

Experiences Testing a Busbar Protection Using Process Bus with Simultaneous Injection in all Bays

Alex Takeda – ISA CTEEP

João Jorge – OMICRON electronics

Luiza Pio – GE

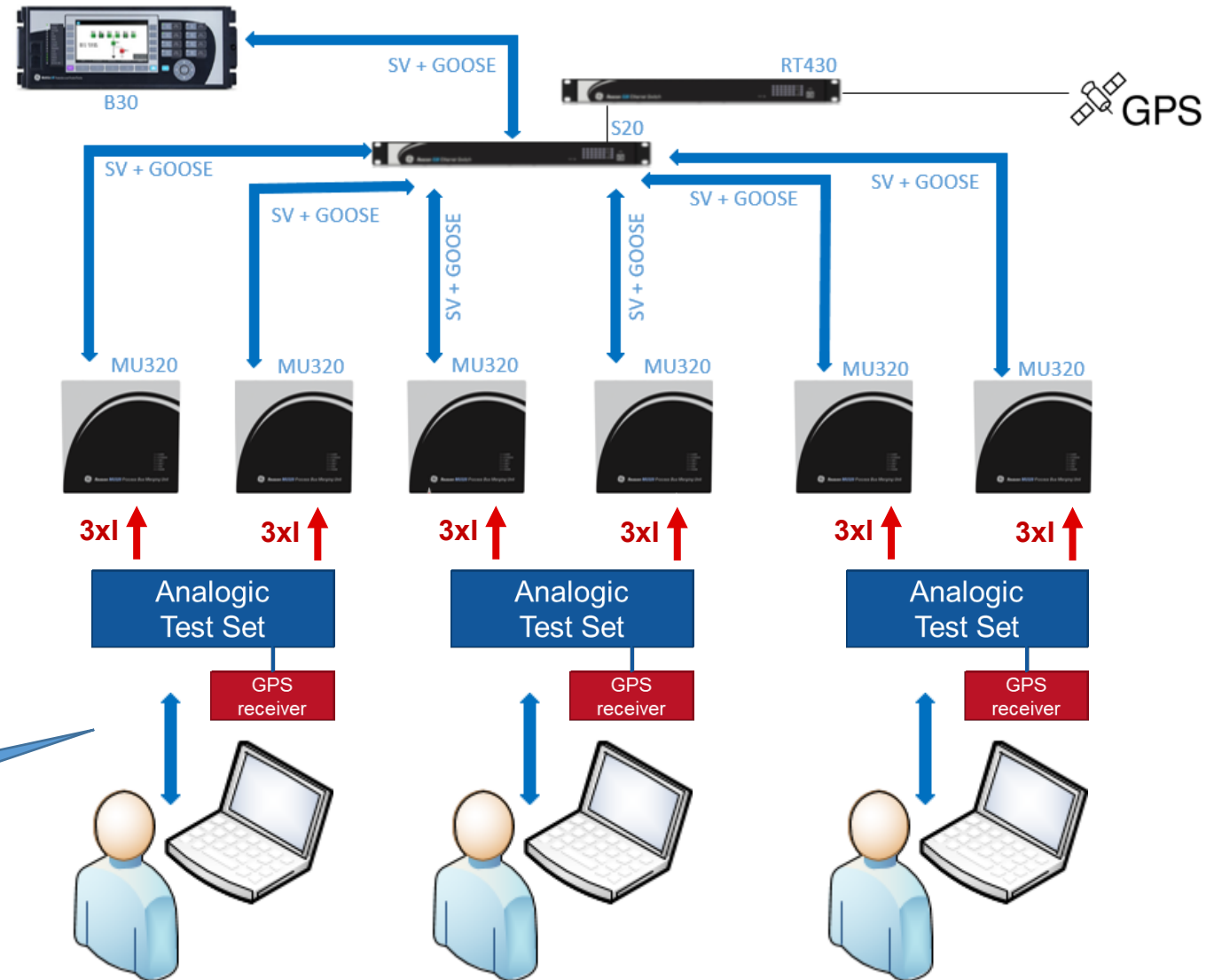
Presenter: Eugenio Carvalheira – OMICRON electronics

76th Annual Conference for Protective Relay Engineers

March 27-30, 2023

Challenges of a conventional integrated Busbar Protection Test

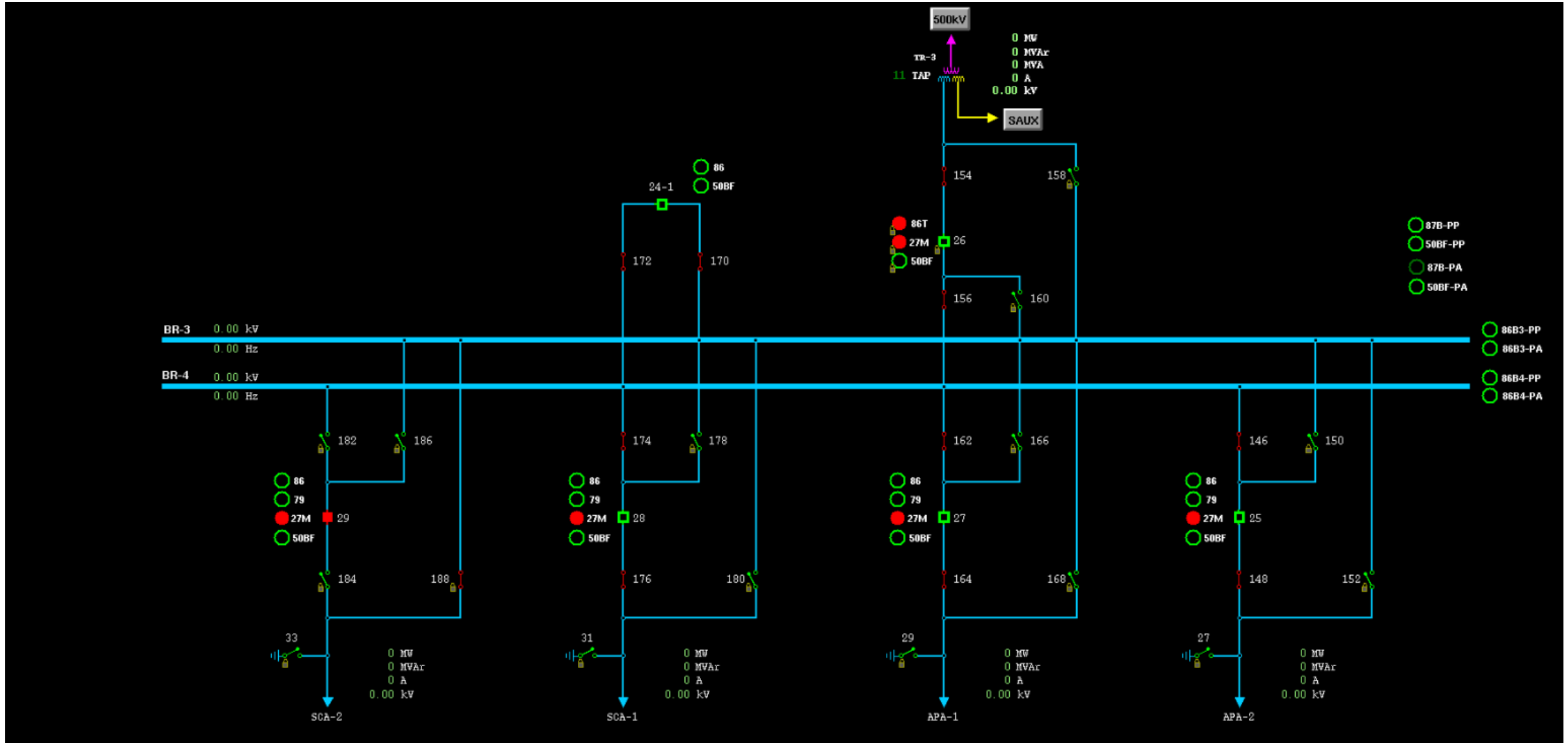
- ▶ Quantity of equipment
- ▶ Quantity of people
- ▶ Wiring assembly and simulation obstacles
- ▶ Time synchronization of test sets
- ▶ Simulation of circuit breaker failure
- ▶ Calculation of short circuit values
- ▶ Test 2 bays at a time with only 1 test set
- ▶ Test multiple bays at a time with many test sets and multiple GPS, separate test files and reports



Schematic of conventional test solution

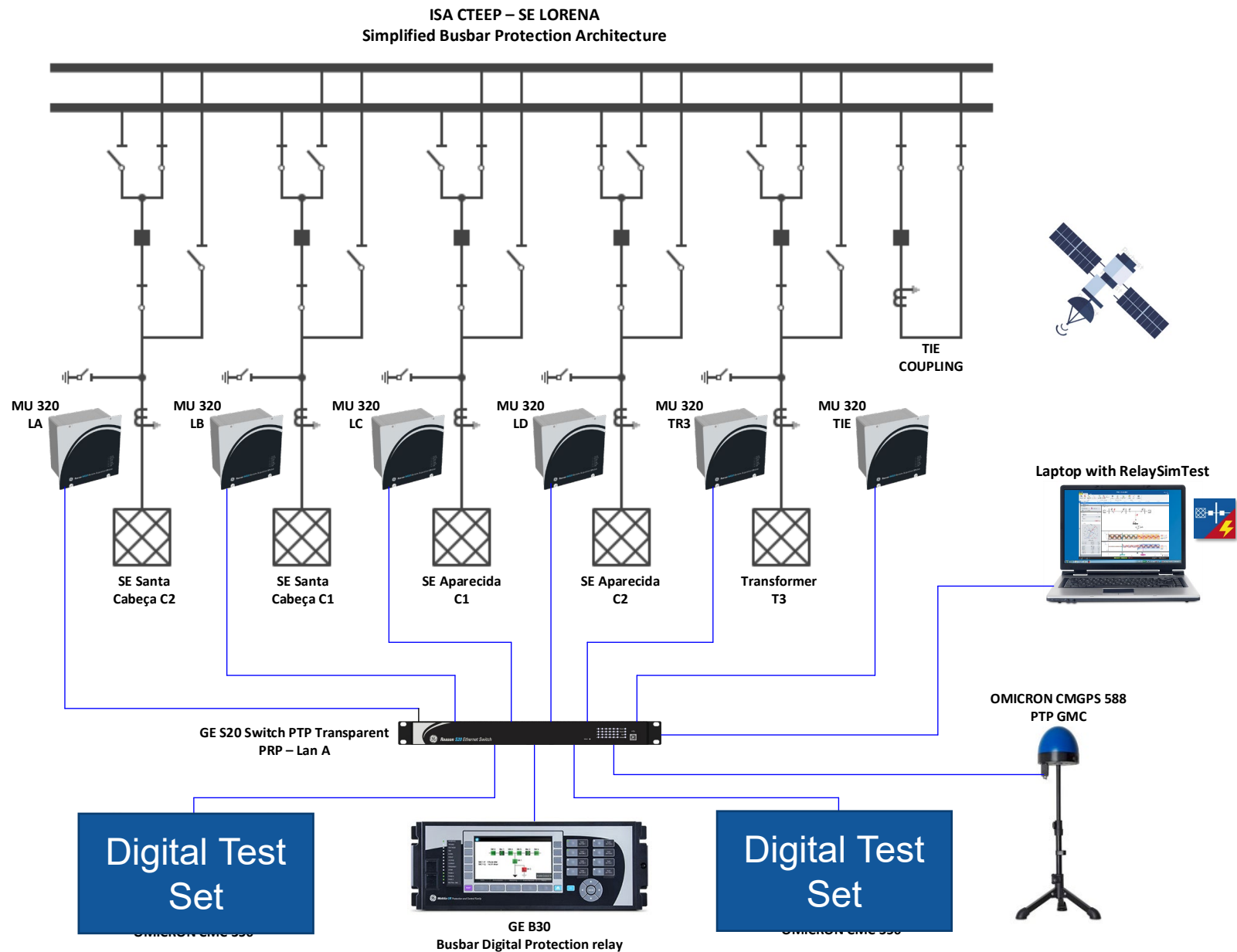
Single-line diagram of Lorena Sub (230kV)

(1st Fully Digital Substation of ISA CTEEP)



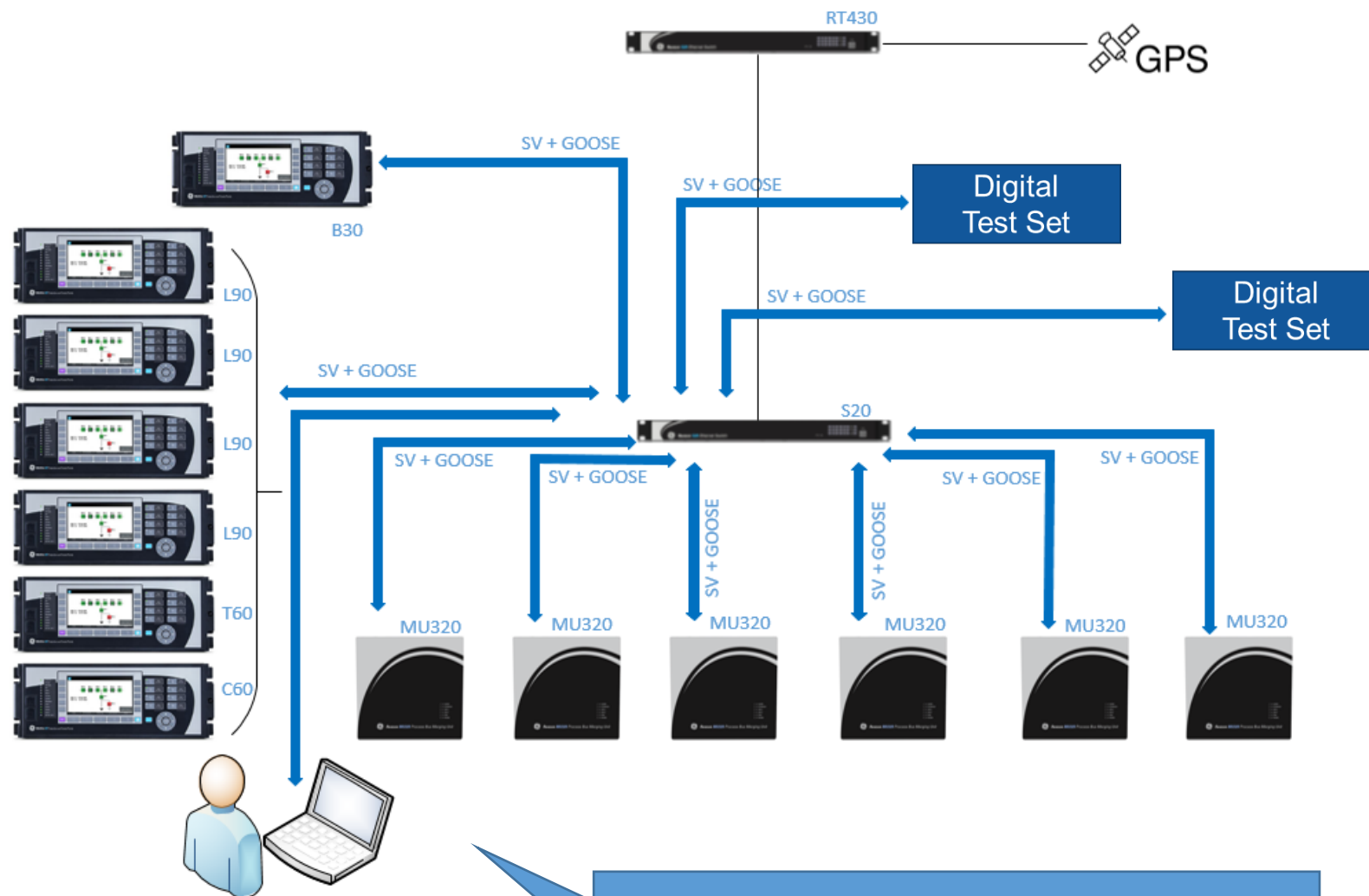
Full Digital test scheme proposed with system-based software

- ▶ Everything connected over the network
- ▶ Each test set publishes up to 4 streams of Sampled Values (1 SV = 1 Bay)
- ▶ Time Synch via PTPv2 Simulation and Injection of Real Transient Signals from system model
- ▶ Test scenarios defined by ISA CTEEP



Full Digital test scheme proposed with system-based software

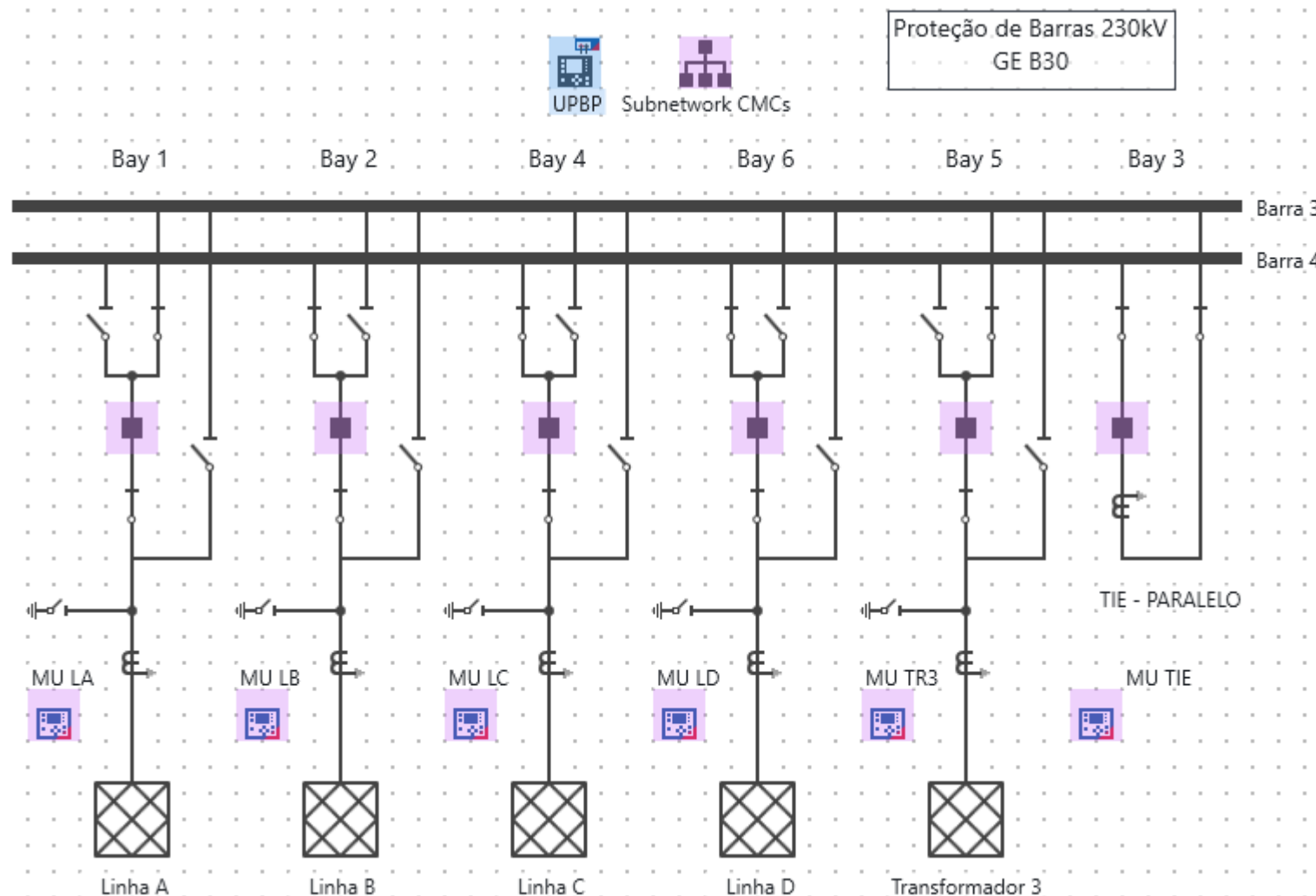
- ▶ Everything connected over the network
- ▶ Each test set publishes up to 4 streams of Sampled Values (1 SV = 1 Bay)
- ▶ Time Synch via PTPv2 Simulation and Injection of Real Transient Signals from system model
- ▶ Test scenarios defined by ISA CTEEP



Test solution based on the power system model used for 87B tests at Lorena Substation

Full Digital test scheme proposed with system-based software

- ▶ Simulation of circuit breakers and disconnectors contacts via software through GOOSE
- ▶ Simulation of faults inside and outside the protected busbar
- ▶ System modeling with the equivalent Thevenin source of each bay for injection of realistic short circuit currents
- ▶ CT saturation by inserting CT's nameplate data into the system model



System model used for 87B tests in Lorena Substation

▶ Validate simulated streams

- ▶ Sniffer the network prior to start the test
- ▶ Check that there are no conflicts between the simulated SV and GOOSE and those present in the network
- ▶ Avoid duplicate signals on the network

Warning: If you continue, real GOOSEs and Sampled Values will be output!

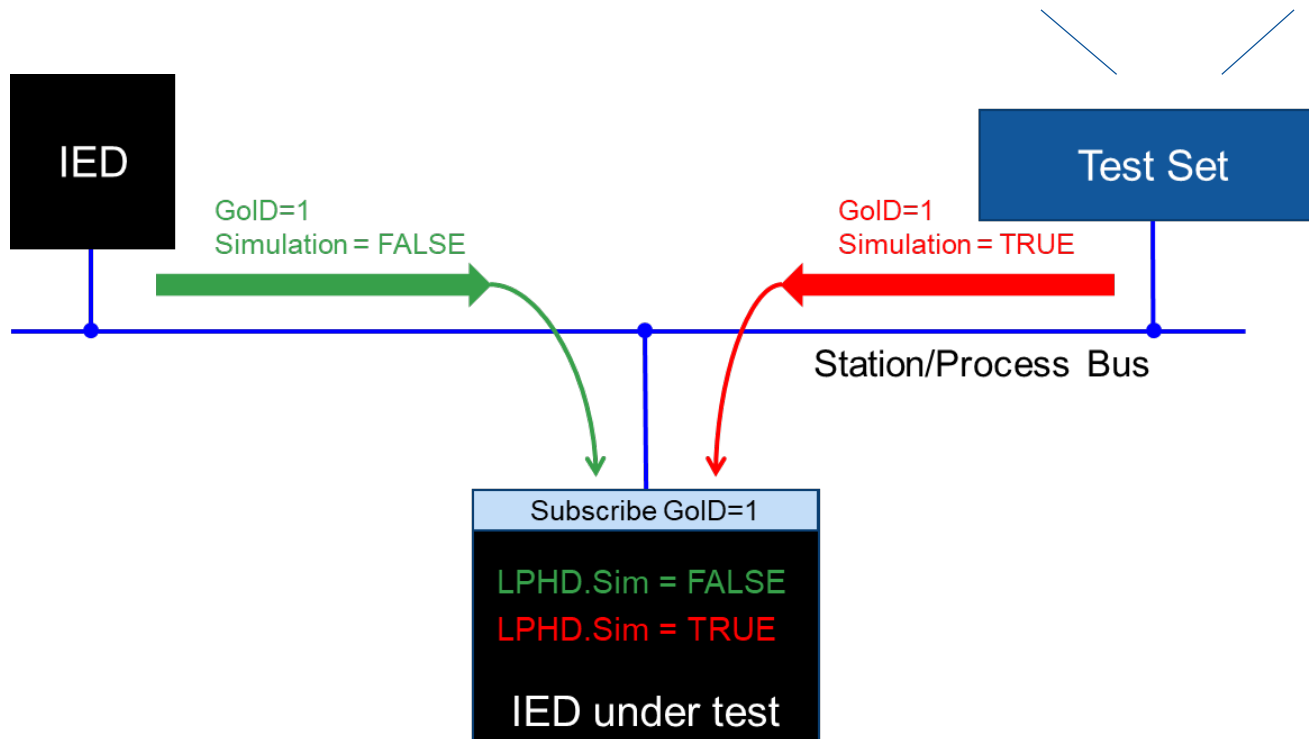
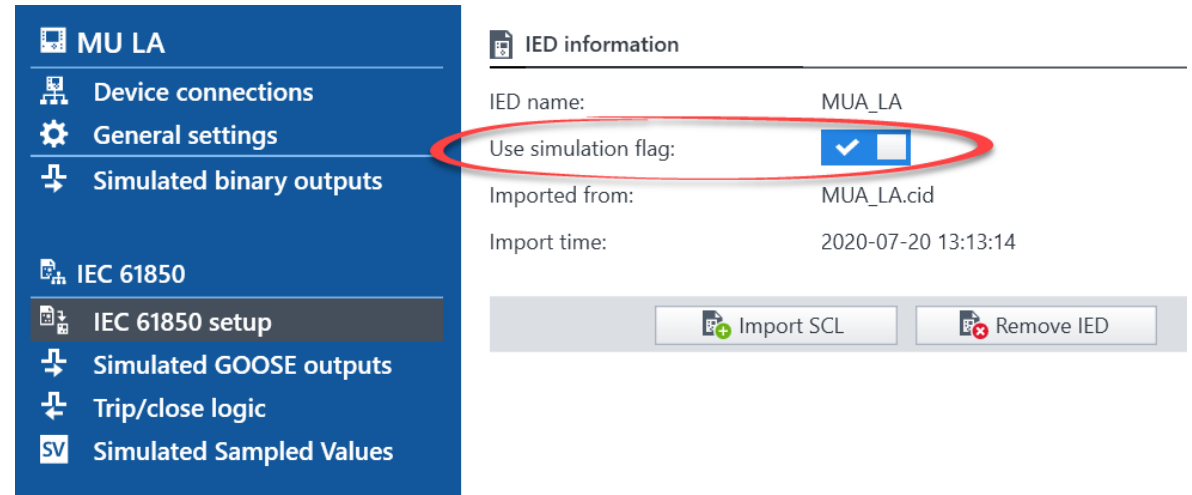
GOOSEs to be simulated	Simulation flag	Found on network
G MUA_LA - CTRL/LLN0.FastGOOSE1	Yes	✓ No duplicate
G MUA_LC - CTRL/LLN0.FastGOOSE1	Yes	✓ No duplicate
G MUA_LD - CTRL/LLN0.FastGOOSE1	Yes	✓ No duplicate
G MUA_LB - CTRL/LLN0.FastGOOSE1	Yes	✓ No duplicate
G MUA_TIE - CTRL/LLN0.FastGOOSE1	Yes	✓ No duplicate
G MUA_T3 - CTRL/LLN0.FastGOOSE1	Yes	✓ No duplicate

Sampled Values to be simulated	Simulation flag	Found on network
SV MUA_LA - MUA_LA0101	Yes	✓ No duplicate
SV MUA_LB - MUA_LB0101	Yes	✓ No duplicate
SV MUA_LC - MUA_LC0101	Yes	✓ No duplicate
SV MUA_LD - MUA_LD0101	Yes	✓ No duplicate
SV MUA_TIE - MUA_TIE0101	Yes	✓ No duplicate
SV MUA_T3 - MUA_T30101	Yes	✓ No duplicate

Continue Cancel

Simulation Mode

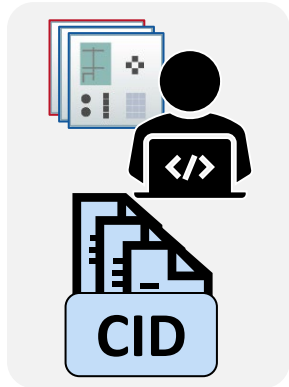
- ▶ From IEC 61850 Ed 2
- ▶ Method for virtual/digital isolation of digital data during test



▶ System Configuration Files

- ▶ Data such as SvID, appID, priority, vlan, etc taken automatically from imported SCL files (*.cid) of Merging Units

- ▶ Datasets 9-2-LE



MU LA

- Device connections
- General settings
- Simulated binary outputs

IEC 61850

- IEC 61850 setup
- Simulated GOOSE outputs
- Trip/close logic
- SV Simulated Sampled Values**

Available signals

TC LA

3xl →

Outgoing Sampled Values

SV MUA_LA0101

Properties

Control block attributes

Control block reference:	MUA_LAMU01/LLN0\$MS\$MUA_LA	Sampling frequency:	4800 Hz
Destination MAC address:	01:0C:CD:04:00:AA	Frames per second:	4800
Application ID:	16384		
Sampling mode:	Samples per cycle		
Sample rate:	80		
Number of ASDUs:	1		
VLAN ID:	128		
VLAN priority:	4		
Configuration revision:	1		

Voltages:

A: Select to map a signal.

B: Select to map a signal.

C: Select to map a signal.

N: Will be calculated - or select to map a signal.

Currents:

A:

B: TC LA - 3xl Name:

C:

N: Will be calculated - or select to map a signal.

▶ Time Synchronization

- ▶ All test sets and IEDs synchronized by the same source GMC PTP
- ▶ PTP profile selected: IEC/IEEE 61850-9-3: 2016 (Utility Profile)

Example of settings from GPS RT430

PTP	
Enable PTP	<input checked="" type="checkbox"/>
Profile	Power Utility - IEC/IEEE 61850-9-3/2011 ▾
Domain number	0
Network protocol	Ethernet level 2 ▾ VLAN <input checked="" type="checkbox"/> id 0x0005 priority 0
Operation mode	One step ▾
Delay mechanism	Peer-to-Peer ▾
Grandmaster priority	#1 128 #2 128
Force operation as	<input type="checkbox"/> Slave
Delay request interval	1 second (0) ▾
Announce interval	1 second (0) ▾
Sync interval	1 second (0) ▾
Announce receipt timeout	3
Send Alternate Time TLV	<input type="checkbox"/>
Send local time	<input type="checkbox"/> Enabled

CT realistic simulation

- ▶ Nameplate data representing the nonlinear saturation behavior of the CTs in each bay during the simulation of the transients published through Sampled Values
- ▶ Data taken from Lorena Substation CT's nameplate (TPY)

The screenshot displays a software interface for a substation simulation. The background shows a schematic diagram of a substation with two bays, Bay 1 and Bay 2. The diagram includes components like busbars, switches, and CTs (MU LA and MU LB). Labels include "ISA CTEEP - SE LORENA Subestação Full Digital GE", "Proteção de Barras GE B30", "UPBP Subnetwork CMCs", "Linha A SE Santa Cabeça C2", and "Linha B SE Santa Cabeça C2".

The "CT Data" dialog box is open, showing the following settings:

- Use customizable preset: TPY
- Import CT Analyzer report: Choose report...
- CT data**
- Winding resistance (Rct): 3.3000 Ω
- Rated burden (Sbn): 8.0000 VA
- Rated symm. short-circuit current factor (Kssc): 25.0
- Transient dim. factor (Ktd): 7.3
- Operating burden (Sb): 100.00 %

On the right side of the interface, the "TC LA" settings are visible:

- Name: TC LA
- Show label
- Type: Three-phase
- Rated prim. current: 2.0000 kA
- Rated sec. current: 1.0000 A
- Polarity: Toggle
- Dynamic behavior: Ideal transformer, Simulate saturation
- i These settings will only affect simulation test cases in which CT saturation simulation is enabled.
- Edit CT data...
- Simulate traveling wave pulses:

The "Done" button is located at the bottom right of the dialog box.

▶ 52a and 52b simulation

- ▶ Simulation of circuit breakers and disconnectors contacts via software (considering the timing values for movement of the contacts) through GOOSE

The screenshot displays a software interface for simulating GOOSE (Generic Object Oriented Substation Event) outputs and binary traces. The interface is divided into several sections:

- Left Panel (Navigation):** Contains a tree view with the following items: MU LB, Device connections, General settings, Simulated binary outputs, IEC 61850, IEC 61850 setup, **Simulated GOOSE outputs** (highlighted), Trip/close logic, and Simulated Sampled Values.
- Main Panel (Outgoing GOOSEs):** Shows the configuration for a specific GOOSE output. At the top, it says "Outgoing GOOSEs" and "Simulate unmapped GOOSEs: x". Below this, the configuration is for "MUA_LB - CTRL/LLN0.FastGOOSE1" in the "Subnetwork CMCs" network. Under "GOOSE settings", there is a table of 12 GOOSE outputs, each with a "DA" (Data Attribute) name and a value field set to "000000000000".
- Right Panel (Binary traces):** Shows four binary trace windows for different circuit breakers, all marked as "Automatically simulated":
 - CB52b - DJ LB Aberto:** Trace for "CTRL/BININGGIO1.Ind1.stVal" with a value of "false".
 - CB52a A - DJ LB - Fechado:** Trace for "CTRL/BININGGIO1.Ind2.stVal" with a value of "false".
 - CB52a B - DJ LB - Fechado:** Trace for "CTRL/BININGGIO1.Ind3.stVal" with a value of "false".
 - CB52a C - DJ LB - Fechado:** Trace for "CTRL/BININGGIO1.Ind4.stVal" with a value of "false".

▶ 52a and 52b simulation

Configure Auxiliary Contact Simulation

Times: Absolute

Circuit breaker opening

52a CB not closed: 22.0 ms
52b CB open: 30.0 ms

Circuit breaker closing

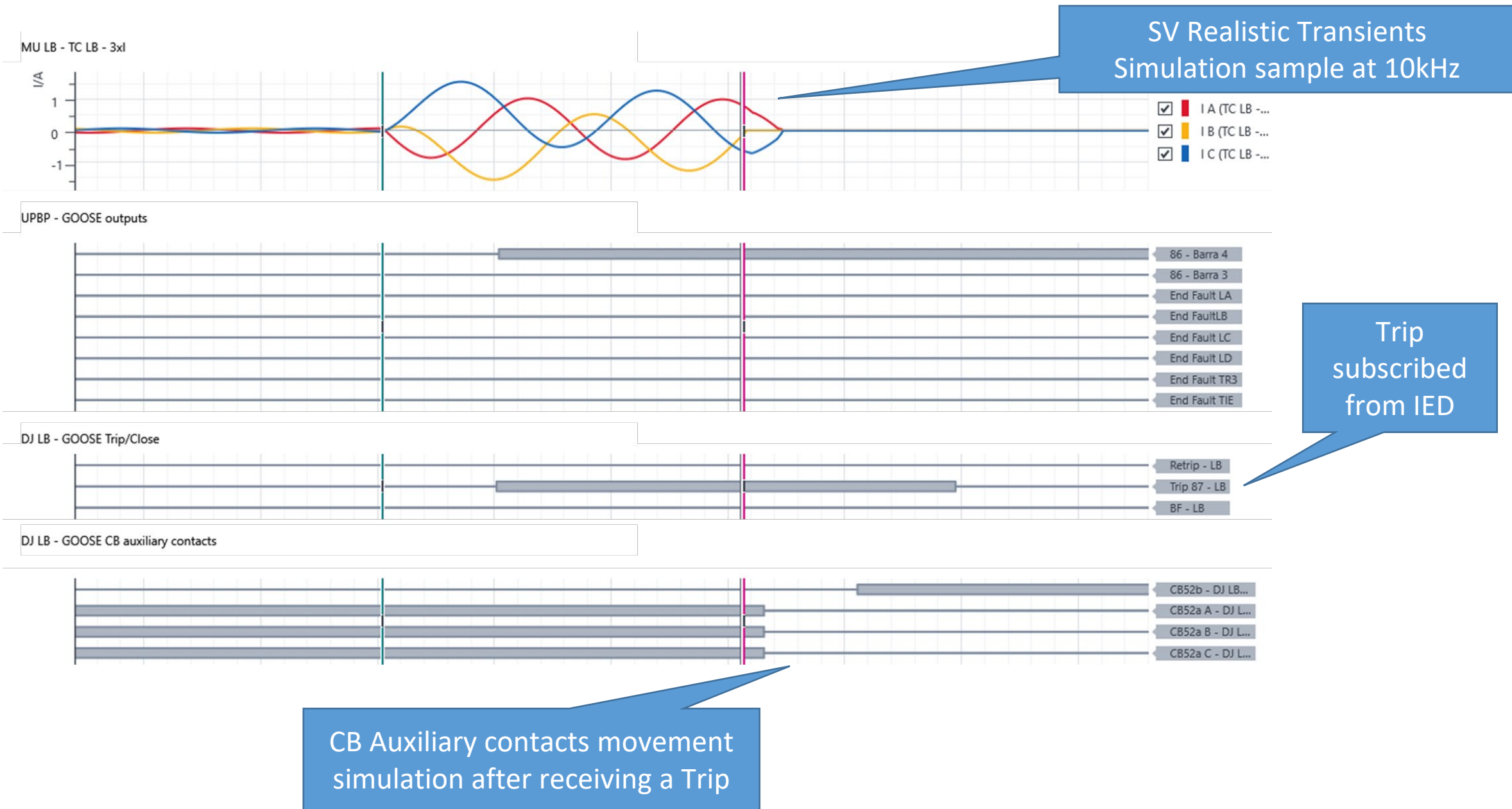
52a CB closed: 55.0 ms
52b CB not open: 10.0 ms

CB52a: Per pole
CB52b: One for all three poles

Done

- ▶ Timers of the Simulation Setup from the reception of a Trip or Closing command

Example of published and subscribed data



► Simultaneous Current published in all Bays

MU LA - TC LA - 3xl



MU LB - TC LB - 3xl



MU LC - TC LC - 3xl



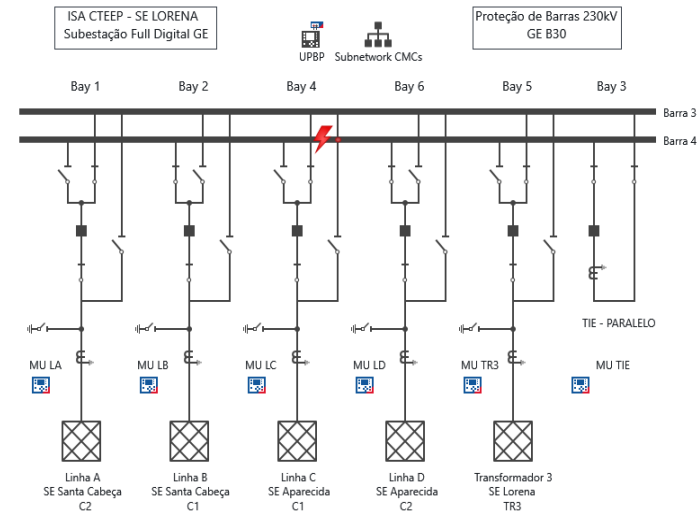
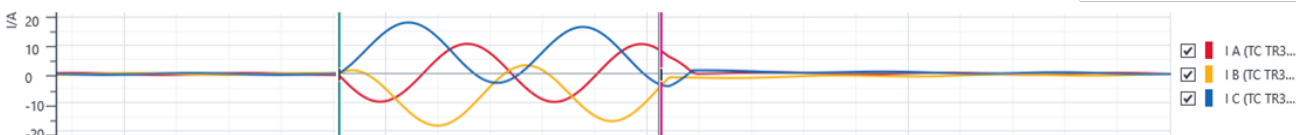
MU LD - TC LD - 3xl



MU TIE - TC TIE - 3xl



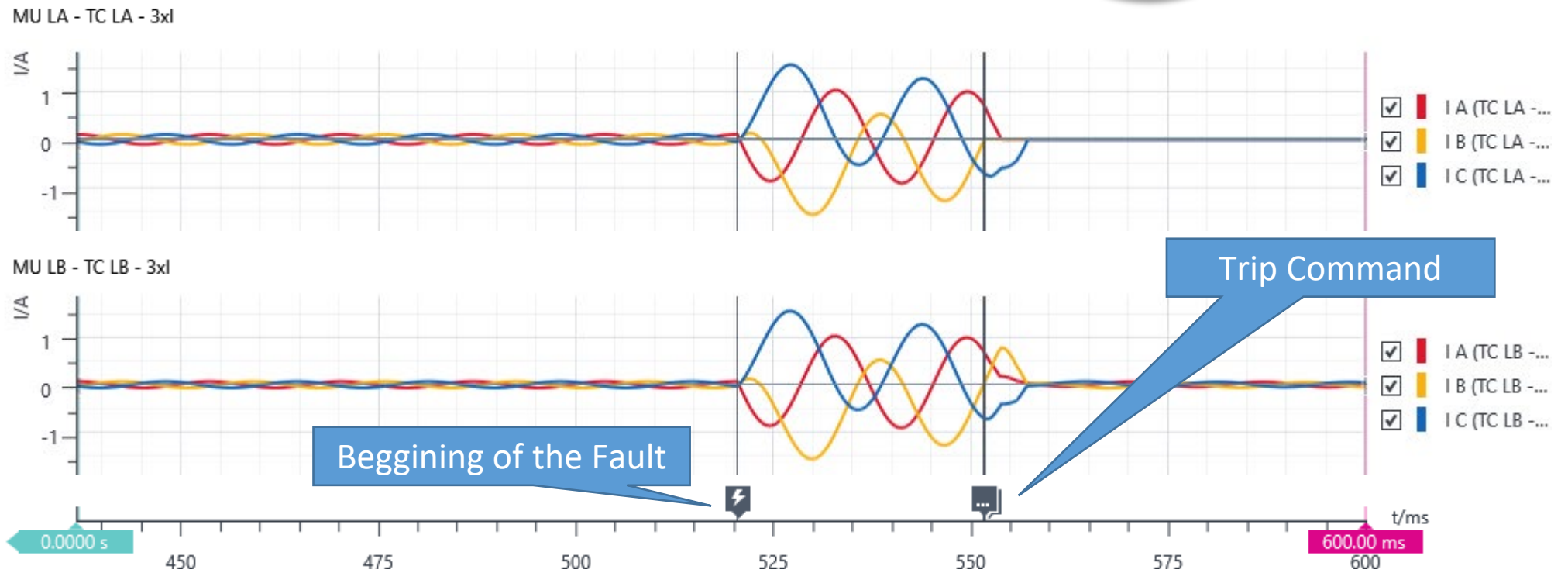
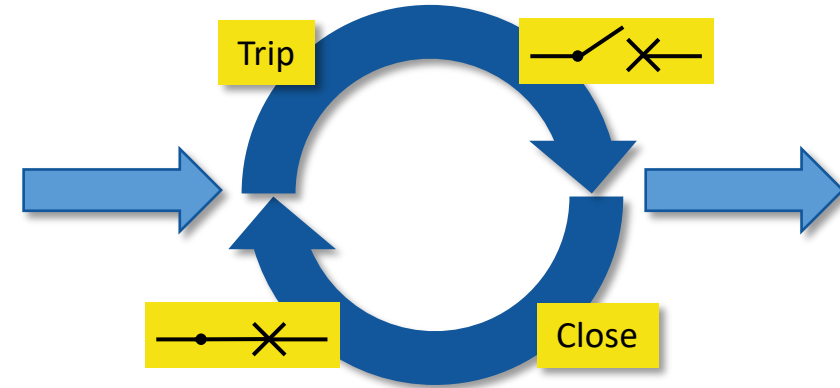
MU TR3 - TC TR3 - 3xl



- 3-Phase Fault on Busbar 4
- After clearing the fault, the bays that weren't connected to the Busbar 4 continued to feed normal currents (bays LA, LC and TR3) and the current of the other bays were interrupted after the simulated CB opening time

Transients after CB reaction

- Simulation of the opening CB currents in each bay through iterations



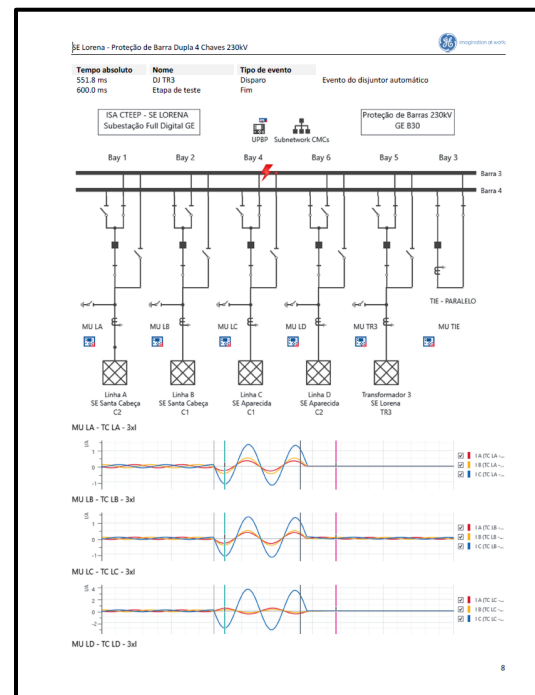
▶ Test Assessment

- ▶ Results based on predetermined criteria for operating times or non-operation of each bay

<div style="display: flex; justify-content: space-between; font-size: 0.8em; font-weight: normal;"> <div style="width: 15%;"> Test case settings Iterative Closed-Loop </div> <div style="width: 15%;"> Add fault Delete fault </div> <div style="width: 15%;"> Duplicate test steps Delete test steps </div> <div style="width: 15%;"> Vary parameters Define measurements Set assessment conditions </div> <div style="width: 15%;"> Assess manually Clear results </div> <div style="width: 15%;"> Export to COMTRADE Copy graphics to clipboard </div> </div>													
<div style="display: flex; justify-content: space-between; font-size: 0.8em; font-weight: normal;"> <div style="width: 15%;">Setup</div> <div style="width: 15%;">Manage Test Steps</div> <div style="width: 15%;">Define Test Steps</div> <div style="width: 15%;">Results</div> </div>													
	Faltas Barra 4	Falta no nó 1 - F...	Falta no nó 1 - F...	TRIP 87 LA	TRIP 87 LB	TRIP 87 LC	TRIP 87 LD	TRIP 87 TR3	TRIP 87 TIE	86 Barra 3	86 Barra 4	Time stamp	Comment
1	✓ Passed	A-N	0.0000 Ω	+∞	10.7 ms	+∞	10.7 ms	+∞	10.7 ms	+∞	10.9 ms	2020-07-20 14:16:45	✓
2	✓ Passed	B-N	0.0000 Ω	+∞	10.4 ms	+∞	10.4 ms	+∞	10.4 ms	+∞	10.7 ms	2020-07-20 14:26:29	✓
3	✓ Passed	C-N	0.0000 Ω	+∞	9.7 ms	+∞	9.7 ms	+∞	9.7 ms	+∞	9.9 ms	2020-07-20 14:30:07	✓
4	✓ Passed	A-B	0.0000 Ω	+∞	10.7 ms	+∞	10.7 ms	+∞	10.7 ms	+∞	10.8 ms	2020-07-20 14:34:03	✓
5	✓ Passed	B-C	0.0000 Ω	+∞	10.4 ms	+∞	10.4 ms	+∞	10.4 ms	+∞	10.6 ms	2020-07-20 14:38:15	✓
6	✓ Passed	C-A	0.0000 Ω	+∞	10.3 ms	+∞	10.3 ms	+∞	10.3 ms	+∞	10.5 ms	2020-07-20 14:42:22	✓
7	✓ Passed	A-B-C	0.0000 Ω	+∞	9.7 ms	+∞	9.7 ms	+∞	9.7 ms	+∞	9.9 ms	2020-07-20 14:50:25	✓ ✎

Performed tests

- ▶ Stability and polarity tests
- ▶ Faults in both busbars with different bay connection topologies (according to ISA CTEEP script)
- ▶ Transfer Topology
- ▶ “Busbar Totalization” test
- ▶ END Fault
- ▶ Breaker Failure



Test report

ISA CTEEP 87B test script



DEPARTAMENTO DE OPERAÇÃO – TO

COMISSIONAMENTO E PROTEÇÃO – TOPC

ORIENTATIVO ROTEIRO ENSAIOS DAS LÓGICAS E FUNCIONAIS
PROTEÇÃO DE BARRAS

ARRANJO BARRA DUPLA 4 OU 5 CHAVES COM DISJUNTOR DE
PARALELO E / OU COM JUMPEAMENTO DE DISJUNTOR OU
ARRANJO DISJUNTOR E MEIO

► Cost Benefit Analysis



	Conventional Single Phase	System Based	Conventional 3 Phase
Time for initial preparation (hours)	12	8	8
Time for test preparation (hours)	0.5	0.25	0.5
Quantity of tests	120	40	40
Total time (hours)	72	18	28
Number of engineers	1	1	3
Engineer man-hour cost	4X	X	4,66X
Quantity of Test Sets	1	2	3
Test set rental (R\$/hour)	100	100	100
GPS rental (R\$/hour)	0	0	87.5
Total	3,33Y	Y	4,11Y

▶ Conclusions

- ▶ Busbar protection testing by simultaneous injection in all bays and using realistic transient signals calculated from power system simulation software
- ▶ Enormous time and cost savings with the use of this test method
- ▶ Great gain in quality when applying this method compared to the traditional way
- ▶ Test technology applied in full digital substations must evolve and be applied using all the test features provided by the standard
- ▶ IEDs compatible with IEC61850 Ed 2.1, as well as PTP DAN GPS and transparent PTP switches allow the application of modern testing tools, which were widely used in Lorena Substation



Questions?