Automating Substation Protection Testing

Unleashing the Power of Model Based, Whole-System-Validation Approach

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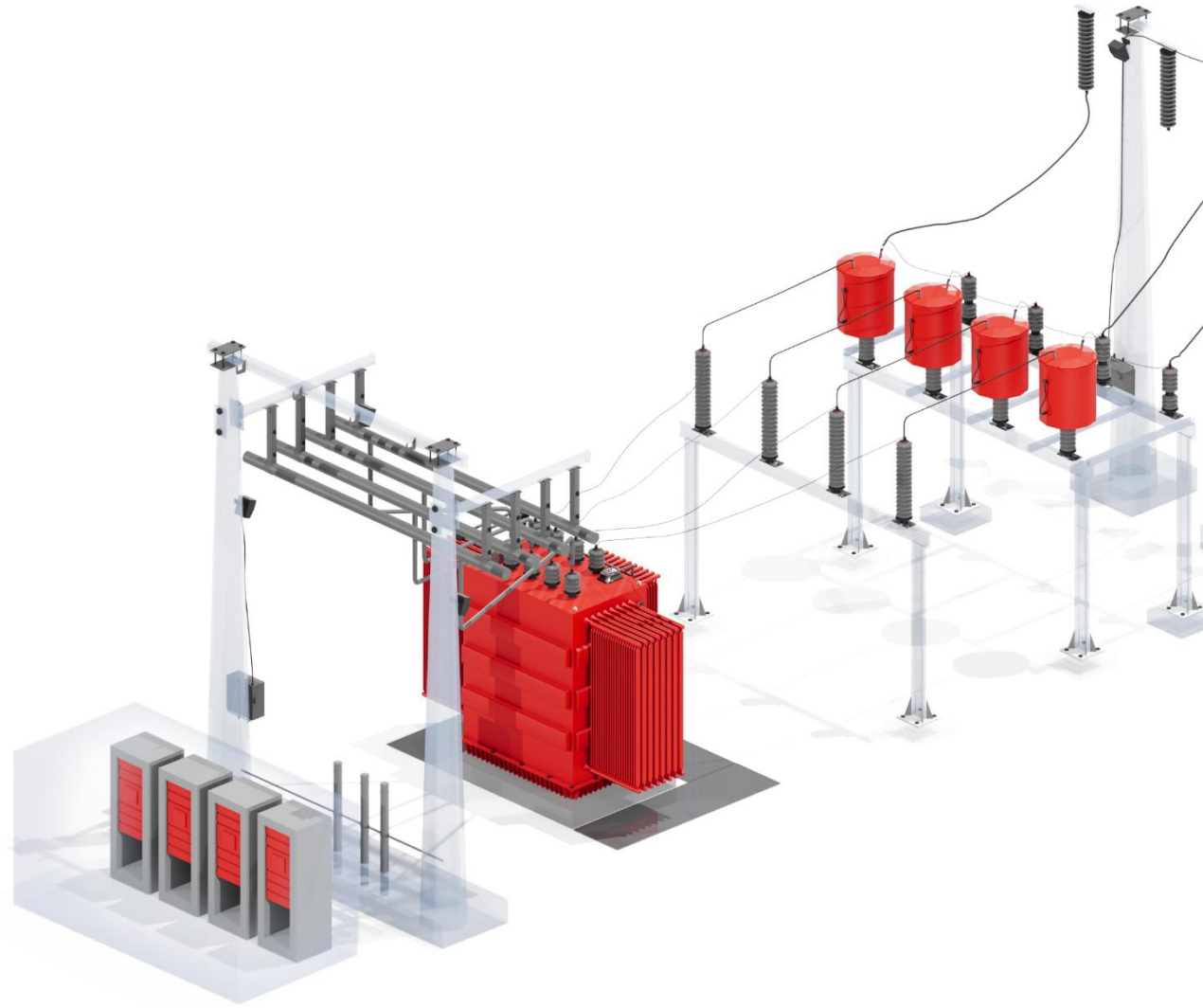
Agenda

- Substation automation evolution.
- Challenges: Physical testing v.s. model-based testing.
- The solution for today’s challenges.
- Experimental results.



Typhoon HIL

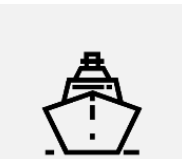
Essentials

TYPHOON HIL IS	HIL TEST SOLUTION PROVIDER
CORE COMPETENCE	HIGH FIDELITY, REAL-TIME EMULATION OF ELECTRICAL SYSTEMS COUPLED WITH MECHANICAL, THERMAL AND SIGNAL DOMAINS
PRIME APPLICATION	TESTING SUBSTATION AUTOMATION AND CONTROL SYSTEMS MODEL BASED, FUNCTIONAL AND PERFORMANCE TESTING AND TEST AUTOMATION.
EXTENDED APPLICATION SCOPE	CONFIGURATION MANAGEMENT RETROFITS AND OPERATIONAL SUPPORT PRODUCT PLACEMENT COMMISSIONING AND VIRTUAL SYSTEM INTEGRATION
METHODOLOGY	C-HIL (Controller Hardware-In-the-Loop) SIL (Software-In-the-Loop), P-HIL (Power Hardware-In-the-Loop)

<1µs

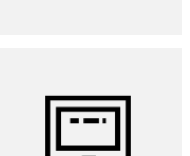
HIL FOR POWER ELECTRONICS

DRIVES



eMOBILITY

BESS



GENERATION & CONVERSION

Typhoon HIL in 2025

Typhoon HIL Inc., Boston, MA, **USA**
Typhoon HIL GmbH, Baden, **Switzerland**
Tajfun HIL d.o.o., Novi Sad, **Serbia**
Typhoon HIL Canada, Vancouver, **Canada**
Typhoon HIL BR Ltda., Florianópolis, **Brazil**
Typhoon HIL Düsseldorf, **Germany**
Typhoon HIL Castelmayran, **France**
Typhoon HIL Tokio, **Japan**
Typhoon HIL Bangalore, **India**

20+
offices and centers

600+
customer sites

▲ Typhoon HIL Offices

■ VARs / Technology & Engineering Centers

● Distributor

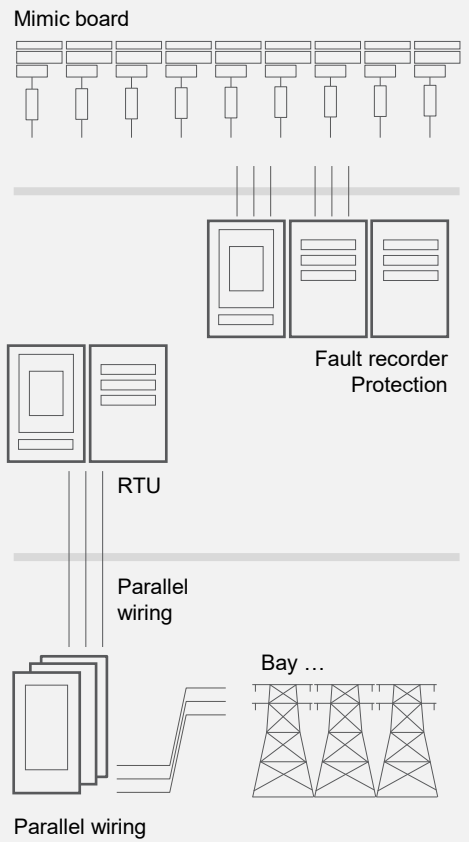
Typhoon HIL

Evolution

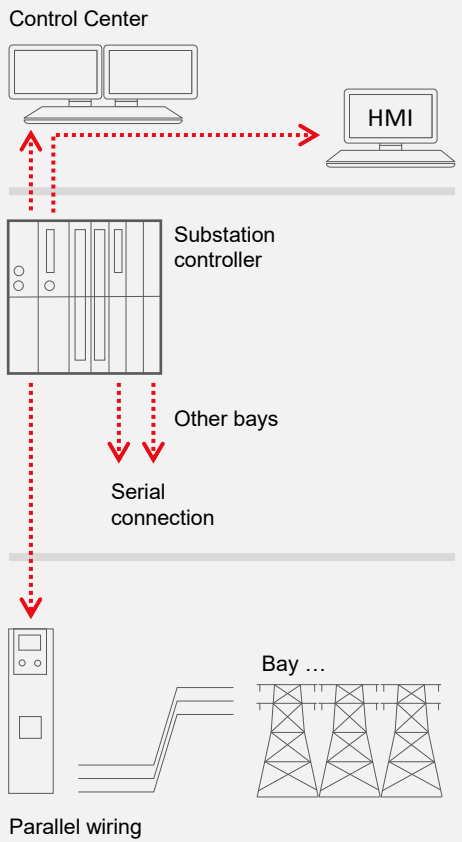
In substation automation

Evolution in Substation Automation Systems (SAS)

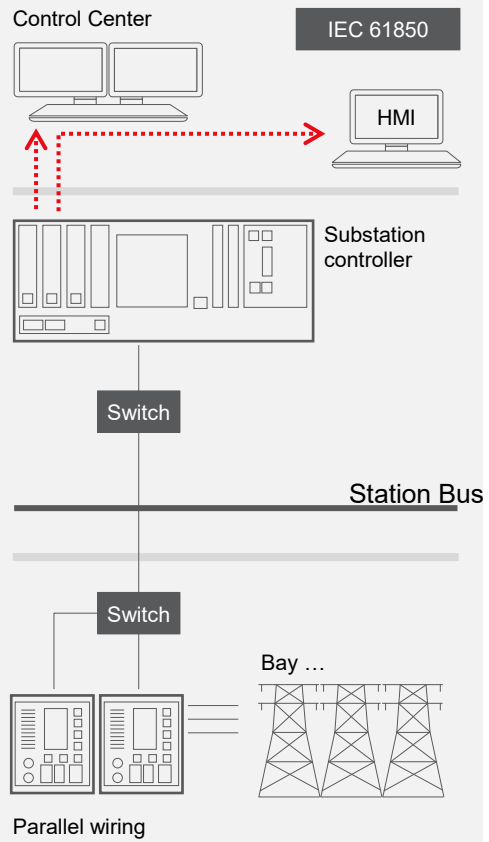
1st Generation – Standard cabling



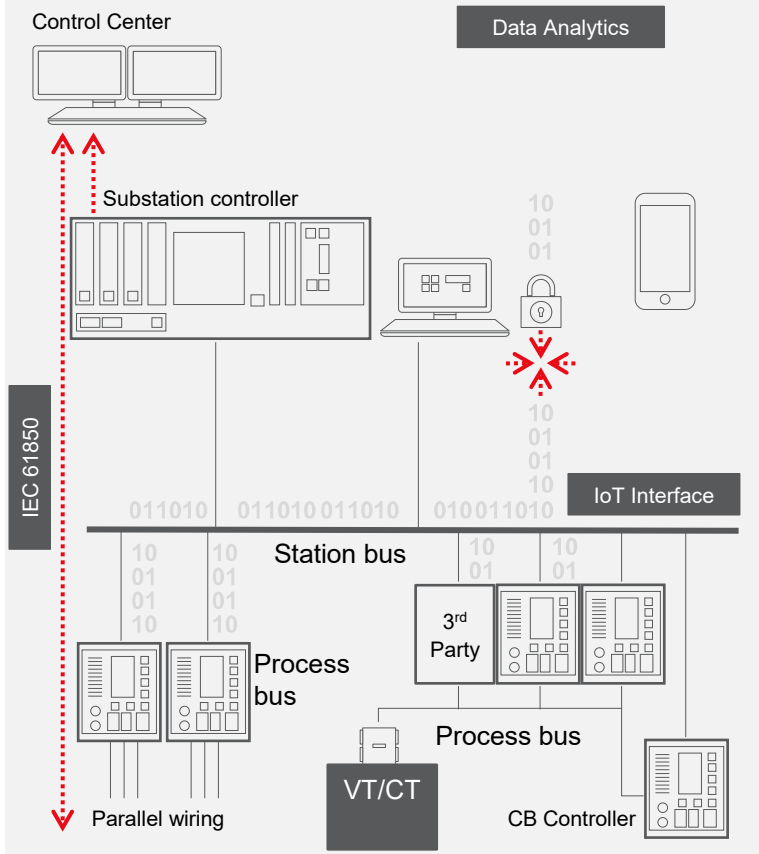
2nd Generation –Point - to – point connections since 1985



3rd Generation – Digital Station Bus since 2004 …

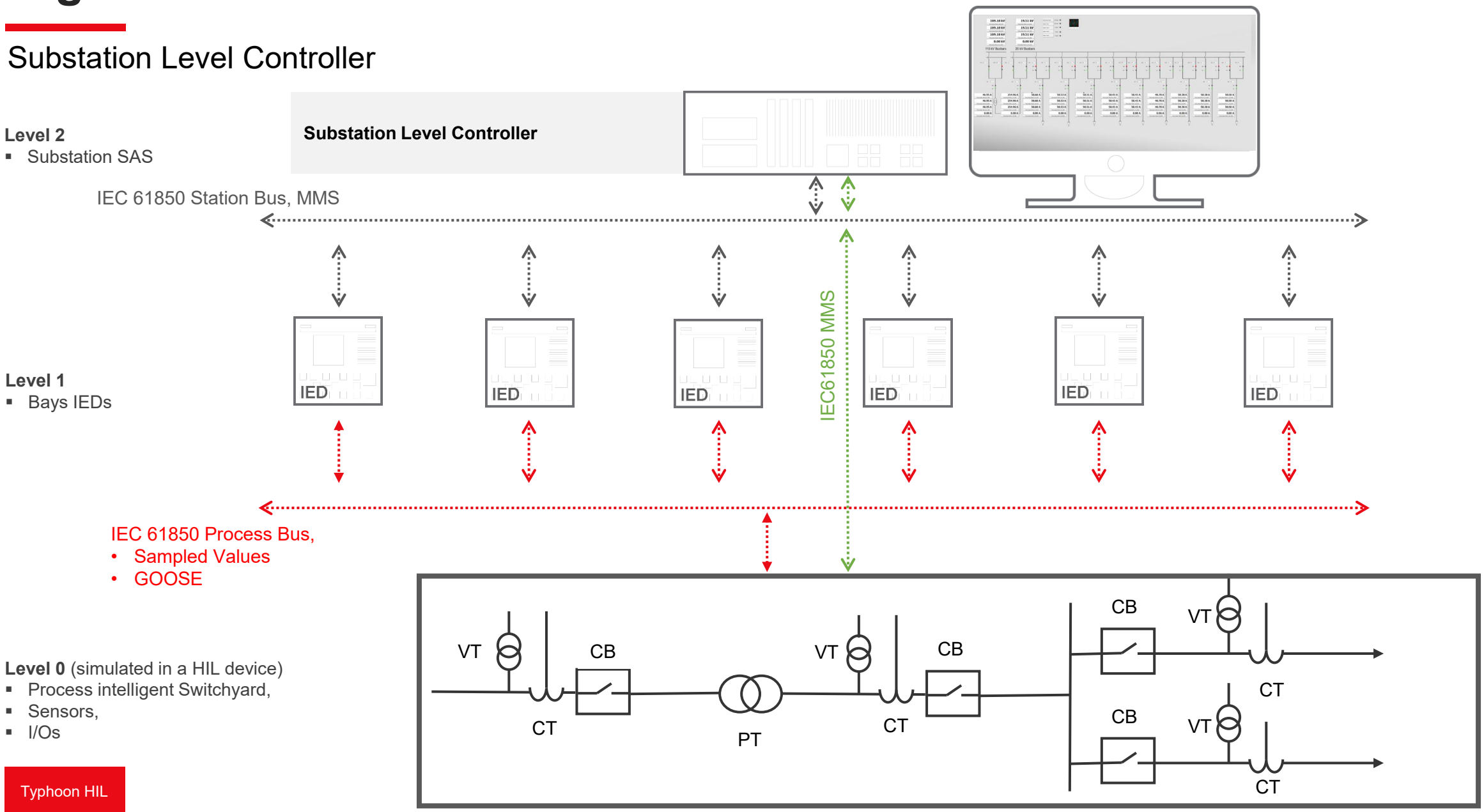


4th Generation



Digital Substation Architecture

Substation Level Controller



Challenges

Physical vs Model Based Testing

Challenges

Physical testing vs model testing

Physical Testing

Component-by-component testing.

Static test, current and voltage injection testing.

Hard to test edge cases and interoperability.

Manual protection testing (labour-intensive).

VS

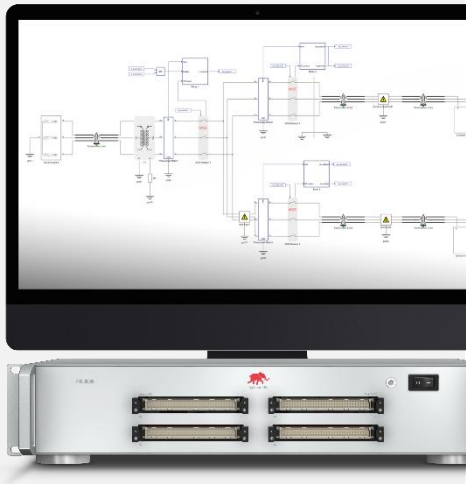
Model-based Testing

Whole system testing.

Dynamic test, model-based testing.

Easy to test edge cases and interoperability.

Fully automated protection testing (labor-light).

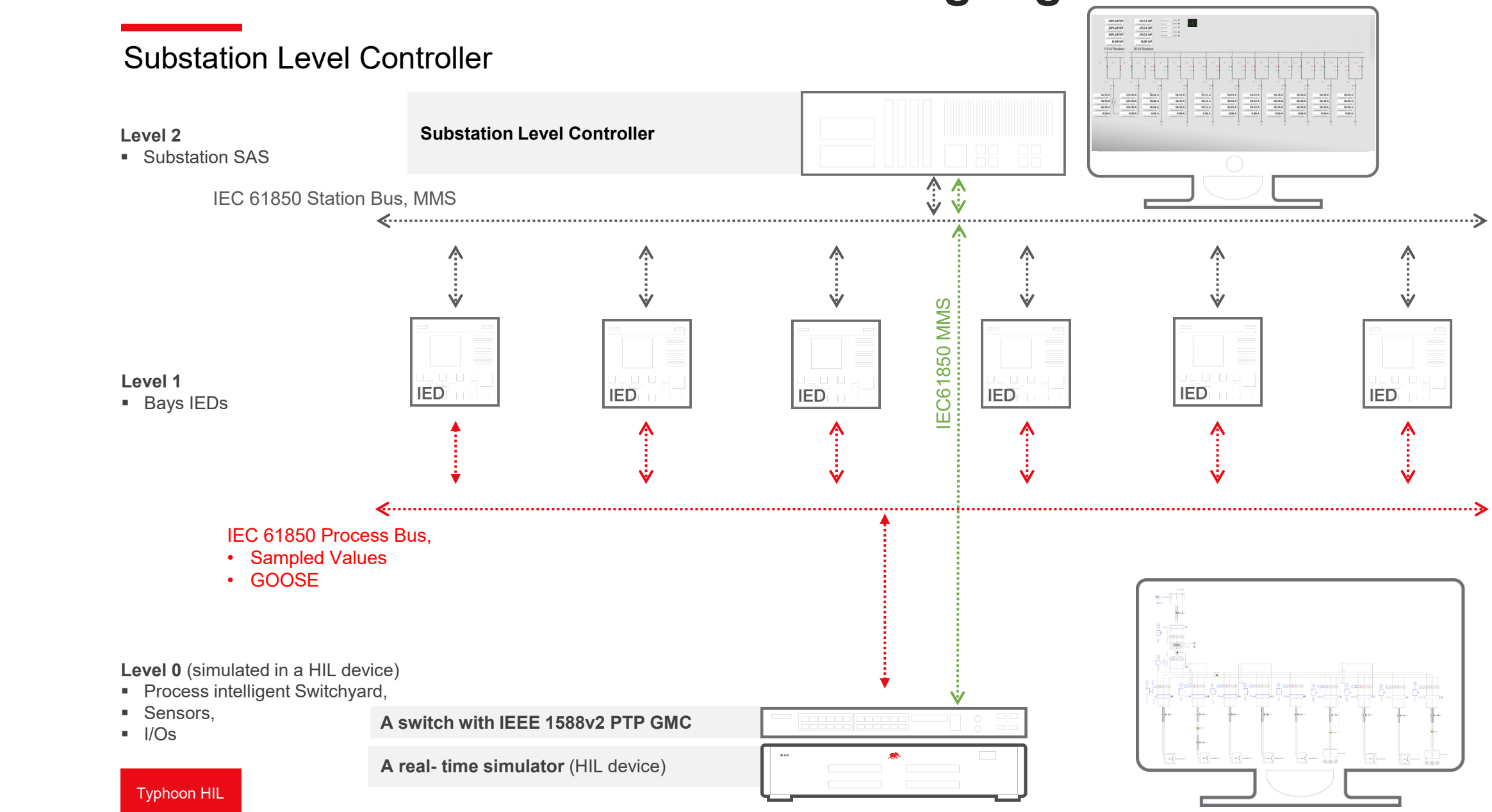


The Solution

for today’s challenges

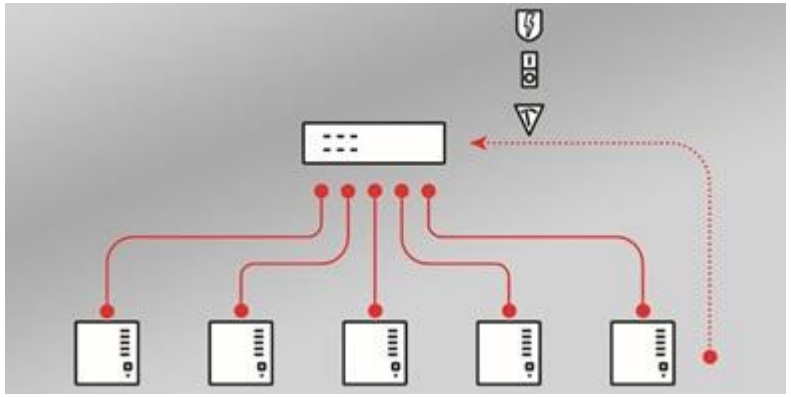
Model-Based HIL Solution for Testing Digital Substation

Substation Level Controller

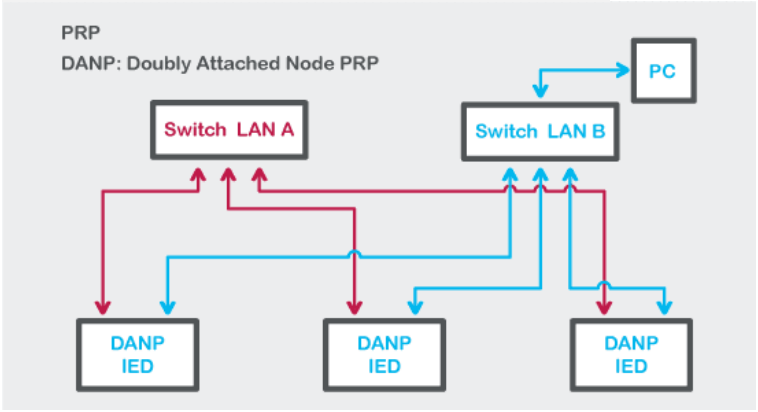


Substation Testbed

Centralized protection device with MUs



PRP capability

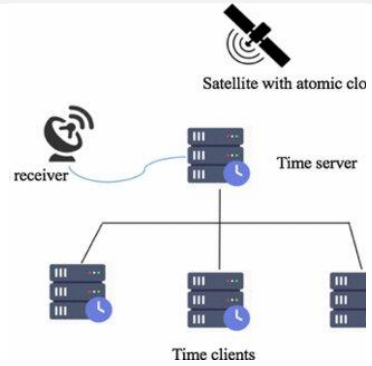


IEC 61850 / 61869 Protocol Toolbox

High-fidelity real-time models

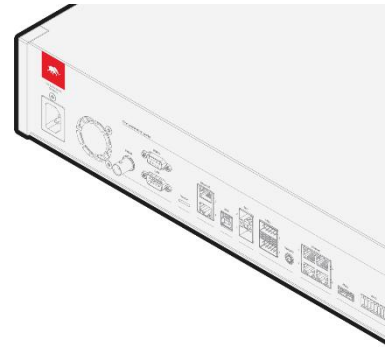
REAL TIME

GPS time synchronization

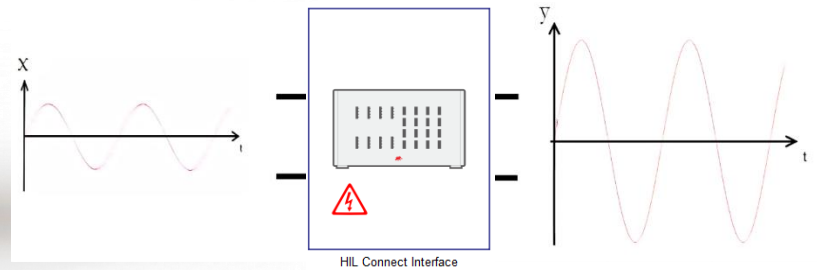


Typhoon HIL606 device

- Up to 30 IEC 61850 SVM streams.
- Interface your controller via 64 analog outputs, 32 analog inputs, 64 digital inputs, and 64 digital outputs.
- Up to 8 standard processing cores.
- Real-time emulation of non-linear machines with spatial harmonics.



Modular HIL Connect



Typhoon HIL

Success Stories: National Grid UK vPAC project

A virtual replica of the digital substation system.

- New HIL Compatible Devices: Integration of ABB SMU615 and ABB REX640.
- Communication Protocols:
  - IEC 61850 SV
  - IEC 61850 GOOSE
- Network Reliability:
  - Parallel Redundancy Protocol (PRP).
- Time Synchronization:
  - Full Precision Time Protocol (PTP).
- Complex Substation Model:
  - Detailed simulation of an interconnected substation.

Panel PC for the webHMI

REX640 and SMU615

GPS master clock

Switches PRP managed

DELL server with vSSC600

DELL server with vSSC600

Typhoon HIL606 device with PRP

Modular HIL Connect

Success Stories: ABB ELSE vPAC project

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- Time Synchronization:
  - Full Precision Time Protocol (PTP).

SSC600

Panel PC for the webHMI

3 x REF615, and REX640

Typhoon HIL606

Modular HIL Connect

Success Stories: Red Hat vPAC project

A virtual replica of the digital substation system.

- Real-time substation model of 10 bays.
- Communication Protocols:
  - IEC 61850 SV
  - IEC 61850 GOOSE
- Network Reliability:
  - Parallel Redundancy Protocol (PRP).
- Time Synchronization:
  - Full Precision Time Protocol (PTP).

Panel PC for the webHMI

GPS master clock

Typhoon HIL606

Advantech SSC600 SW (Red Hat OS)

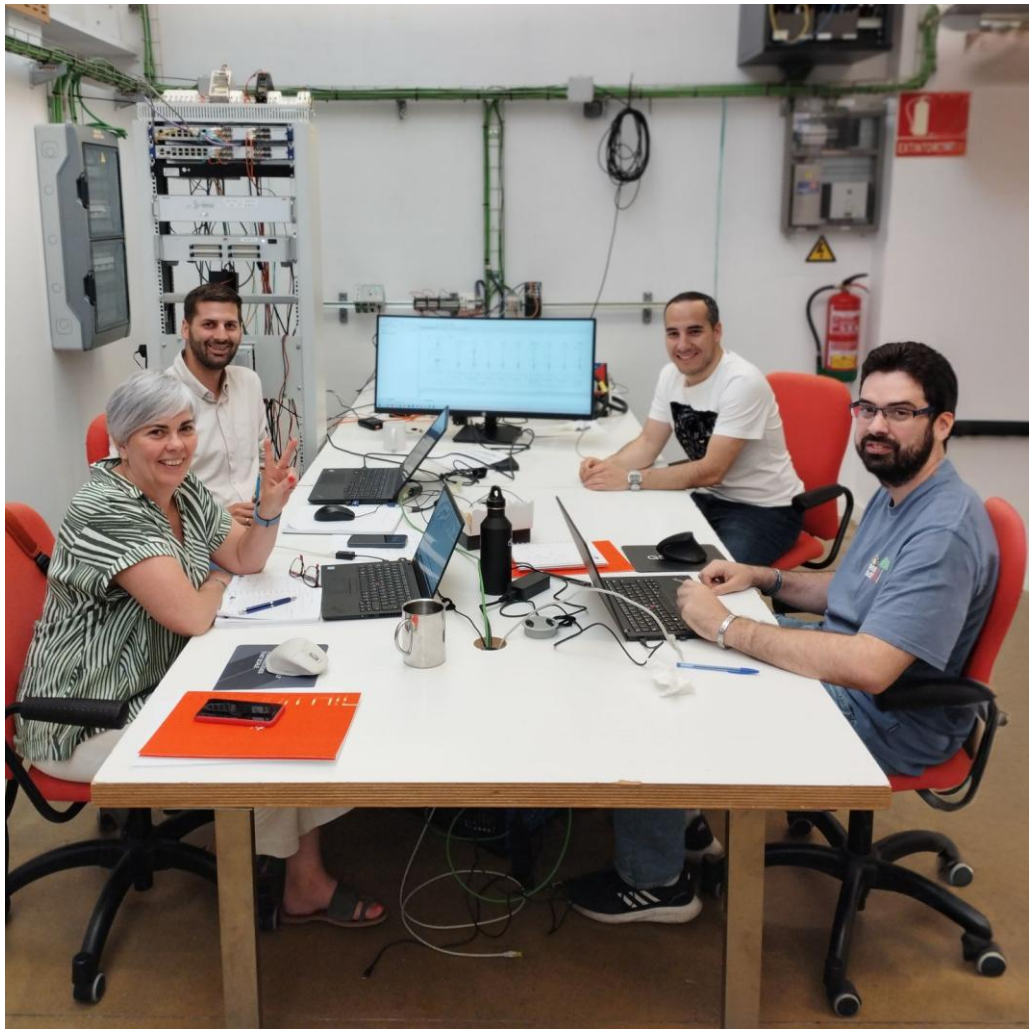
Advantech Industrial Switch (LAN A)

Advantech Industrial Switch (LAN B)

Success Stories: Digital Substation GedLux

A virtual replica of a digital substation system.

- Real-time substation model of eight bays.
  - Testing of virtualized MUs and SSC600 device.
  - Testing in early phase of the project.
- Communication Protocols:
  - IEC 61850 SV
  - IEC 61850 GOOSE
- Network Reliability:
  - Parallel Redundancy Protocol (PRP).
- Time Synchronization:
  - Full Precision Time Protocol (PTP).



Experimental Results

Credits:

prof. Zoran Stojanovic
Head of Relay Protection Laboratory at the School of Electrical Engineering, University of Belgrade.

ABB Support Team

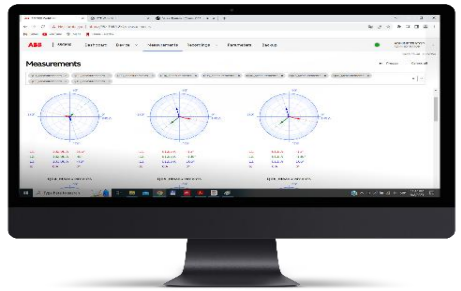
Model-Based HIL Solution for Testing Digital Substations with Centralized Protection

Level 2
- Substation SAS

ABB ZEE600

IEC 61850 Station Bus

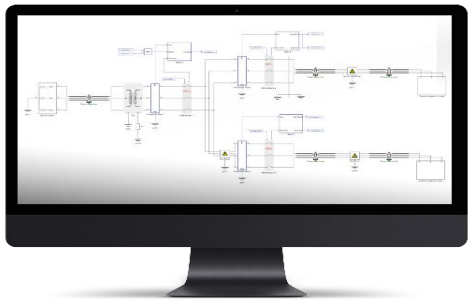
IEC 61850 MMS



Level 1
- Bays IEDs

ABB SSC600

IEC 61850 Process Bus,
- Sampled Values
- GOOSE



Level 0 (simulated in a HIL device)
- Process intelligent Switchyard,
- Sensors,
- I/Os

A switch with IEEE 1588v2 PTP GMC

A real- time simulator (HIL device)

Typhoon HIL

Testing Digital Substations with Centralized Protection

Model-based HIL solution laboratory setup

ABB SSC600 device

Switch with GPS master clock source

Typhoon HIL606 device

ABB SSC600 experimental results

Overcurrent and selectivity testing

- Model consist of 10 (ten) bays
- The testing objectives:
  - Differential protection of the busbar testing (ANSI 87B - Bus Differential)
  - Overcurrent protection of the busbar testing (ANSI 51 - AC Time Overcurrent Relay)
  - Overcurrent phase-to-phase feeder testing (ANSI 51 - AC Time Overcurrent Relay)
  - Directional overcurrent testing (ANSI 67 - AC Directional Overcurrent Relay)

ABB SSC600 experimental results

Differential protection of the busbar

- The capture represents the results from secondary phase to phase (B-C fault) fault on the busbar.
- The SSC600 differential protection scheme is performed without time delay.
- In the SCADA panel you can see that the transformer contactor on the secondary side tripped.

ABB SSC600 experimental results

Overcurrent protection of the busbar

- The capture represents the results from secondary phase to phase (B-C fault) fault on the busbar.
- The SSC600 overcurrent protection scheme is tested with the 100ms trip delay
- In the SCADA panel you can see that the transformer contactor on the secondary side tripped.

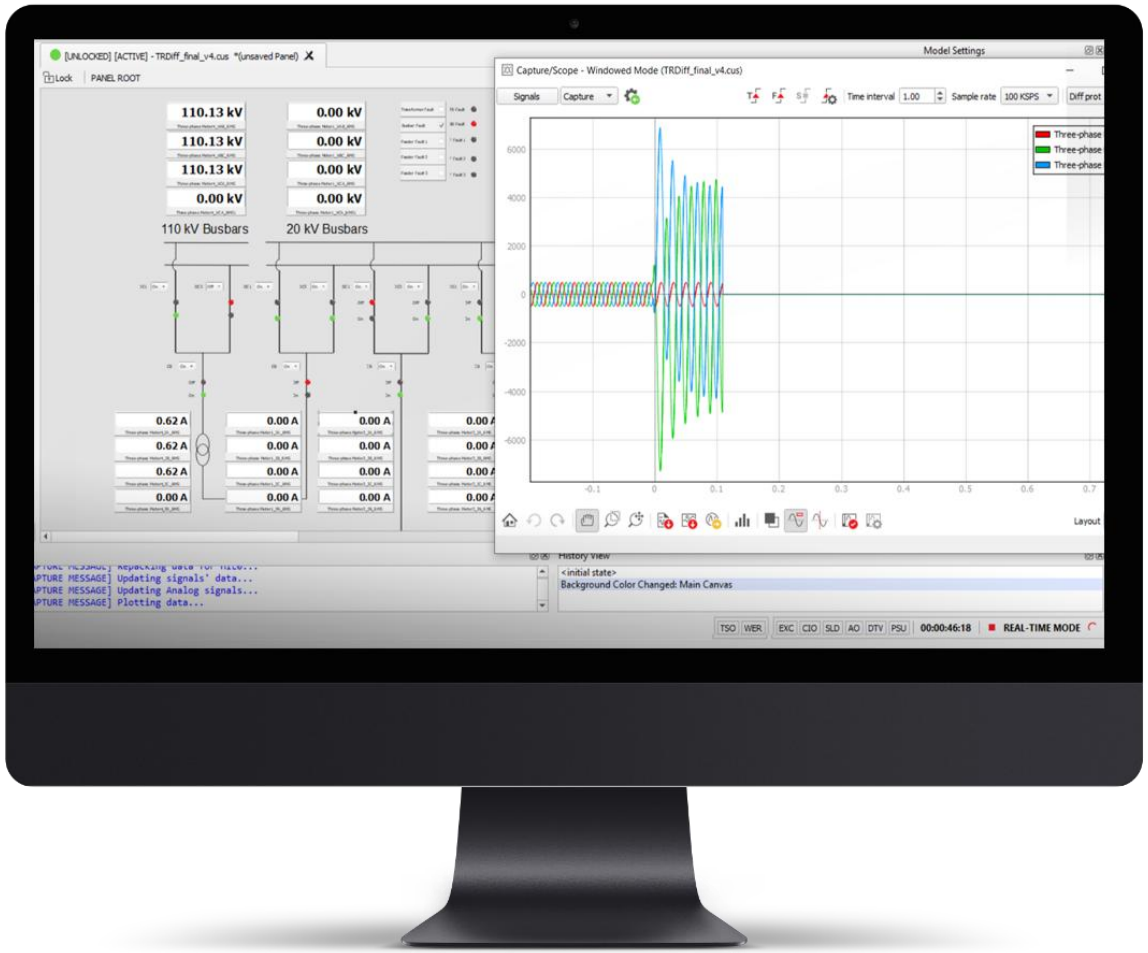


ABB SSC600 experimental results

Overcurrent protection of the feeder

- The capture represents the results from secondary the phase to phase (B-C fault) fault on the feeder number three.
- The SSC600 overcurrent protection scheme is tested with the 500ms trip delay
- In the SCADA panel you can see that the feeder contactor is tripped.

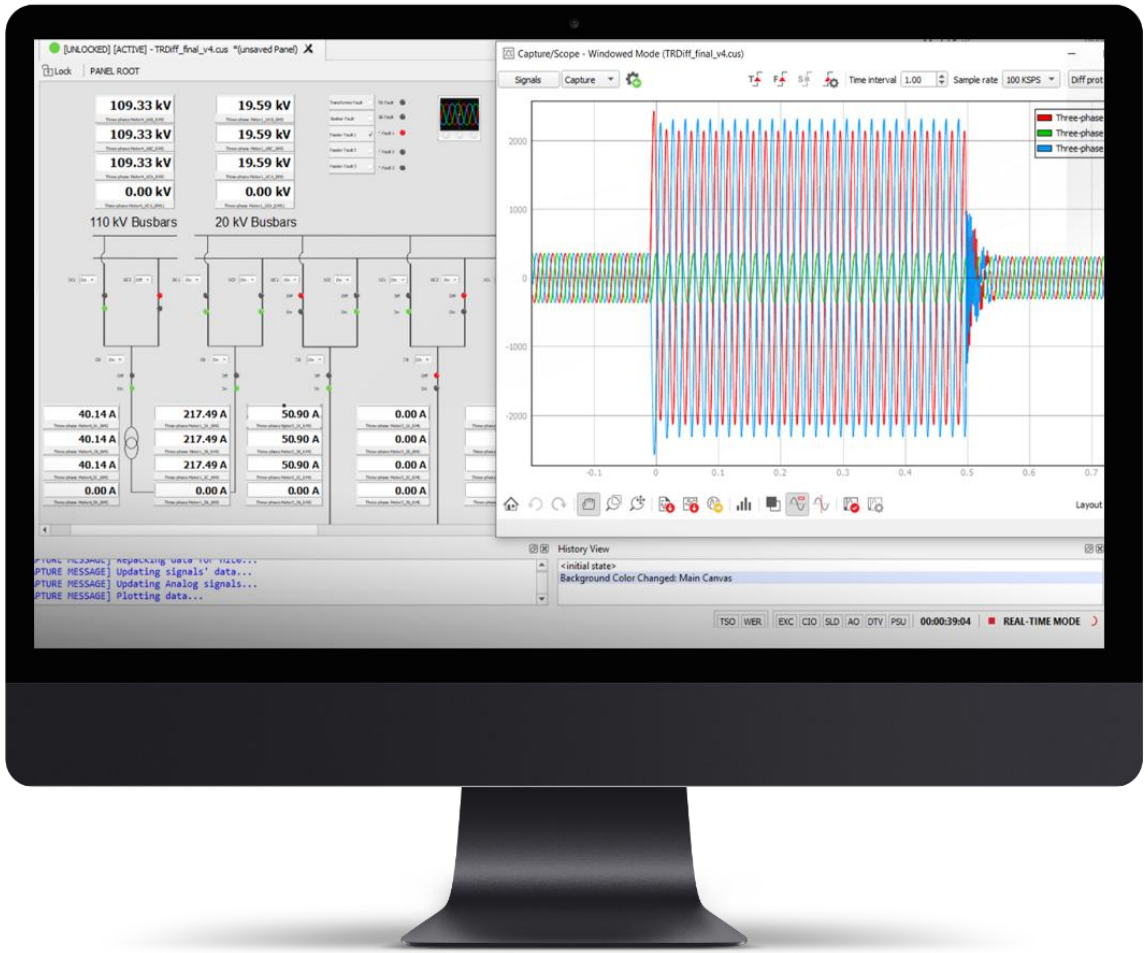


ABB SSC600 experimental results

Directional overcurrent fault

- The capture represents the results from secondary the phase to phase (A-B fault)
- This test is performed on feeder 10
- The SSC600 directional overcurrent protection scheme is tested with the 40ms trip delay
- The contactor on feeder 10 tripped (not visible here).

Differential protection testing results

Fully automatize of differential protection testing

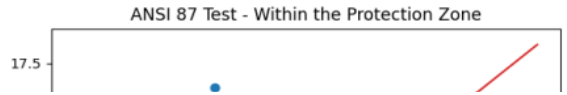
- ANSI 87: This test checks the Differential Protection Function reaction to faults within the protection zone using TyphoonTest
- Total test number is 15.
- Duration of test execution is 02 minutes and 35 seco

$$i_{Op} = i_{1_{(RMS)}} - i_{2_{(RMS)}}$$

$$i_{Res} = \frac{i_{1_{(RMS)}} + i_{2_{(RMS)}}}{2}$$

Description: ANSI 87: This test checks the Differential Protection Function reaction to faults within the protection zone

Figure: ANSI 87 Test - Within the Protection Zone



Fault and trip signals - Test within the Protection Zone

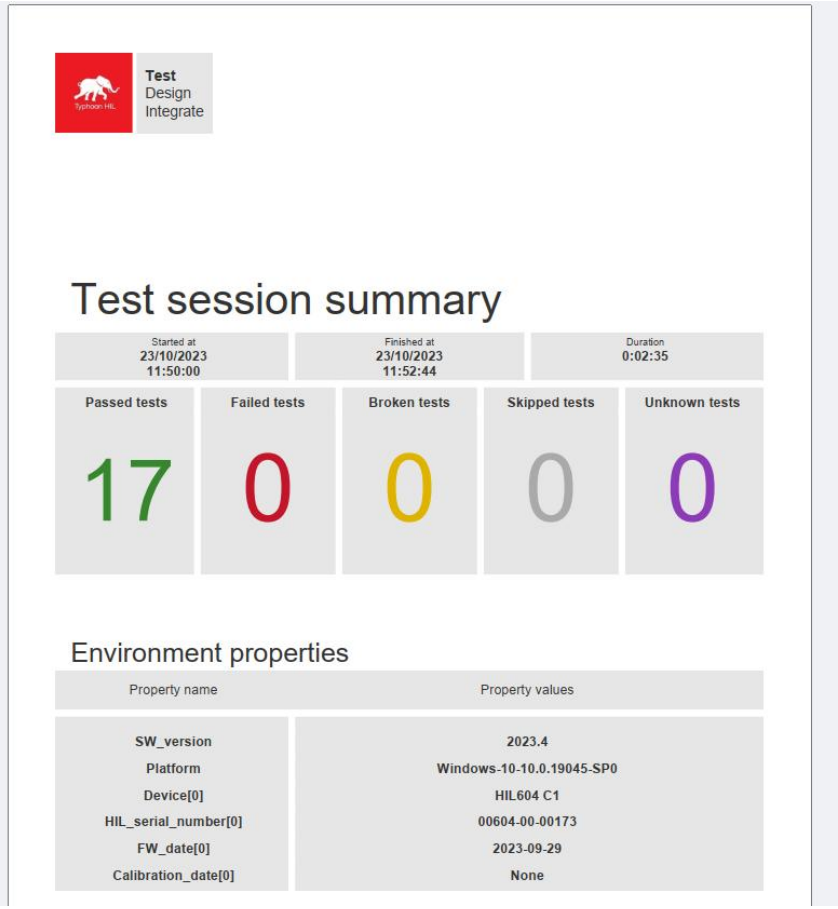
Tests within the protection zone

	Type	Operates	Opperation time	Element	Status	Iop [p.u.] - Phase A	Ires [p.u.] - Phase A	Iop [p.u.] - Phase B	Ires [p.u.] - Phase B	Iop [p.u.] - Phase C	Ires [p.u.] - Phase C
0	1ph	Yes	52ms	87R	Passed	0.22	1.07	0.0	0.99	0.22	1.08
1	2ph	Yes	22ms	87U	Passed	16.13	9.05	7.31	2.91	7.62	4.71
2	2ph-G	Yes	27ms	87U	Passed	17.19	9.54	9.15	3.74	7.94	4.85
3	3ph	Yes	17ms	87U	Passed	16.79	9.38	0.0	0.99	3.1	2.3
4	3ph-G	Yes	18ms	87U	Passed	16.37	9.17	16.62	9.3	5.73	3.74

Differential protection testing results

Test automation benefits

- ☐ Automatic detailed report generation, with all API calls, images, tables and more through both interactive Allure reports and static PDF reports.
- ☐ Rich TyphoonTest API with system level substations testing in mind for.
- ☐ Code-based testing for added flexibility and change updates which are easy to track.
- ☐ Reduced effort of maintaining and scaling your tests



Thank you for your attention!

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