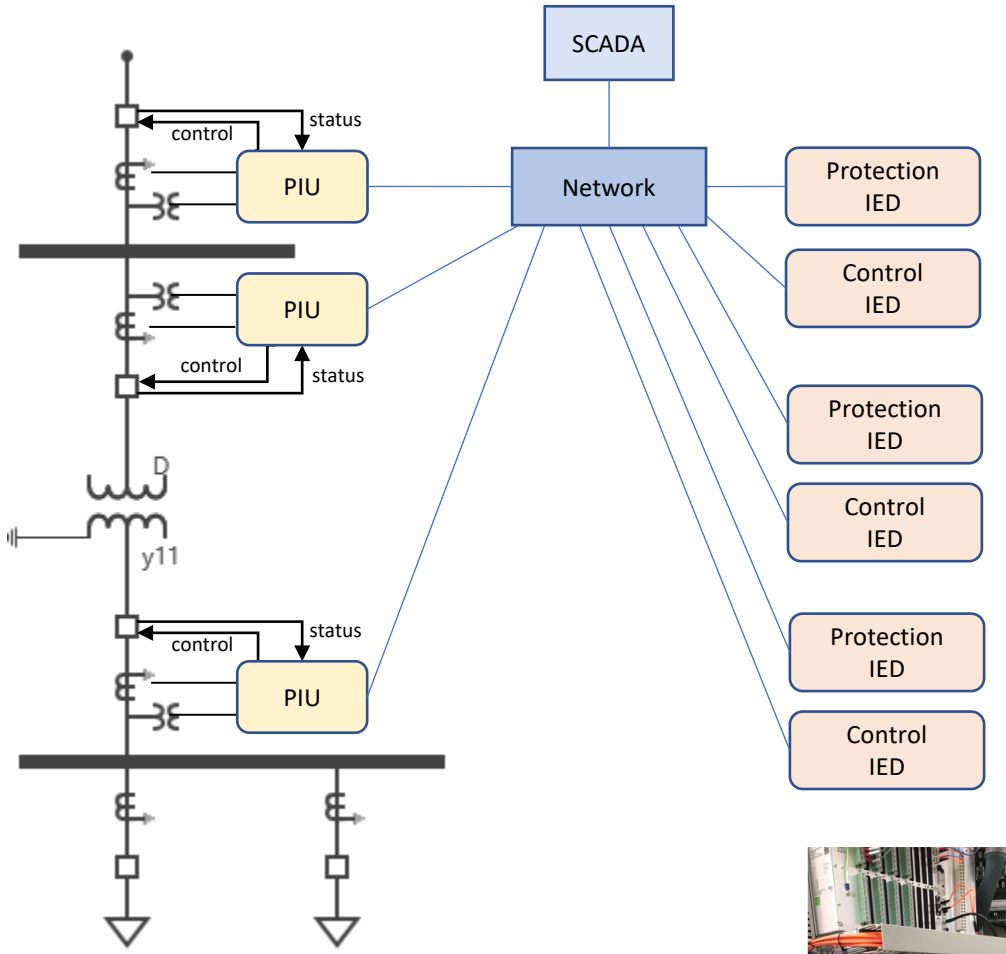
Testing logic sequences



Digital Substations

Typical Architecture

- Process Interface Units (PIU)
  - Merging Units (MU)
  - Switchgear Control Units (SCU)
- IEDs
  - Protection
  - Control
- Communication Network
  - Digital Interfaces
  - Sampled Values, GOOSE, MMS

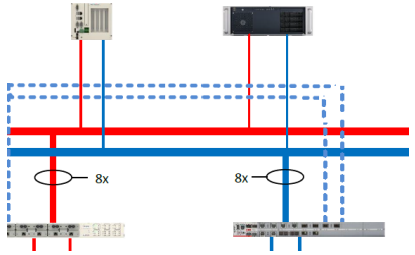


PIU cabinet

IED panel

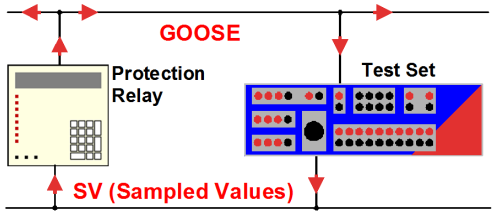
What’s new in digital substations

- Substation communication network
  - Integral part of the system → Testing is required!

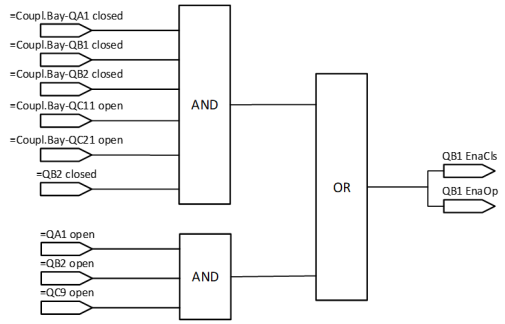


- New connections to primary equipment
  - Instrument Transformers with MU
  - Only fiber connections into the relay room

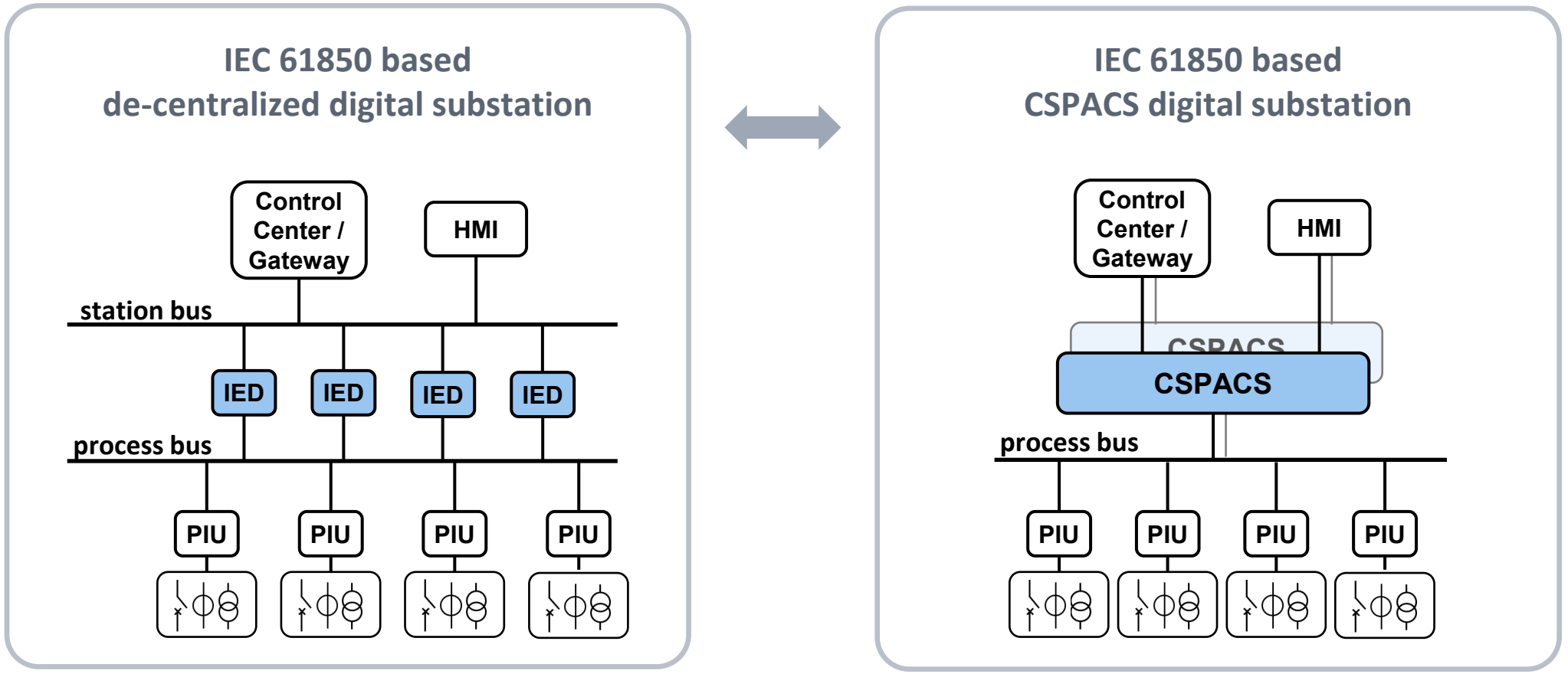
- Protection system
  - SV and GOOSE instead of conventional wiring
  - New way to isolate the devices under test



- Increased use of logics

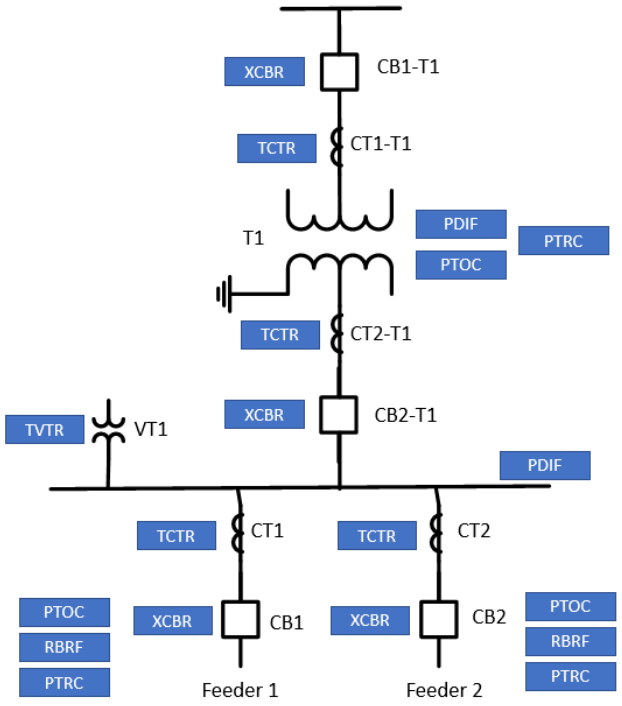


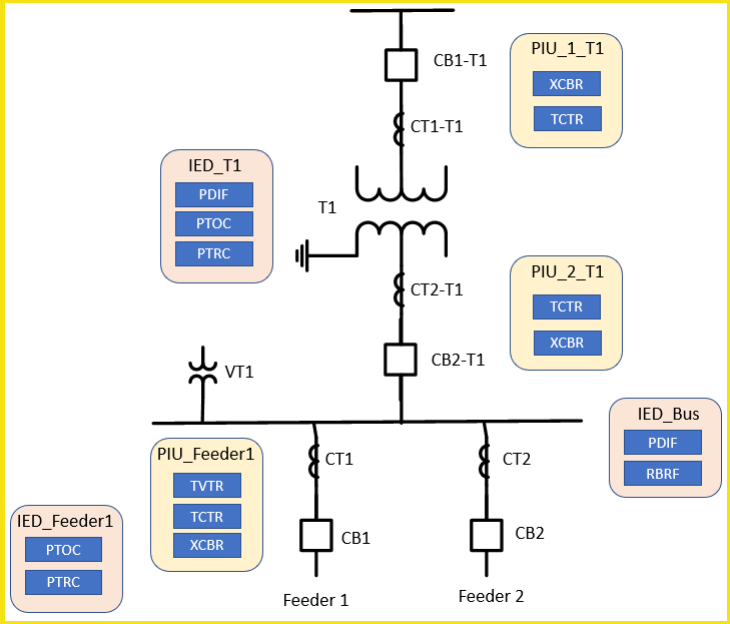
De-centralized vs Centralized Digital Substations

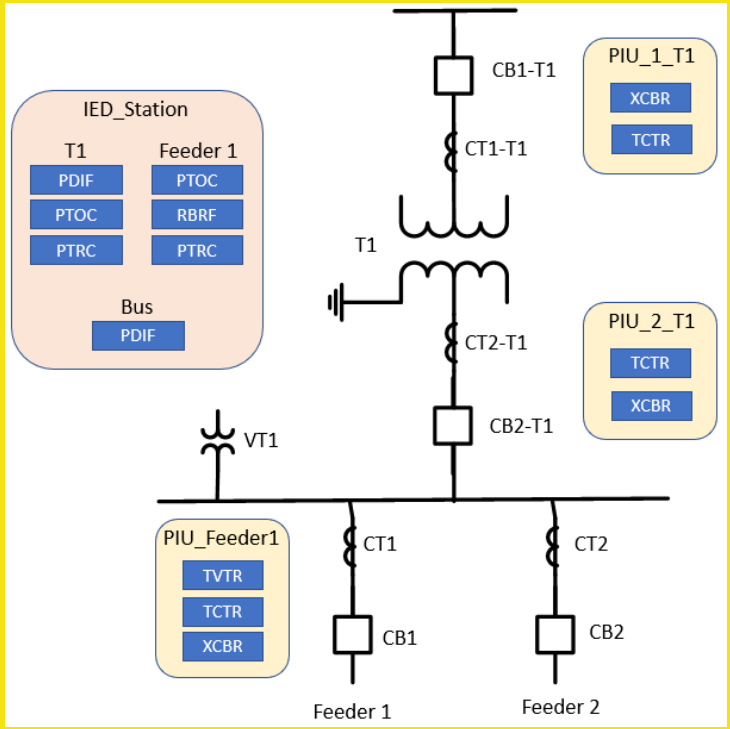


Distributed x Centralized in an IEC 61850 Based System

- Logical Node Specification
- LN Allocation to Physical IEDs





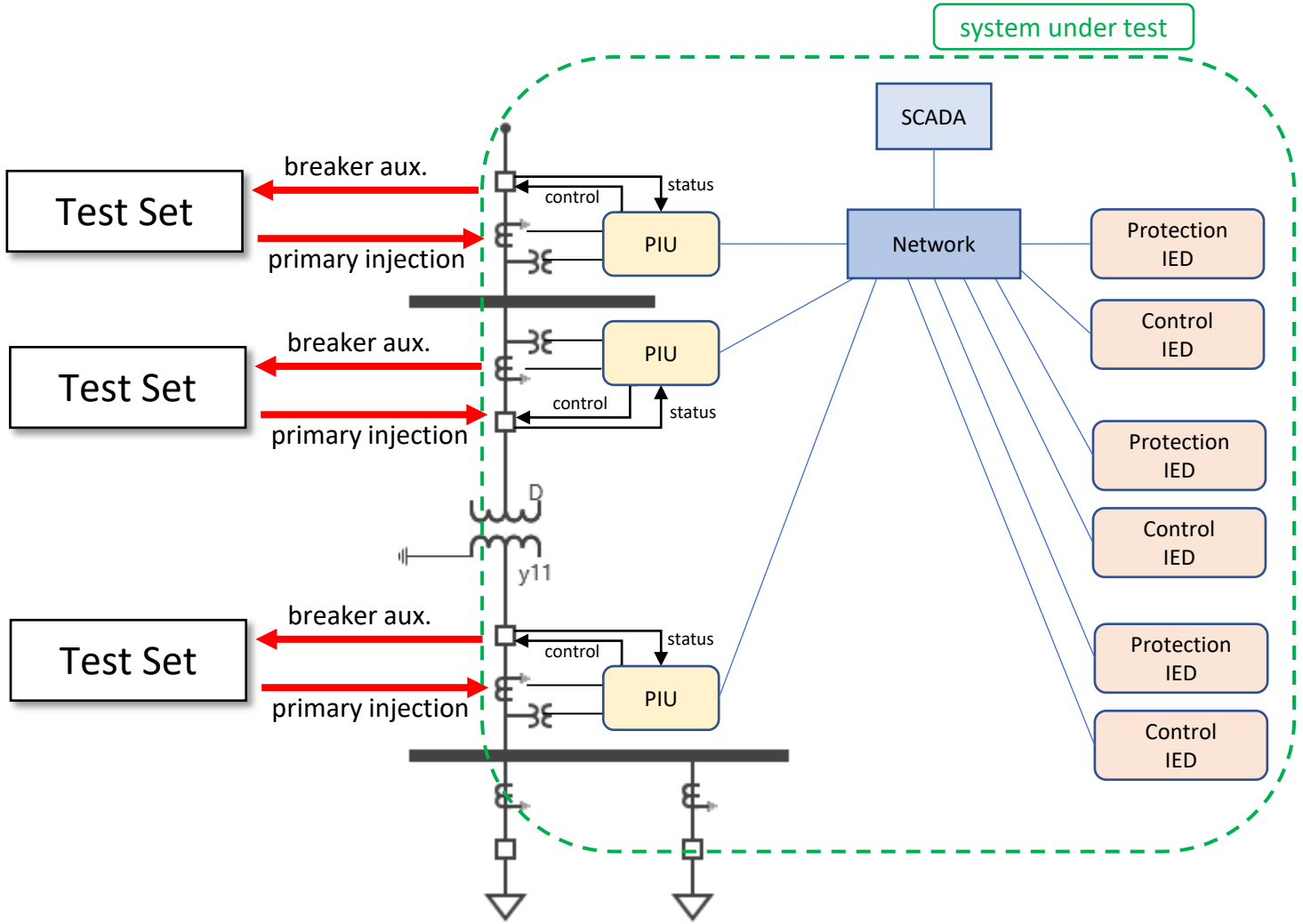


Test Strategy

How to Test the Protection? Challenges...

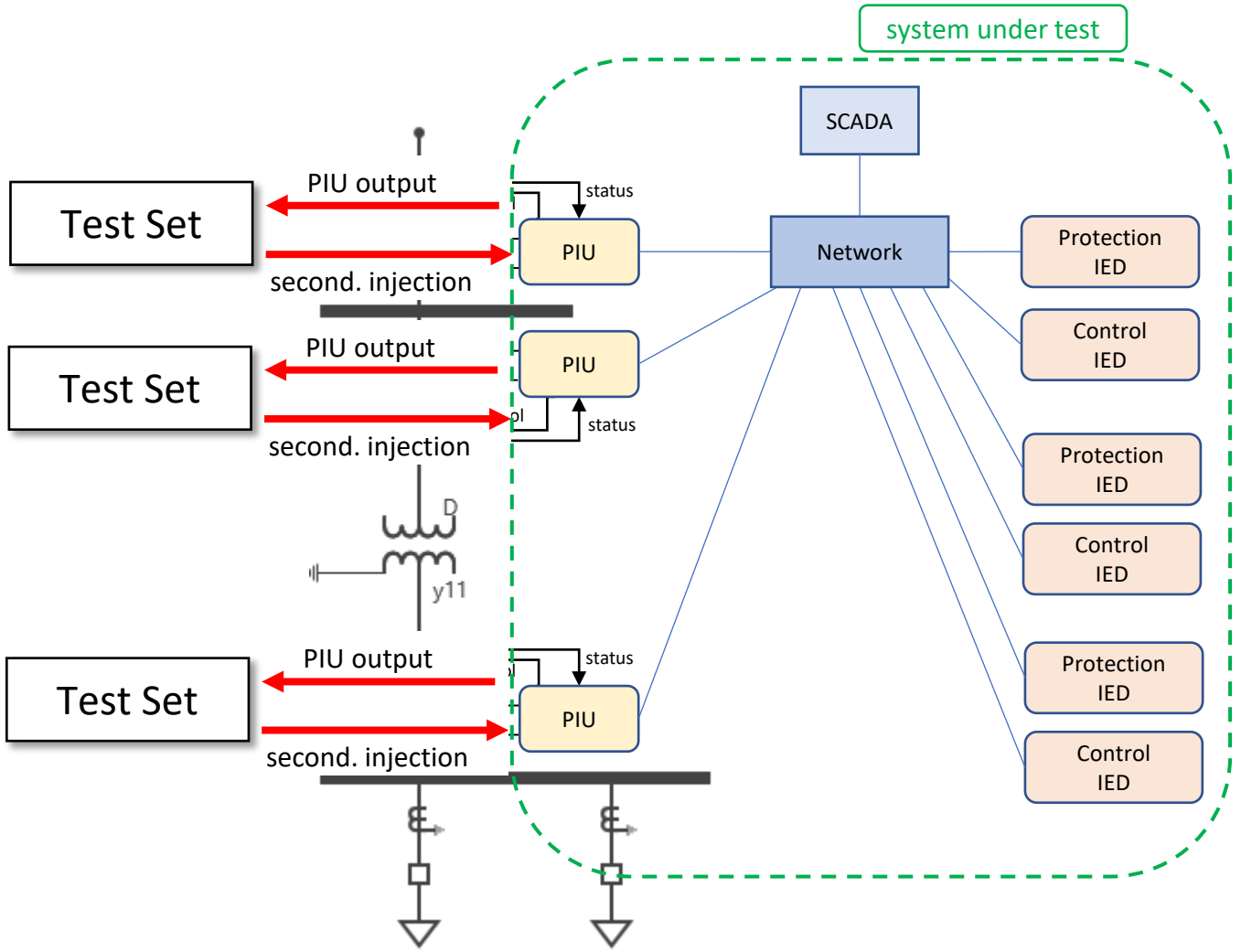
- Test as a Black-box?
- Test with primary injection?

- Challenges:
  - Test set limitations
  - High effort to simulate complex scenarios
  - After all components (CT, VT...) are installed



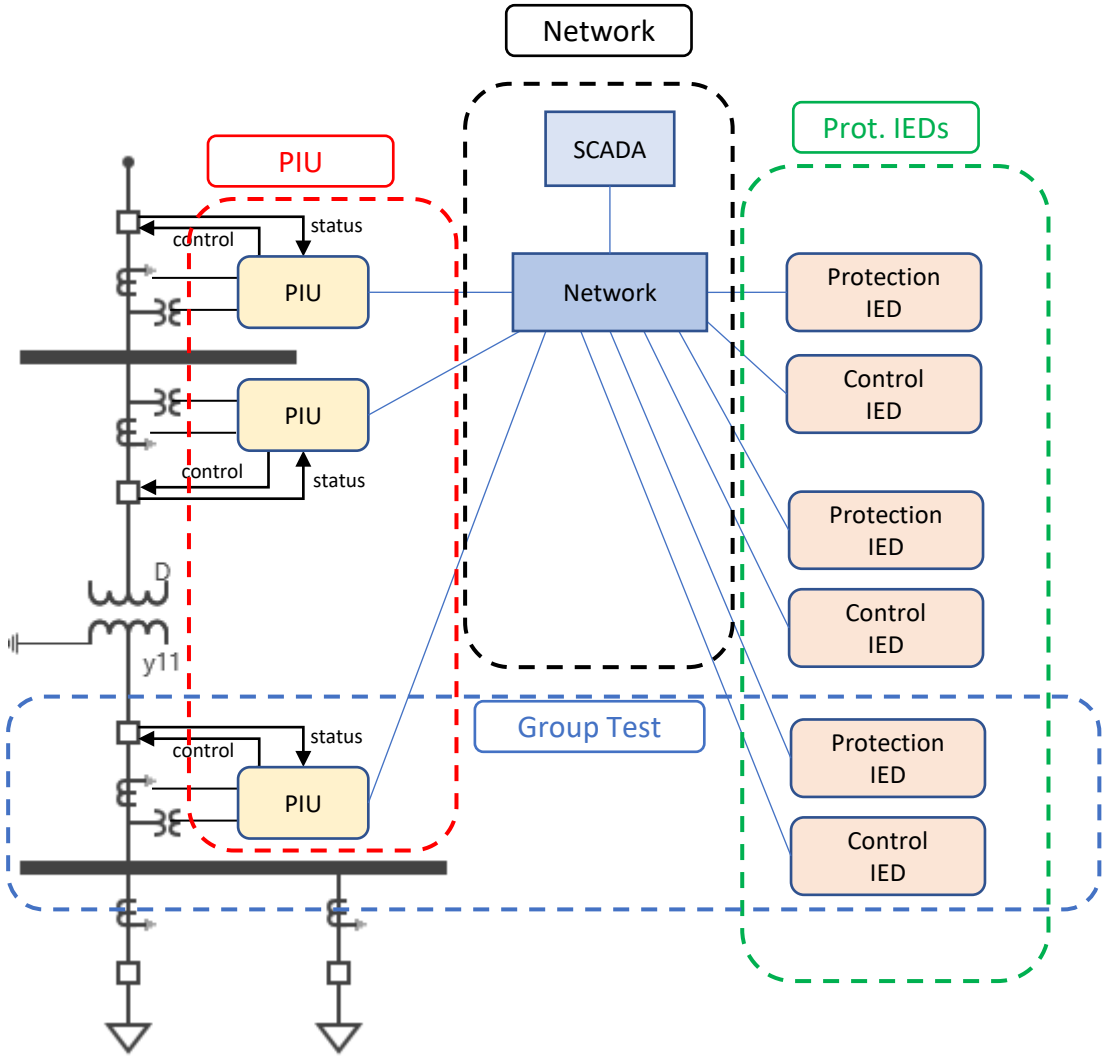
How to Test the Protection? Challenges...

- Focus on system-based Method!
- Test with primary injection?
  - Test set limitations
  - High effort to simulate complex scenarios
  - After all components (CT, VT...) are installed
- Test connecting to the PIU?
  - Devices in substation yard
  - Availability of PIU during commissioning
  - High number of test sets
  - Difficult troubleshooting (IED logic error or PIU wiring issue?)



Subsystems and Test Coverage

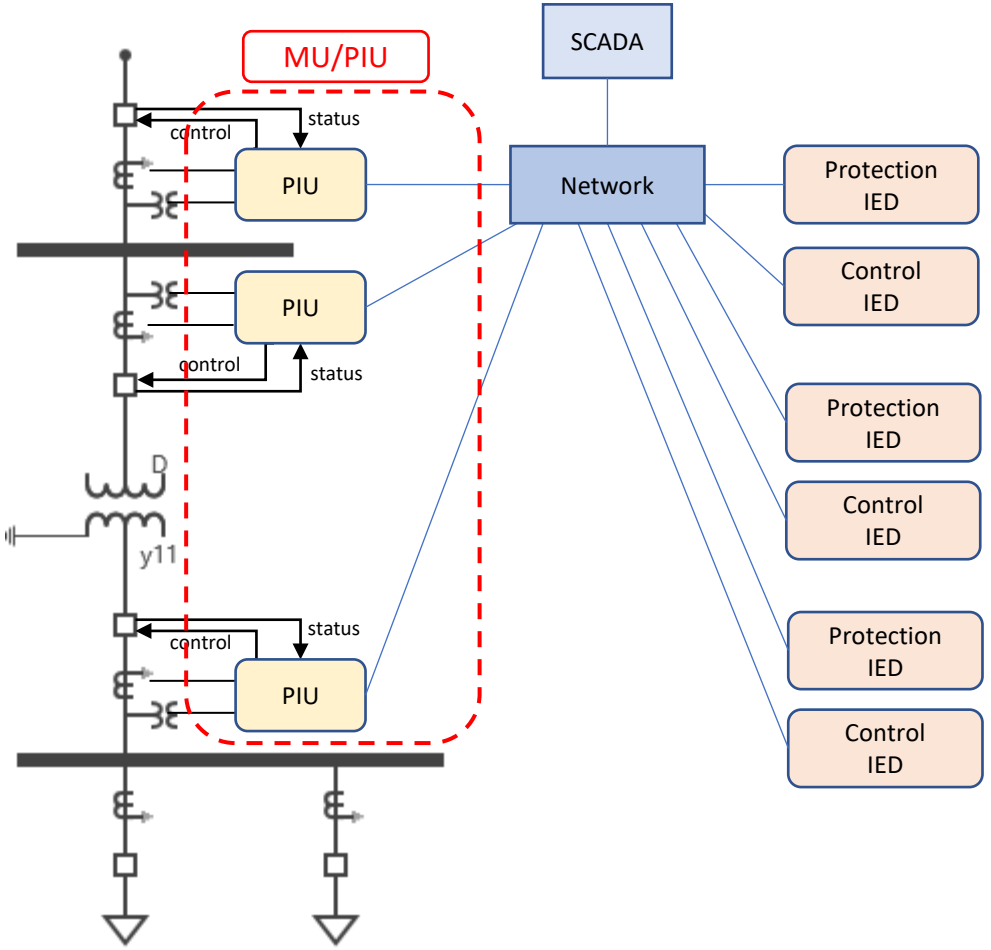
- Define Subsystems
  - Process Interfaces (MU/PIU)
  - Protection IEDs
  - Group Test
  - Network
- Test subsystems separately
- Overlapping Test Coverage



Process Interface Subsystem

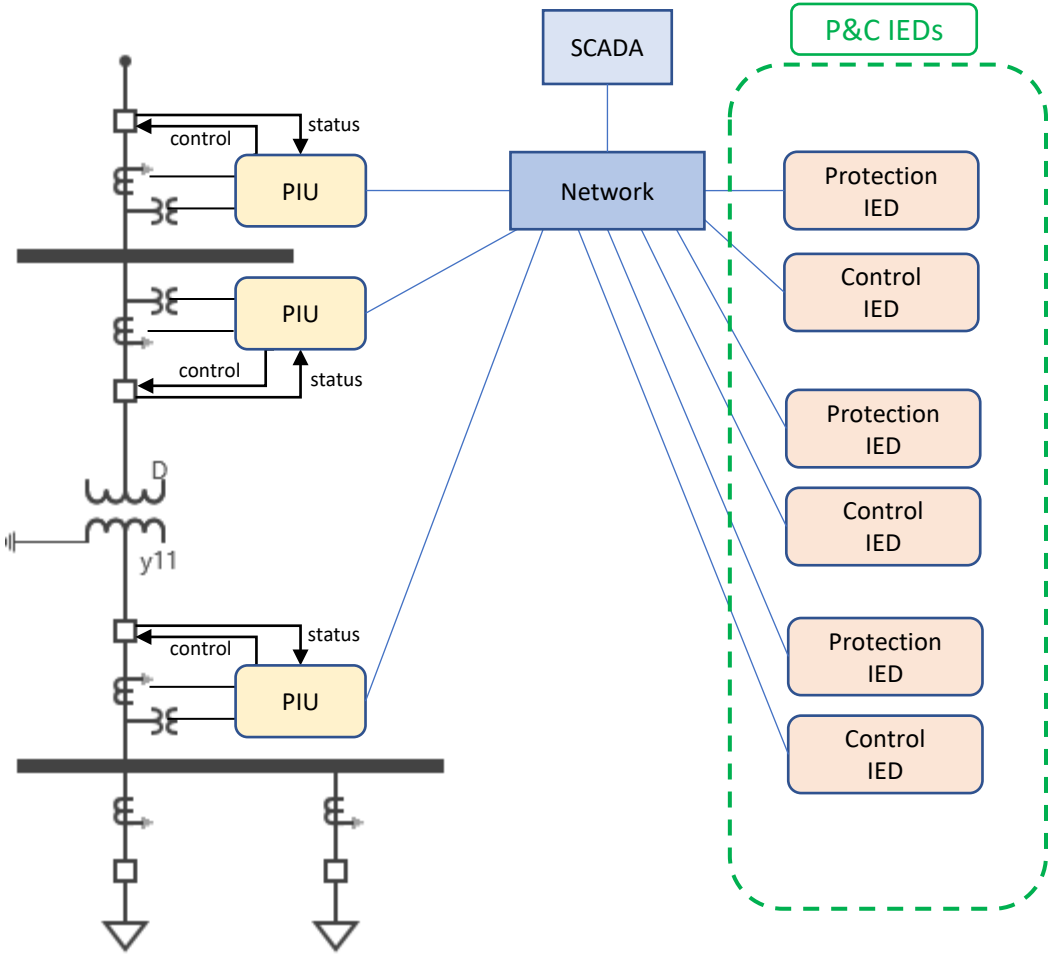
- Wiring check of process interface cabinets
- PIU Configuration
  - Mapping of analogs to Sampled Values
  - Mapping of inputs to GOOSE or MMS
  - Mapping of subscribed GOOSE to outputs
- Check network

- Can be performed at FAT



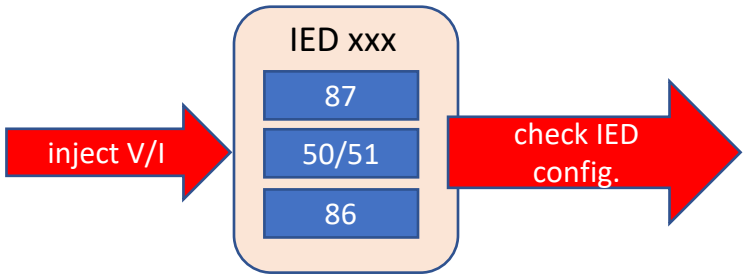
Protection & Control Subsystem

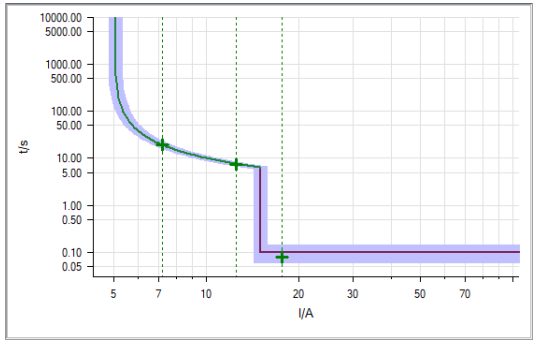
- Test sets simulate Merging Units
  - Injection of Sampled Values
  - Monitoring of GOOSE messages
- Test isolation with IEC 61850 Ed.2 features
  - Test Mode
  - Simulation Flag
- IED Unit Tests
  - Validate IED Configuration
- System-Based Tests
  - Validate schemes



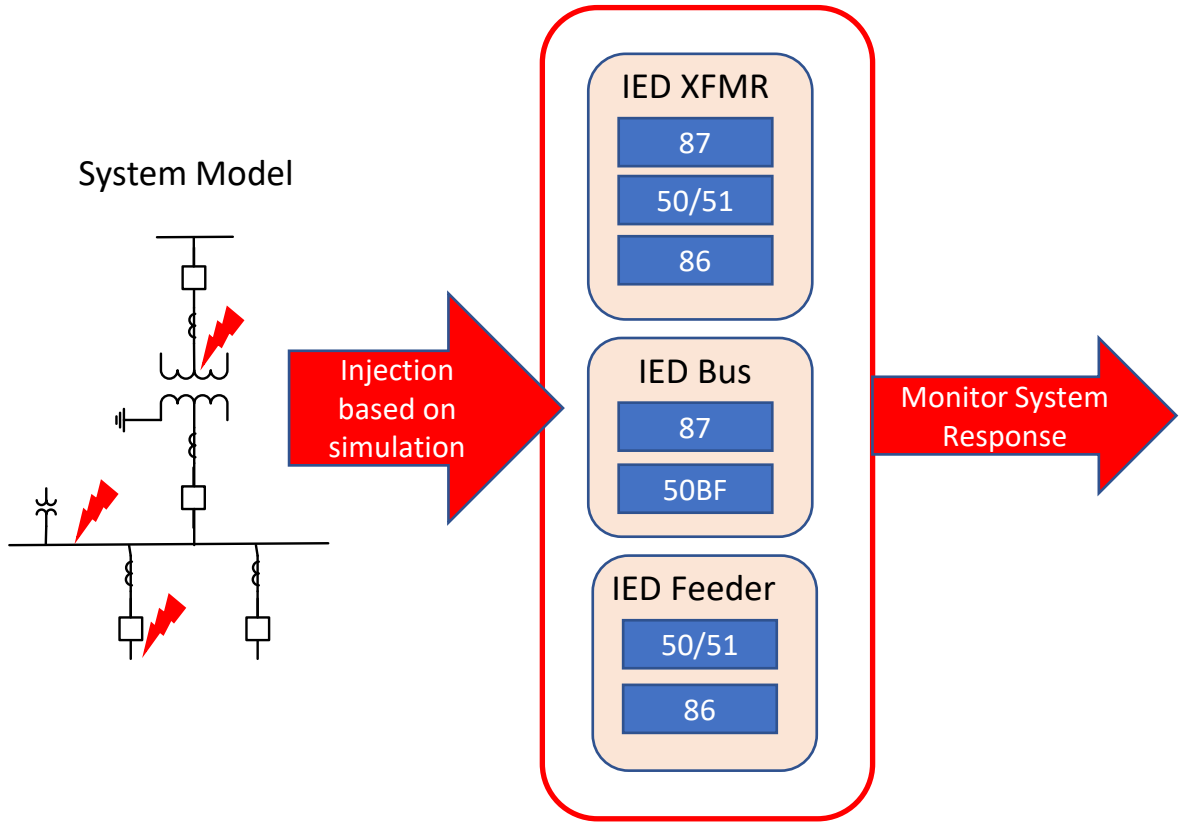
Protection Testing strategy

- Unit Tests
  - Test templates per IED
  - Not very extensive, but validate main settings, mappings, configurations
  - Re-used for maintenance



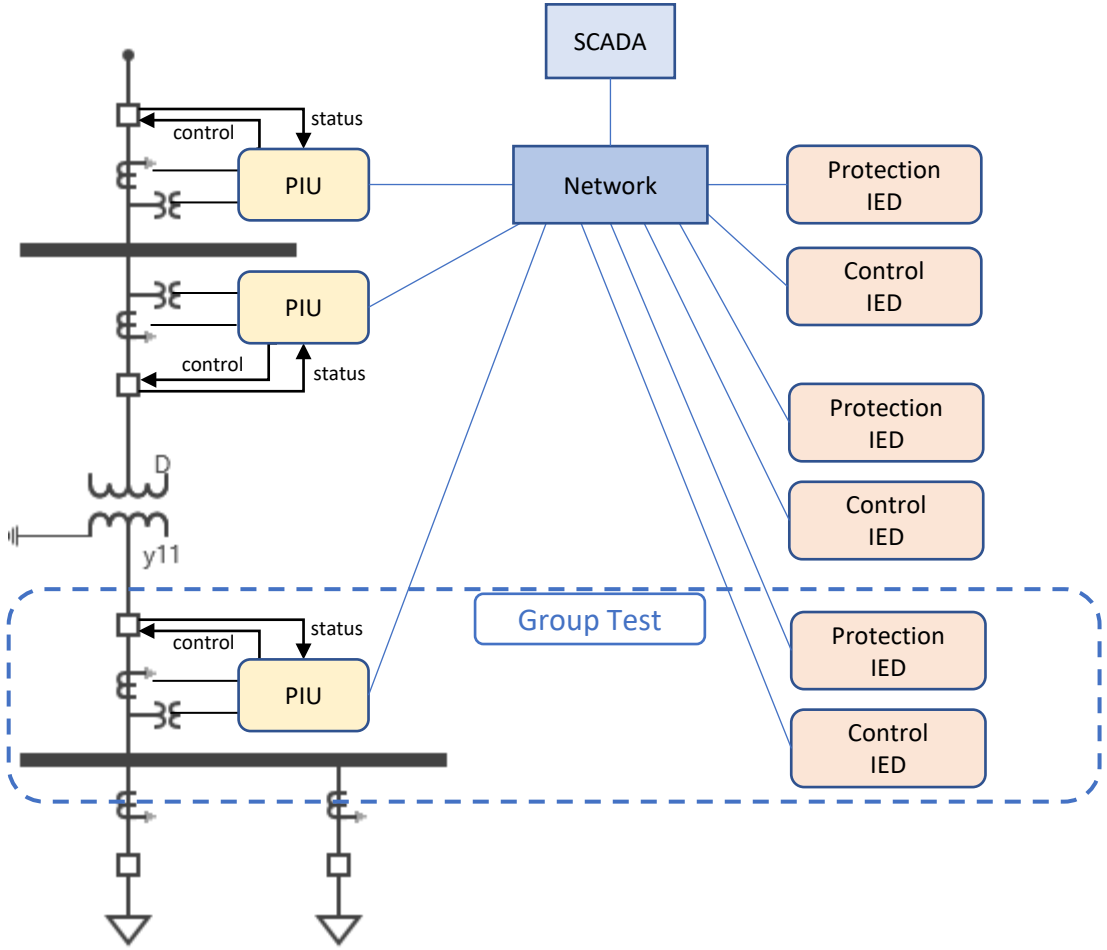


- System-based protection tests
  - Templates per application (system models)
  - System response against simulations
  - Check IED interactions, logics, supervision



Group Test

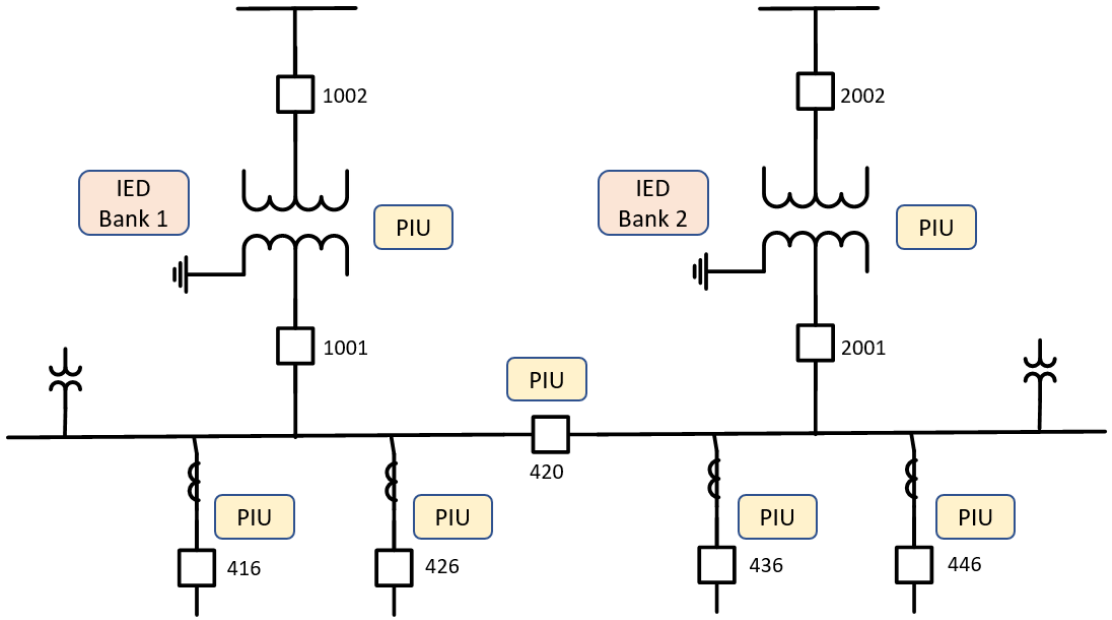
- Simple primary injection
- Meter check in IEDs
- Trip / Close breaker
- Performed at commissioning



Case Study

Case Study: Digital Substation Design

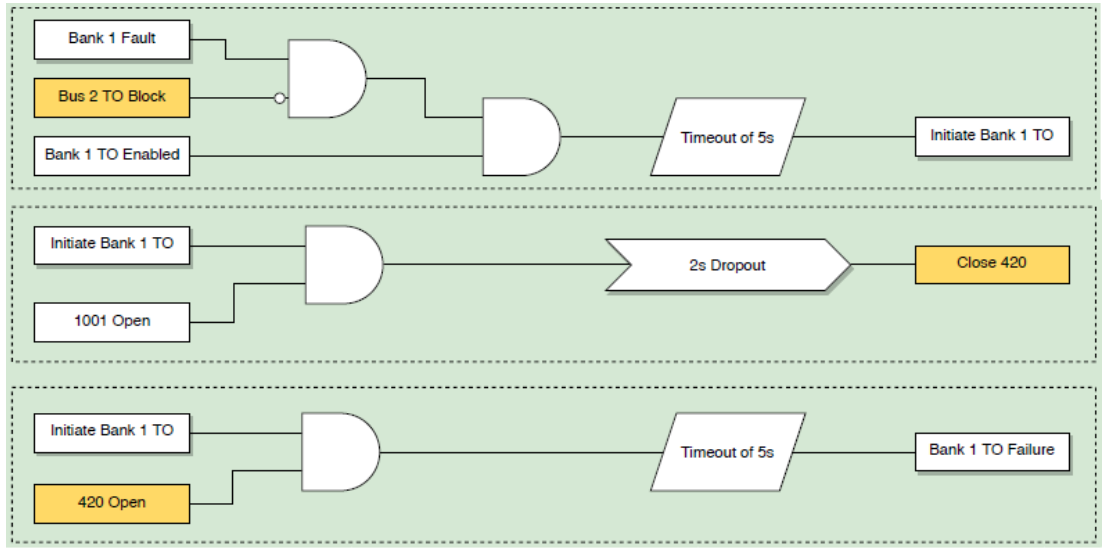
- 115 kV / 13.8 kV distribution system
- Multiple topologies being designed and tested
- Example is a centralized IED design
  - Single IED provide protection for transformer, bus and feeders



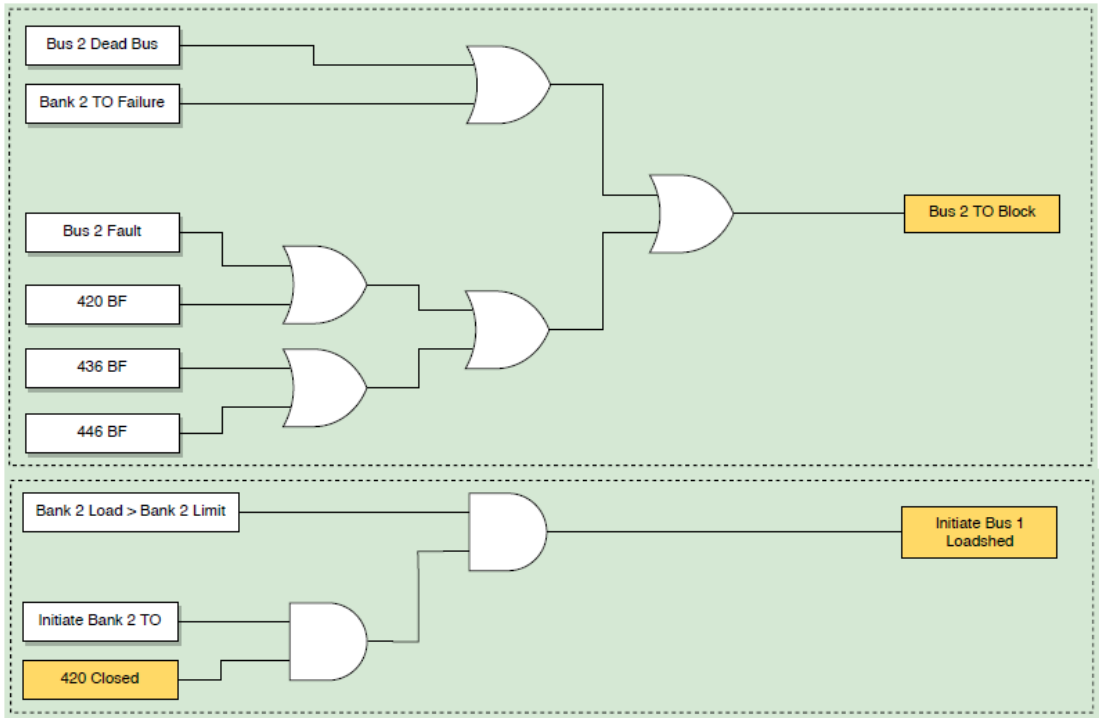
Case Study: Throw-Over Logic

- For a fault in one bank, system initiates throw over to the other bank

Logic IED Bank 1

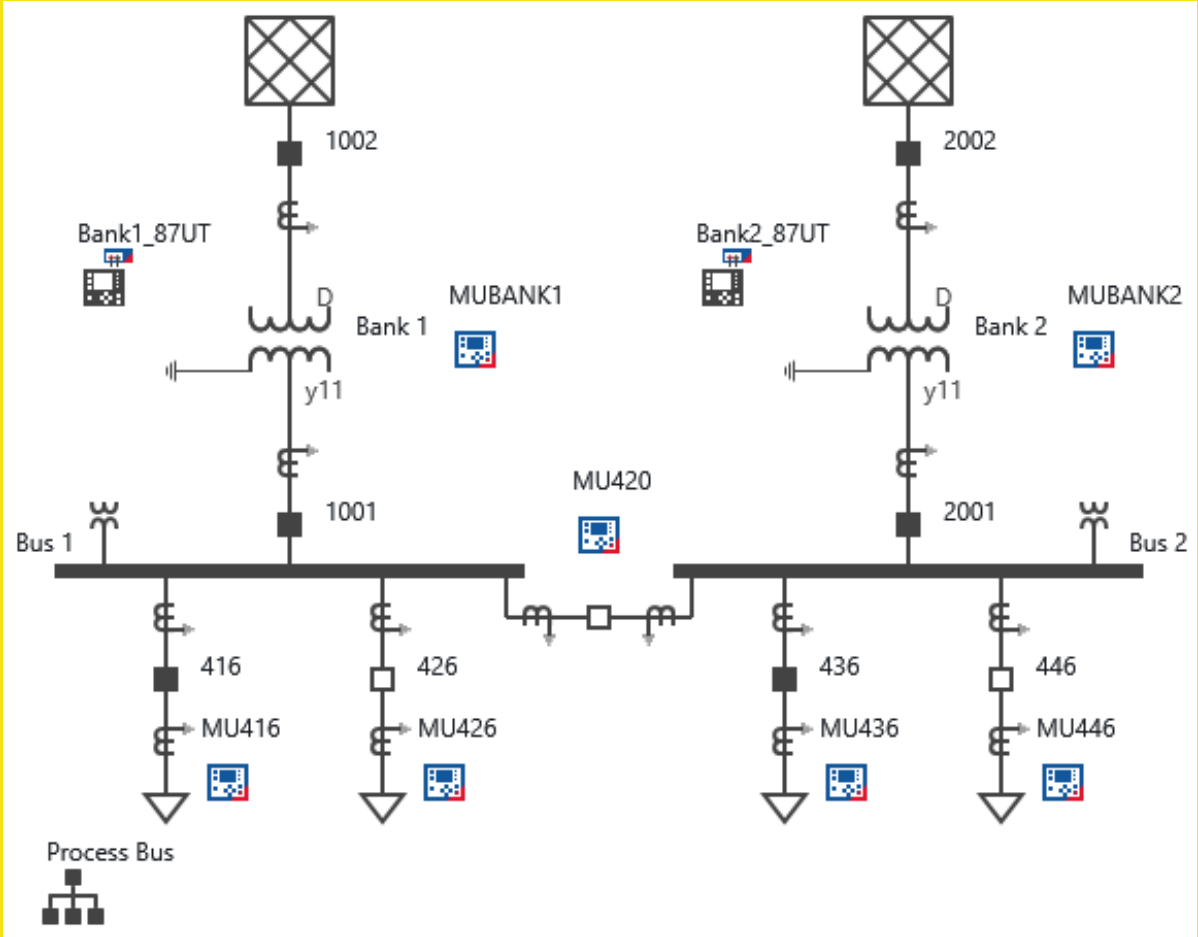


Logic IED Bank 2



System-Based Protection Test

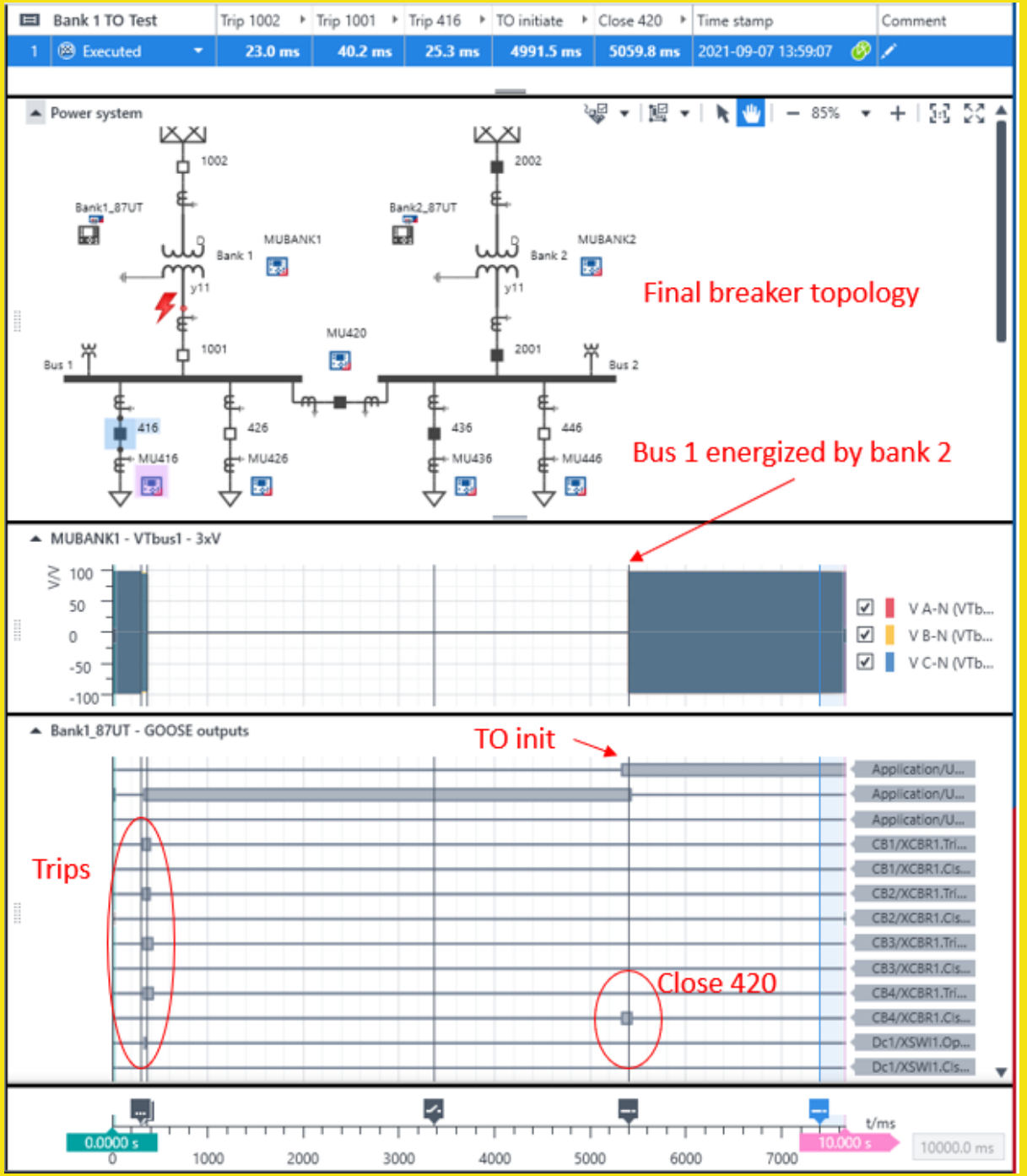
- System Model
  - (estimated) 115 kV source
  - Transformer nameplate data
  - (estimated) load at feeders
  - Import MU and IED SCL files
- Test setup
  - 2x test sets
  - 1x laptop with simulation software
- Devices under test
  - 2x IEDs (Bank 1 and Bank 2)
  - 8x Sampled Values Streams
  - Network



Test Case example 1

- Fault bank 1, throw-over successful

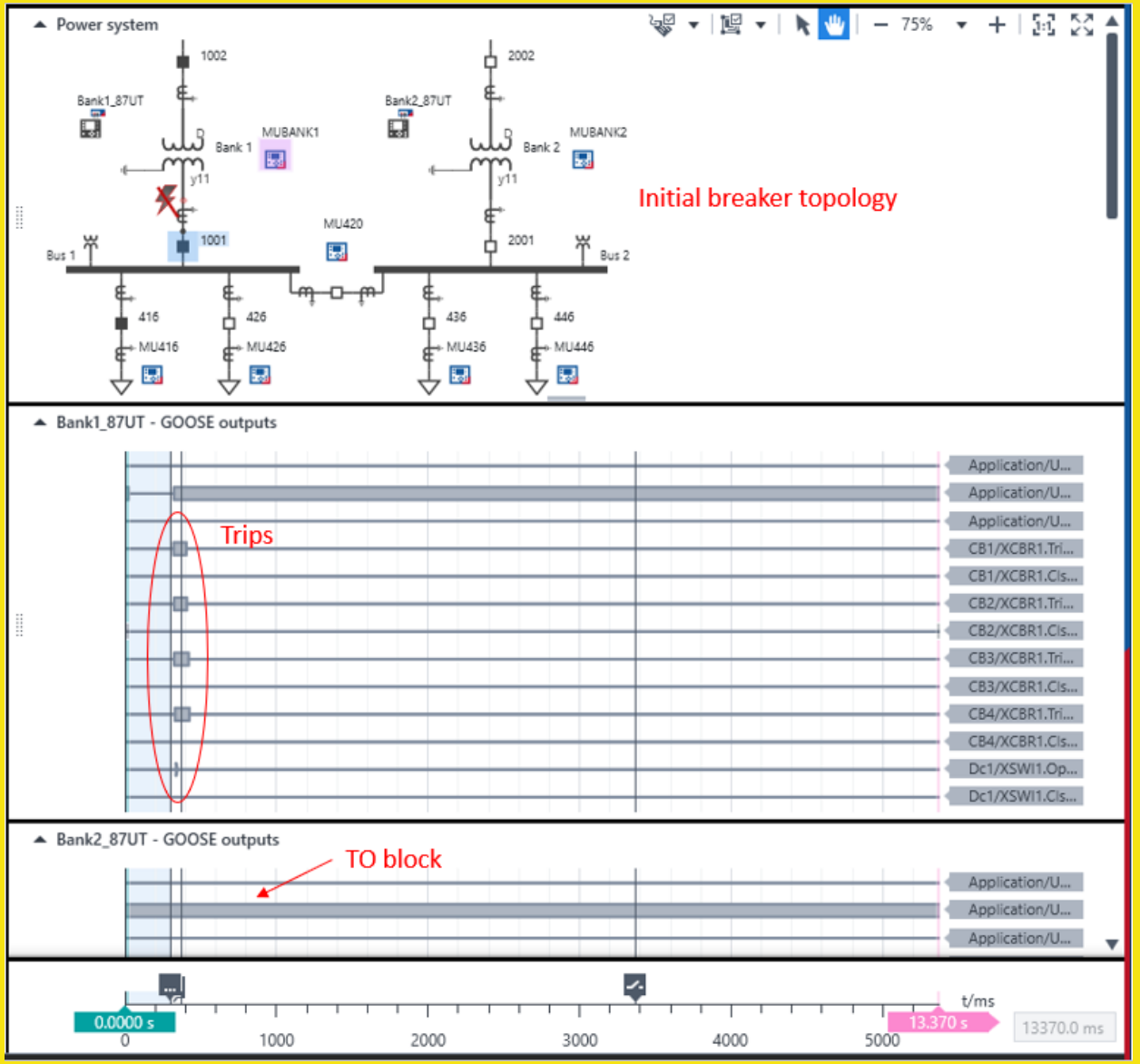
Test Case	*Test Conditions*	*Expected Results*
Fault Bank 1 when Bank 2 is energized	All initial breaker positions as in Figure 12; Fault at LV-side terminal of bank 1 after 300ms.	Trip 1002 < 30 ms; Trip feeders (416, 426) < 30 ms; Trip 1001 (1001 is actually a disconnect swicth that cannot interrupt current. Opening the disconnect takes some seconds); Bank 2 IED doesn't send TO block (Bus 2 voltage is healthy); Bank 1 IED initiate TO after 5 seconds of bank fault; Close breaker 420 following TO initiate; Close back feeders (416, 426).



Test Case example 2

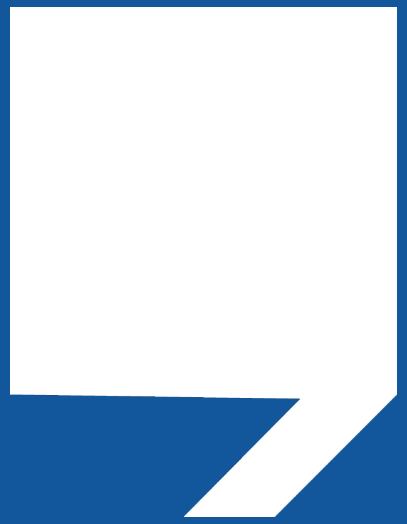
- Fault bank 1, throw-over blocked

Test Case	*Test Conditions*	*Expected Results*
Fault Bank 1 when Bank 2 is open	All initial breaker positions as in Figure 12, except 2002 and 2001 that are open; Fault at LV-side terminal of bank 1 after 300ms.	Trip 1002 < 30 ms; Trip feeders (416, 426) < 30 ms; Trip 1001 (1001 is actually a disconnect swicth that cannot interrupt current. Opening the disconnect takes some seconds); Bank 2 IED send TO block (Bus 2 dead); Breaker 420 and bus 1 feeders remain open.



Conclusions

- Test in subsystems adds flexibility and efficiency
- Protection testing strategy divided in:
  - Unit Tests
  - System-Based tests
- System-Based as a proven method for digital substations due to:
  - Increased communication interfaces and user-configurable logics
  - Independent of design (de-centralized vs centralized)
  - Easier setup with Sampled Values simulation



Questions?

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