EXPERIENCES TESTING A BUSBAR PROTECTION USING PROCESS BUS WITH SIMULTANEOUS INJECTION IN ALL BAYS

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Abstract:

This article describes in detail the test strategies used for commissioning a busbar protection scheme at Lorena Substation from ISA CTEEP, electrical utility in Brazil. The scheme is based on a centralized busbar protection IED subscribing to measured current signals via IEC 61850 Sampled Values published by Merging Units in each bay. The main objective of this article is to present how the test of a busbar protection IED on a Process Bus can be simpler, more realistic, and more comprehensive, if using a system-based approach based off the system model of the substation. Time effort, resources, and costs of such a commissioning are calculated and a timing and economic comparison with conventional methods is presented.

Keywords: Busbar Protection, IEC 61850 Sampled Values, Digital Substations, System-Based Testing

1. Introduction

During the modernization process of the Lorena Substation (in Brazil, São Paulo state), belonging to ISA CTEEP, the implementation of an IEC 61850 Full Digital solution was adopted, considering the efficient implementation and testing aspects of the Station Bus and the Process Bus.

The digitization of CTs and PTs measurements and their transmission in a multicast messaging over the communication network brings several advantages such as simplifications and cost reduction with cabling, possibilities for online monitoring, redundancy, security, and many others. This is a true technical revolution for substation automation, and the main concern of “protection engineers” is how to adapt to this new technology and verify how the overall functionality of the PAC system is affected by the Process Bus, in this case especially for a Busbar Protection implementation.

With a power system electrical model driven approach for testing Busbar Protection, it is possible to inject currents into all field bays simultaneously and conduct a complete test of the entire protection system in a more realistic way. Within a new application software, the busbar topology is modeled, so that all current transients can be calculated for different types of faults and operating scenarios automatically, using dynamic simulation. Using a closed loop simulation approach through iterations, the software can simulate fault scenarios where the correct reaction of the protection system is considered in the transient simulation.

2. Challenges of Bus Differential (87B)

In a busbar protection relay, the main protection function is the bus differential function, which applies Kirchhoff's law to identify faults in the protected area. As the requirements for this type of IED are highly focused on the speed and stability of the protection, usually these modern devices decide to trip based on multiple different measurements, as for example the check zone measurement, which is independent of the position of any disconnector. Differential measurements are typically stabilized with a percentage characteristic [2], as shown in Figure 1.

When the measurements indicate a fault within the zone protected by the bus, the IED will work to trip selectively, for example by disconnecting only the circuit breakers of the bays that supply the fault.

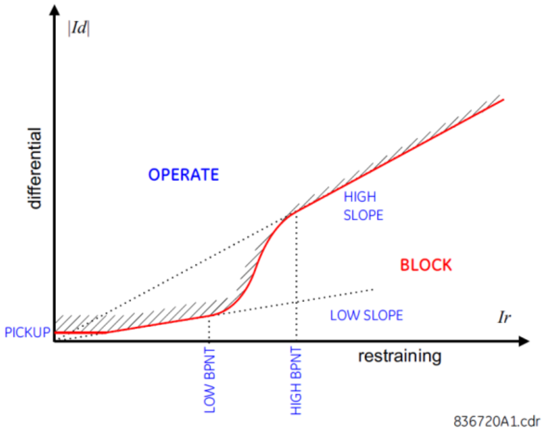


Figure 1. Differential Characteristic example [2]

However, in addition to the percentage busbar differential function, the most modern protection relays are multifunctional and contain additional features that must be tested with equal importance: breaker failure and fault on the dead zone.

To test a differential characteristic, at least two currents must be injected towards the busbar, so that it is possible to simulate a fault scenario. Some modern protection software supports this feature by modeling the differential characteristic and running the test based on the test point selected in the characteristic plane, although for busbar protection tests this may have certain limitations, such as the number of bays that can be simultaneously injected with currents.

When we have distributed busbar protection systems, another challenge is the distance between each bay, which could lead to dependence on the use of very long test leads or that the test system can also operate with distributed test equipment, and to avoid unwanted differential currents, these devices should then be synchronized with each other.

As for the test of the trip logics of an IED, this can be the most complex part of a bus protection device, since there are different connection topologies for each bay, and because different fault conditions are also considered, which could take weeks of testing depending on the topology and size of the busbar under test. To determine the correct bays to disconnect, the protection relay must know the topology of the busbar by measuring the position of the circuit breakers and disconnectors in the system. In this way, the test system must provide consistent positions of disconnectors and circuit breakers, in addition to injecting currents, which means that the current will only be measured in a specific bay if the circuit breaker and the corresponding disconnector are closed, otherwise the other supervision systems can interfere with testing such as measurement and breaker failure supervision.

Currently, these tests are achieved in a conventional way through test scripts with different states of disconnectors and circuit breakers and current values per bay that are defined by a table, and position signals are simulated through manual physical simulators, or even forcing the actual position of the real switches in the field. If the test script is not very detailed, and the person performing the test is different from the person who idealized the test, then identifying an unexpected reaction may be quite complex.

2. Requirements of Bus Differential (87B)

For proper testing of a busbar protection relay, we can summarize the following requirements [1].

a. Flexible test system: the number of bays to be tested is different from substation to substation, in this way the test system must allow the simultaneous control of as many test sets as necessary to simulate the required currents (using analog injection of currents or through Sampled Values).
b. Ability to consistently simulate position contacts (physically or digitally), without limiting quantities, and consistently (by controlling the timing of the contacts and the injection/cutting of currents appropriately), exactly to adapt to the required number of bays of the existing busbar topology, avoid supervisory alarms, unwanted blockings, and enable testing extra functions such as breaker failure (50BF).

These requirements can be achieved using a simulation method based on the electrical model of the system. In this condition, it is possible to easily design the electrical system, and the topology to be tested can then be defined by moving the position of the disconnectors of the test scheme, and each different test case can be defined by the fault location to be simulated in the system. With the definition of polarity, turns ratio and the saturation curve model of each CT, and with the definition of the equivalent source model for each bay, the test software can perform the calculations and start the injection in multiple bays in a synchronized way.

This proposed technique is based on systemic simulation (which is the opposite of conventional tests based on relay settings), it seeks to test the protection system in a complete way, injecting real transient test signals (without abrupt jumps from pre-fault and fault) and checking the behavior of the system.

Testing only the differential characteristic of Figure 1 is the opposite of a systemic test. If the characteristic testing is required, conventional testing equipment can be used, but the actual response to systemic events would not be proven. It is important to emphasize that the electrical system must be protected, not just one or two bays, and since there are mutual iterations and communication between different elements of this system, the most important requirement for the tests would be to use the simulation technique based on the electrical model of the system, instead of testing just to validate the settings defined in a protection study.

In many busbar relay test steps, it is important to react to relay actions. This means that when a trip command is sent by the relay, the circuit breaker must open within the simulation and no current flow must be simulated, so the simulation must be consistent. If this is not the case, the lack of position change of the breaker would be wrongly considered by the relay as a breaker failure, and the test scenarios that are waiting for actions after the first trip cannot be executed. This ability of a simulation to react to the action of the system under test is often called real-time closed loop, which is limited to laboratories and is expensive. An alternative to this combines the advantages of reacting to relay actions and injecting/publishing SV through the usage of distributed test equipment, the reaction technique is called iterative closed-loop approach.

When applying this technique to simulate a fault on a busbar, the first iteration is injected without any reaction (static states). However, the relay will react to the fault with a trip command which is recorded (learned) by the test software. As the relay must react when the same currents are injected, the next iteration will start a repetition of the fault with the same waveform, but this time the breaker opens after the “learned” trip time in the previous iteration plus a constant trip time emulating the circuit breaker opening time. If a second trip or close command occurs, which was not part of the first iteration, but is part of the second iteration, then a third iteration would be performed including both breaker events. This is repeated until no new Trip or unknown close commands are sent by the busbar protection IED. In the end, the entire sequence of events is recorded, and the test requirements are sufficiently fulfilled, while retaining the advantages and ease of a simulation-based testing approach. Figure 2 shows an example with two iterations.

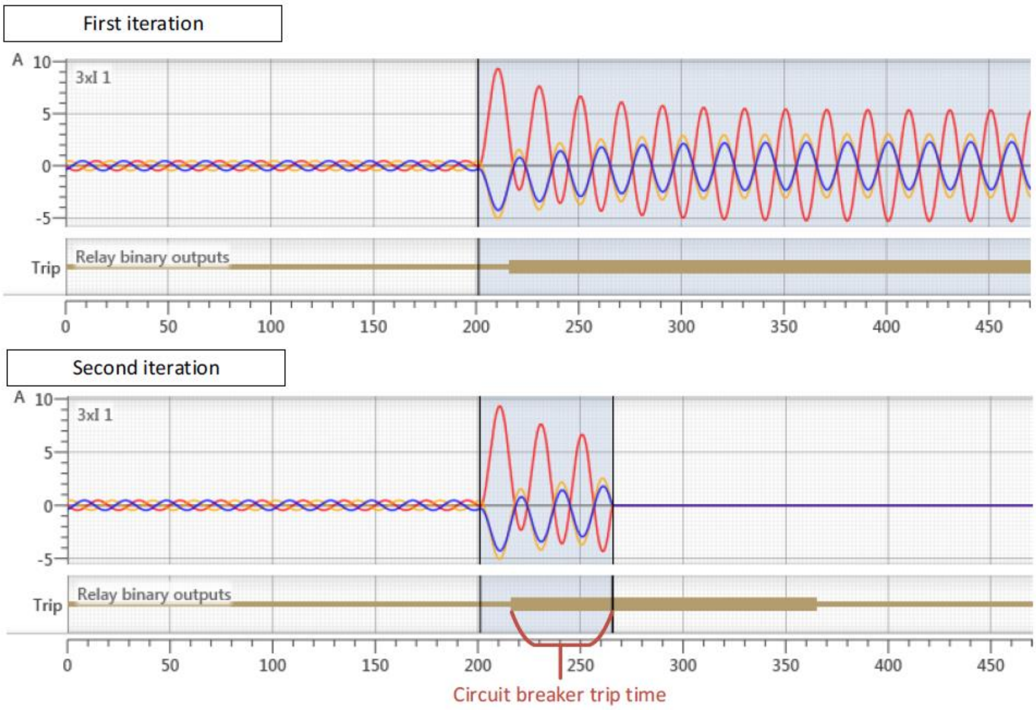


Figure 2. Example of iterative closed-loop sequence

4. Test setup

ISA CTEEP's Lorena Substation has a double bus topology, five 230kV bays plus a bus coupling bay, it is fully digital with a PRP redundant network and PTPv2 redundant clocks, with transparent PTP switches, IEDs and Merging Units (MU).

The test performed in the Lorena Substation was conceived using a power system simulation software, which has exactly the requirements mentioned in Chapter 3, in addition to the fact that it performs the simulation of all currents using Sampled Values with each test set publishing 4 SV streams. For this reason, two test sets were used connected to the Process Bus network, where only the communication ports of these equipment were used (no physical IO). The simulation of position contacts of each disconnecting switch and circuit breaker was done by the software through GOOSE messaging, as well as the Trip, Blockings and End Fault data of each bay were subscribed by the software also using the GOOSE messages published by the relay. In this way, it is concluded that the tests were performed in a fully digital way, as shown in the schematic of Figure 3.

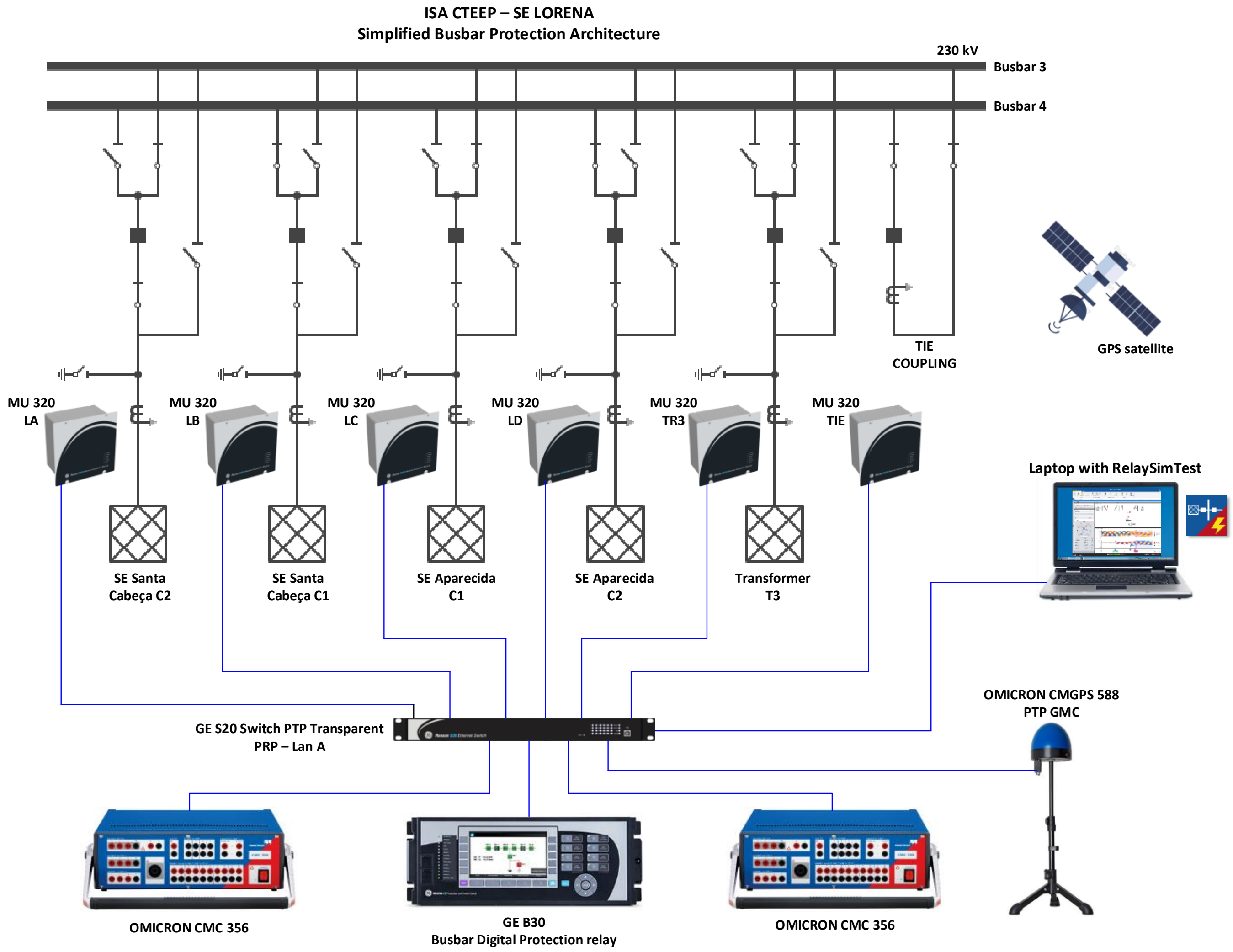


Figure 3. 87B Test setup in SE Lorena

From the protection studies provided, the sources (Thevenin equivalents) of each bay were modeled in the software to provide realistic short circuit currents for the simulation, resulting in the model shown in Figure 4, which also considers CT saturation through the settings taken from each current transformer nameplate data.

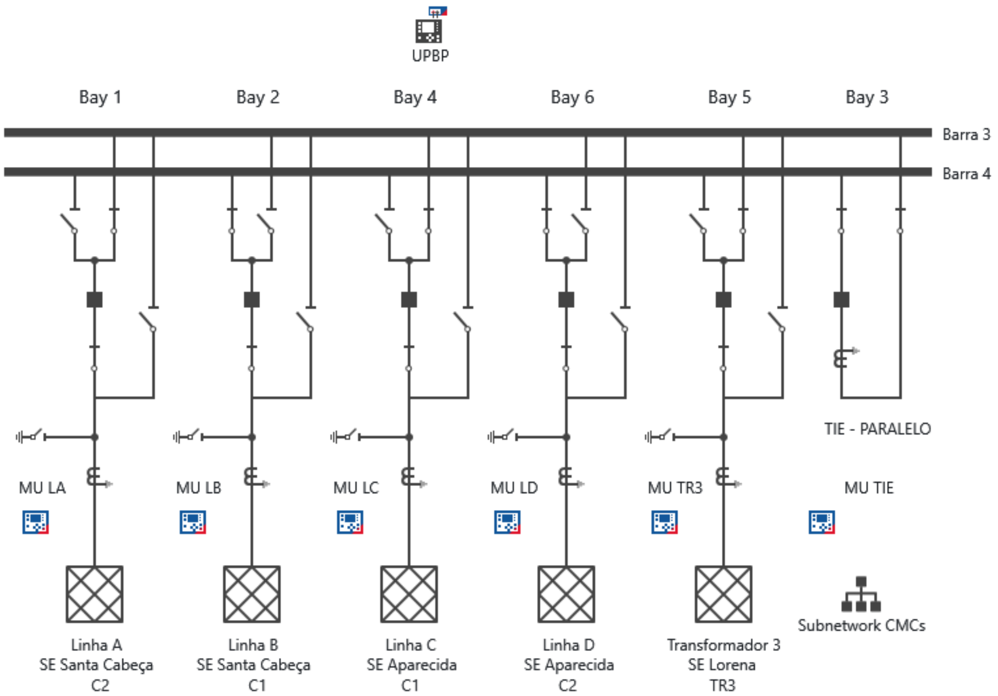
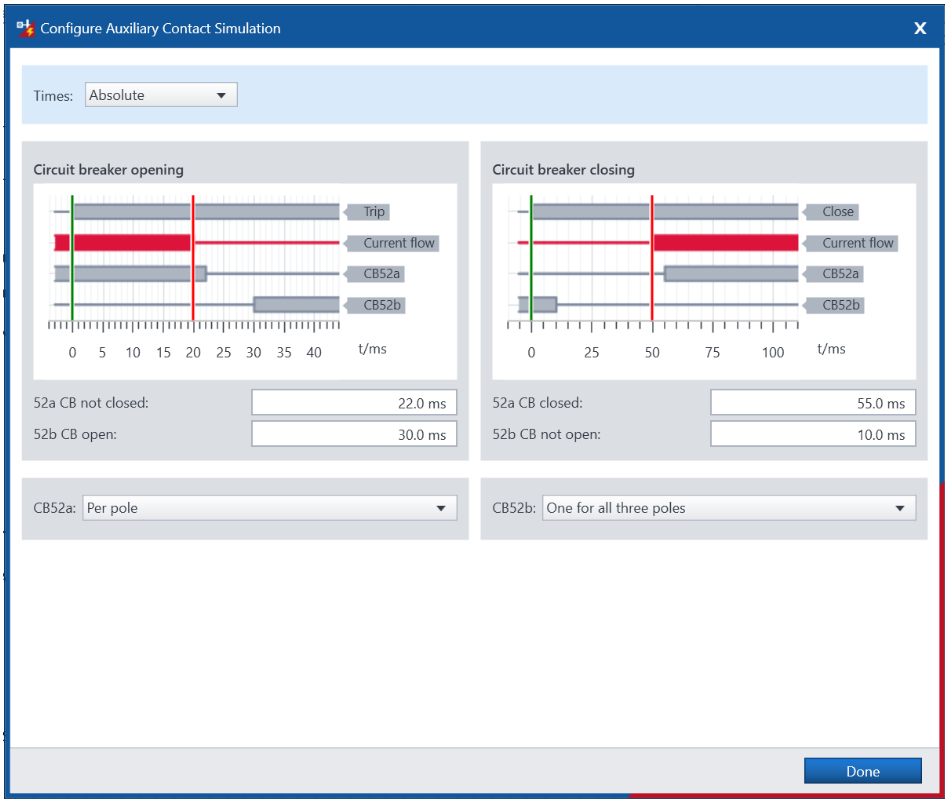


Figure 4. 87B Electric Model represented in the software

The timing of the contacts (52a and 52b) of each circuit breaker (to be simulated via GOOSE) was appropriately modeled, according to the breaker's nameplate, as shown in Figure 5



Times: Absolute

52a CB not closed: 22.0 ms

52b CB open: 30.0 ms

52a CB closed: 55.0 ms

52b CB not open: 10.0 ms

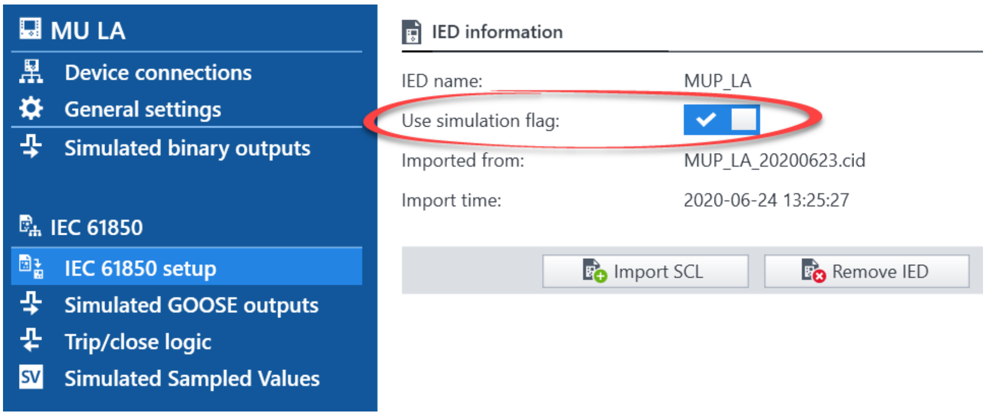
CB52a: Per pole

CB52b: One for all three poles

Figure 5. Settings for the simulation of Circuit Breakers

The protection IED and the test sets were synchronized by the same PTP time source to ensure that the Sampled Values streams published by the two test sets were consistently published in sync.

Each Merging Unit was then replaced by the simulation of 6 streams of Sampled Values, and the Test and Simulation mode features defined in the IEC61850 Ed.2 were properly applied during the tests:



IED information

IED name: MUP_LA

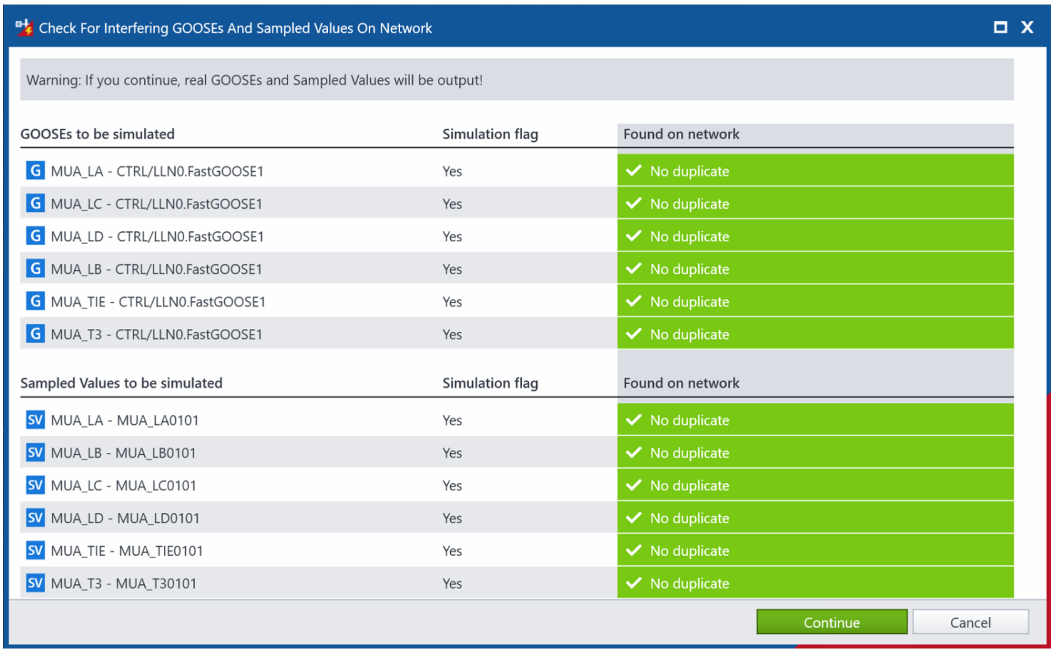
Use simulation flag: ☑

Imported from: MUP_LA_20200623.cid

Import time: 2020-06-24 13:25:27

Figure 6. Simulation Mode for Sampled Values

As a safety feature, before starting to publish any IEC 61850 data on the network, the software sniffs the network and checks if there is no SV stream or GOOSE published on the network the same as the one configured for the simulation, to prevent duplicate data in the network that could confuse the protection IED and cause misoperations.



Check For Interfering GOOSEs And Sampled Values On 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

Figure 7 - Safety check before testing

5. Executed tests

From a script of mandatory tests to be performed provided by ISA CTEEP's engineers, an automated test plan was created in the test software, considering the following types of cases:

a. Initial stability tests for normal load conditions (also serve as check of CTs polarities)
b. Stability tests for faults outside the protected zone
c. Faults in the protected area considering Busbar 3, Busbar 4, and different bays connection setups
d. Breaker Failure
e. End Fault

For the cases of item c, all possible fault loops and different fault impedance conditions were simulated.

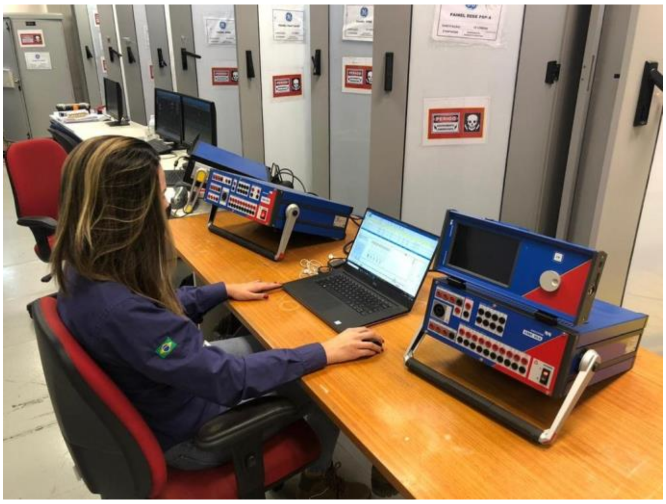


Figure 8. Picture during SE Lorena's 87B SAT (no analog connections)

5.1 Example of Published/Subscribed Signals

Figures 9 and 10 show an example of the waveforms published via Sampled Values (simulation with 10kHz sampling) and other published and subscribed GOOSE signals during a test with a three-phase fault on the Busbar 4.

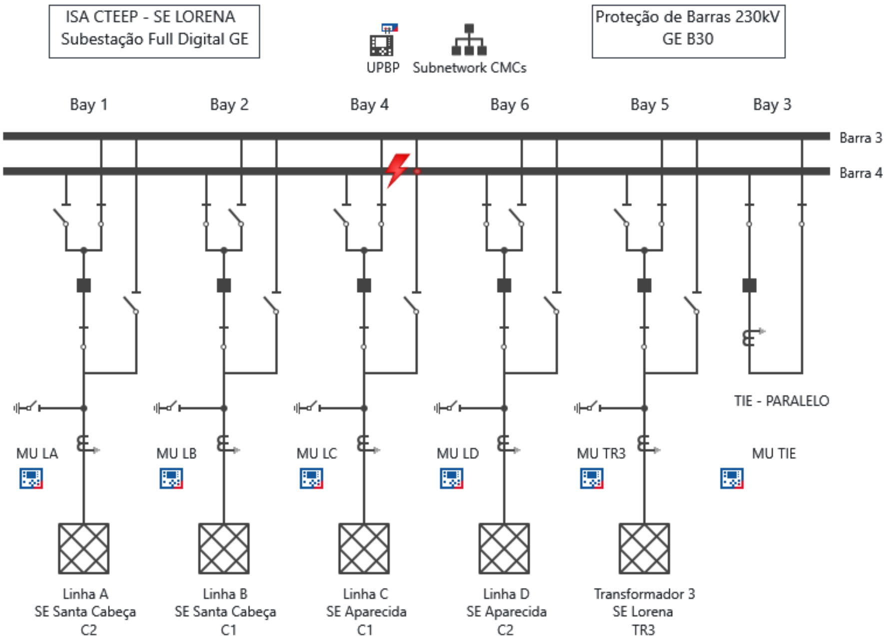


Figure 9. Three-Phase Fault on Busbar 4

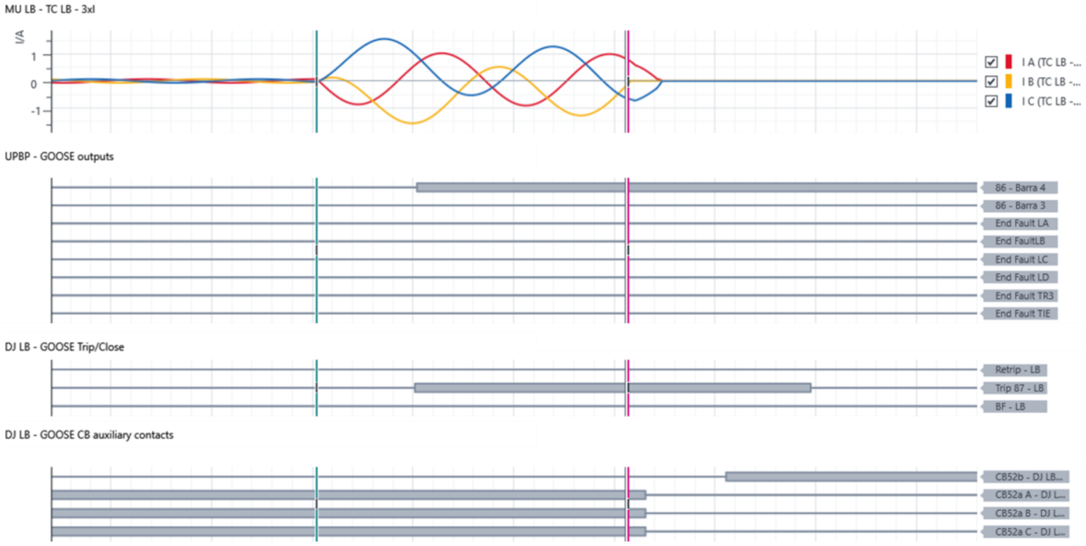


Figure 10. Example of published and subscribed data on bay LD during a fault

On Figure 10 can be observed the current of bay LD published through Sampled Values by the test set, as well the auxiliary contacts of the circuit breaker simulated and published via GOOSE by the same test set, both to be subscribed by the relay. It can be also observed the 87B Trip signal and the blocking of re-energization (signal 86) published via GOOSE by the relay that were subscribed by the test set and brought to the test report.

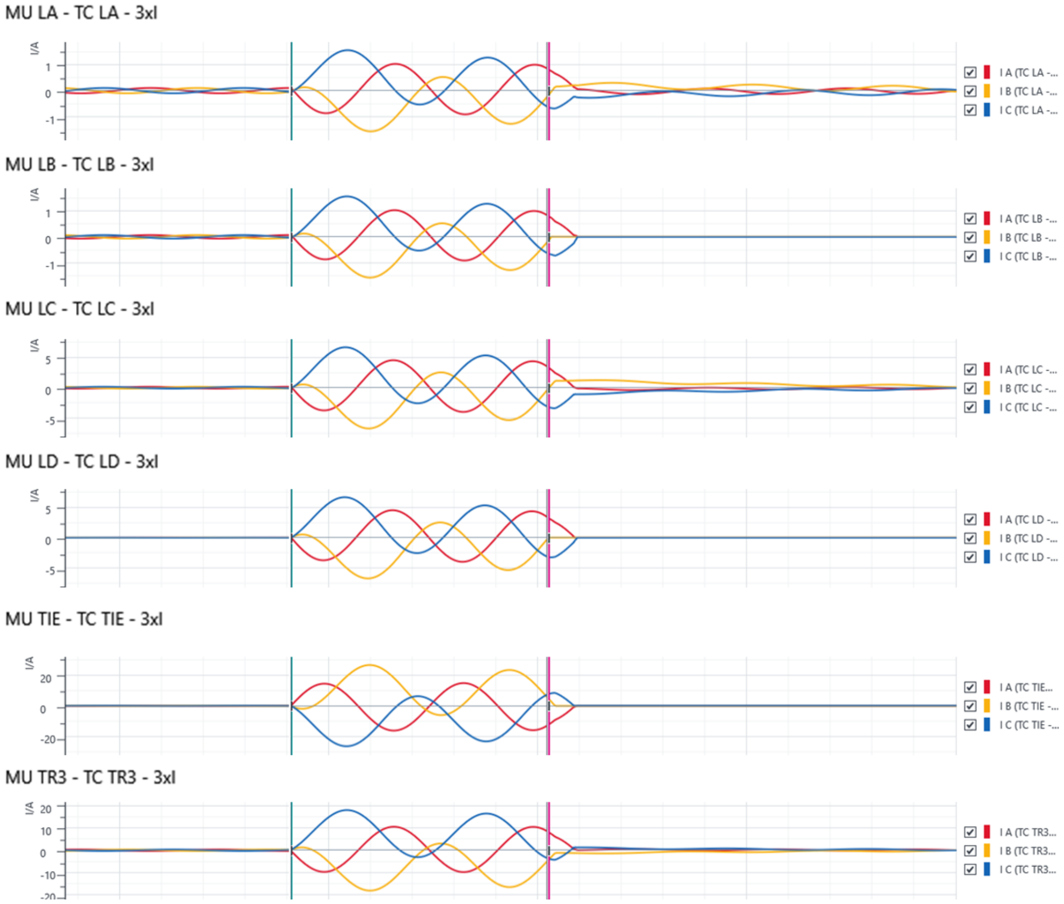


Figure 11. Example of Published SV currents in all bays during a fault

On Figure 11, 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 was correctly extinguished after the simulated CB opening time from Figure 5, showing a very realistic simulation case for the relay.

6. Time and Cost Comparisons

Considering three types of tests among the possible ones for a double busbar topology with 5 bays plus coupling bay, the following comparison was performed – assuming a worst case, where the test sets and GPS antennas are rented and for typical costs in Brazil. Considered scenarios:

a. Conventional single-phase test: simultaneous analog current injection in the 6 bays using 1 test set, it would be 40 tests per phase, totalizing 120 tests for the whole busbar
b. System-Based test: injection of simultaneous 3-phase SV Streams on the 6 bays using 2 test sets
c. Conventional 3-phase test: injection of simultaneous 3-phase analog currents on the 6 bays using 3 test sets synchronized by 3 different GPS antennas

Table 1. 87B test comparison

	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
Number of tests	120	40	40
Total time (hours)	72	18	28
Number of engineers	1	1	3
Engineer-hour cost	4x	x	4,66x
Number 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

As the rental and engineer-hour cost may vary from country to country and the intension was just a simple comparison, the real numbers were replaced by reference values of X and Y.

It can be observed that the most economical and viable (disregarding the initial cost of the system-based software needed for the test sets) is the method using the system-based modelling software, when compared to the conventional methods already known and applied.

6.0 Conclusions

The tests using this new methodology based on the electrical system model allowed reaching a level never reached by ISA CTEEP before, in terms of test automation and documentation using Process Bus technology, allowing to execute the busbar protection test in a more cohesive way, faster and with a better quality, being a reference for the tests of future substations and for future maintenance tests. In addition, time and cost savings were achieved for the complete test when compared to conventional test methods.

These tests proved to be easy to setup since they only use information from electrical modeling and IEC 61850 communication (SCL files taken from the IEDs). In addition, these tests perform close to real simulations by applying transient signals in a systemic way and current injection in all bays simultaneously (what really increases the quality of the tests), something that would not be feasible using conventional test solutions.

This article also shows that the use of innovative test solutions must follow the development of the IEC 61850 standard, addressing all available functionality.

7. References

[1]. PRITCHARD, Christopher; HENSLER, Thomas; Test and verification of a busbar protection using a simulation-based iterative closed-loop approach in the field; (2014).

[2]. GE grid Solutions. (2020). B30 Bus Differential System Manual (Vols. 1601-0109-AI2 (GEK-131093A), Product version: 7.9x).

8. Biographies

Luiza Pio received her B.Sc. in Electrical Engineering at UNESP Bauru and is Postgraduate in project and business management at FIA, both in Brazil. Protection Engineer at Alstom from 2013 to 2016 and Protection Engineer at General Electric from 2016 to 2019, currently Coordinator of the Protection and Control team at General Electric Brazil.

João Jorge received his B.Sc. in Electrical Engineering by UFJF and is post graduated in Power Systems Protection by UNI. He has over 9 years of experience in the design and commissioning of power systems protection, automation, and control systems. He joined OMICRON in 2018 as an Application Engineer and is currently Regional Application Specialist for Protection and IEC 61850 communications for Latin America. He is also an active member of Cigré Brazil B5 working groups.

Alex Takeda received his B.Sc. in Electrical Engineering in Brazil from Universidade Presbiteriana Mackenzie (2013) and specialization in Automation of Electrical Systems from Universidade Inatel, also in Brazil. He is currently an engineer in the Commissioning and Protection area at ISA CTEEP transmission utility. He carries out commissioning of protection and automation systems in several ISA CTEEP substations and performs protection tests for final validation before operation. He focuses on the development of digital substations and implementation of new disruptive technologies in the electrical system.