B5 - Protection & Automation Committee

PS2 - Applications of emerging technology for protection, automation and control

Paper ID – 968

# Automated Hardware in the Loop test bed for protection relays using a decision three algorithm

Mauricio SÁNCHEZ; Jose MONTOYA; Jhonatan ANAYA

XM ; Intercolombia

## The problem

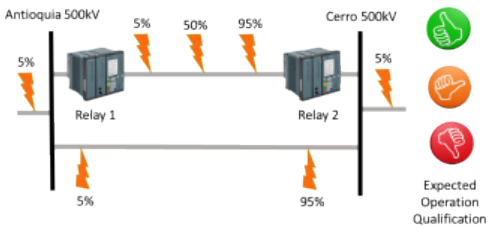
- Most TSO in Colombia must validate the expected behavior of protection relays due to new relay models or firmware upgrades.
- Extensive Protection & control tests for new projects, commissioning and relay malfunction are also carried out very often

Photo credit: elect-pc.com

- With a fleet of around 2300 relays for Colombia alone, this processes has been time demanding and needs the involvement of very skilled protection engineers.

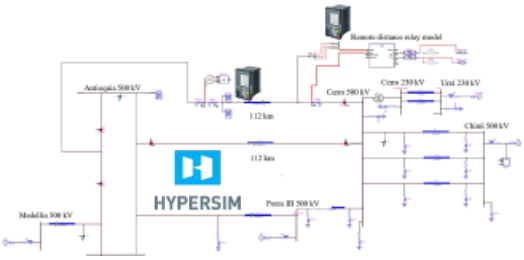
## Approach and Value Proposal

- Automate the execution of multiple distance relay tests and operation scenarios
- New possibility to test the real relays of both ends of the line interacting
- Relays measuring Sampled Values and GOOSE signals for tripping and interacting
- Automate Comtrade file analysis and reporting

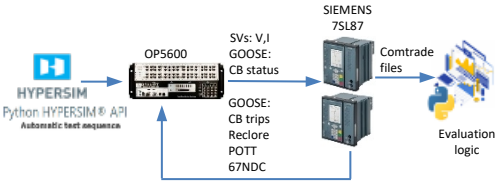



## Network digital twin

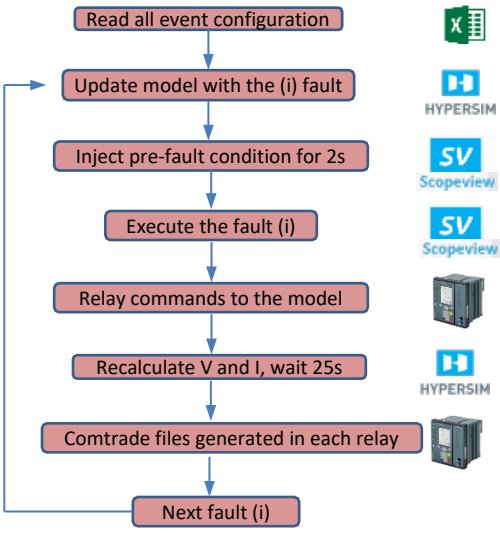
Development and validation against ATP of a digital twin of a portion of the network (7 nodes + equivalents)




## Test bed HIL arquitecture




## The Automatic Test Sequence



B5 - Protection & Automation Committee

PS2 - Applications of emerging technology for protection, automation and control

Paper ID – 968

# Automated Hardware in the Loop test bed for protection relays using a decision three algorithm

Mauricio SÁNCHEZ; Jose MONTOYA; Jhonatan ANAYA

XM ; Intercolombia

## 10 Protection functions in the route map

Line distance protection relay

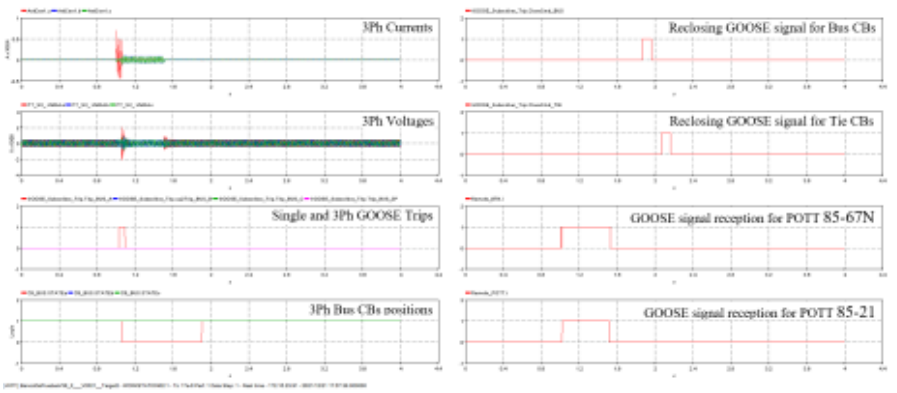
| Protection function (ANSI code) | Description |
|---|---|
| 21 ☑ | Distance (impedance) |
| 67N | Directional overcurrent |
| 85-21 | Permissive Over-Reaching Transfer Trip (POTT) |
| 85-67N | Directional Overcurrent comparison scheme (67NCD) |
| LOP | Loss of potential |
| SOTF ☑ | Switch onto fault |
| 27/59 | Low/over voltage |
| 25 | Synchro check |
| 79 | Reclosing scheme |
| PD | Pole discrepancy |

## 13 Binary variables used for the evaluation logic

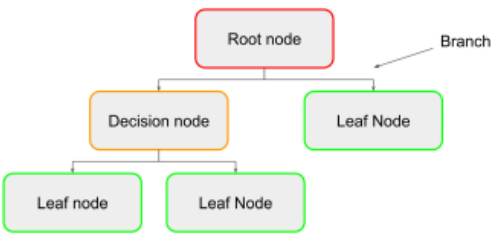
| Variable | Description |
|---|---|
| TripPa | Trip phase A |
| TripPb | Trip phase B |
| TripPc | Trip phase C |
| Pickup FW | Forward direction detection |
| Pickup BW | Backwards direction detection |
| Trip Rev | Trip reverse zone |
| Trip Z2 | Trip Zone 2 |
| Trip Z1 | Trip Zone 1 |
| Trip 67N | Directional overcurrent trip 67N |
| 85-67N Op | Directional overcurrent comparison trip |
| 85-67N Send | Directional overcurrent comparison signal send |
| 85-21 Op | Permissive Over-Reaching Transfer trip |
| 85-21 Send | Permissive Over-Reaching Transfer - signal send |

## HIL test example

Typical HIL test for a phase A to ground fault in the middle of the line is presented. The overcurrent and undervoltage produced by the short – circuit are seen by the relay which short after, sends trip signal to phase A CBs, followed by a successful reclosing to normalize the line operation.




## Decision Tree generic scheme




The data set needed to train the Decision Tree algorithm was built with the experience of an expert in power system protections, putting his knowledge in a data set containing around 3000 combinations for 30 event cases. These combinations are variations of relay responses that can be possible to occur due to its parameter's configurations, firmware version, and some other situations.

B5 - Protection & Automation Committee

PS2 - Applications of emerging technology for protection, automation and control

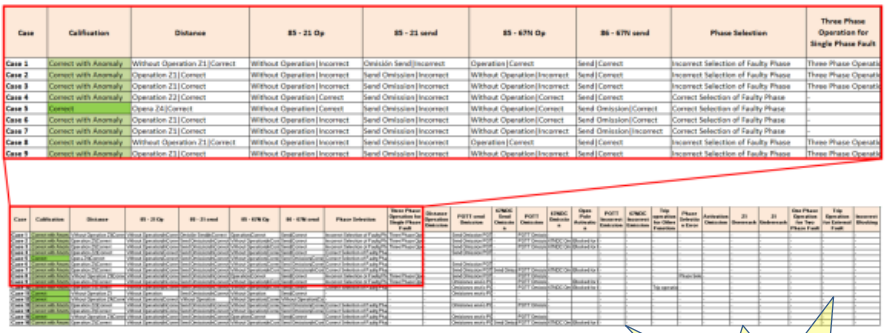
Paper ID – 968

# Automated Hardware in the Loop test bed for protection relays using a decision three algorithm

Mauricio SÁNCHEZ; Jose MONTOYA; Jhonatan ANAYA

XM ; Intercolombia

## Output report for a case of intentional POTT failure



| Case | Calification | Distance | 85 - 21 Op | 85 - 21 send | 85 - 67N Op | 86 - 67N send | Phase Selection | Three Phase Operation for Single Phase Fault |
|---|---|---|---|---|---|---|---|---|
| Case 1 | Correct with Anomaly | Without Operation Z1 \| Correct | Without Operation \| Incorrect | Omission Send \| Incorrect | Operation \| Correct | Send \| Correct | Incorrect Selection of Faulty Phase | Three Phase Operation |
| Case 2 | Correct with Anomaly | Operation Z1 \| Correct | Without Operation \| Incorrect | Send Omission \| Incorrect | Without Operation \| Incorrect | Send \| Correct | Incorrect Selection of Faulty Phase | Three Phase Operation |
| Case 3 | Correct with Anomaly | Operation Z1 \| Correct | Without Operation \| Incorrect | Send Omission \| Incorrect | Without Operation \| Incorrect | Send \| Correct | Incorrect Selection of Faulty Phase | Three Phase Operation |
| Case 4 | Correct with Anomaly | Operation Z2 \| Correct | Without Operation \| Correct | Send Omission \| Incorrect | Without Operation \| Correct | Send \| Correct | Correct Selection of Faulty Phase | - |
| Case 5 | Correct | Opera Z4 \| Correct | Without Operation \| Correct | Send Omission \| Incorrect | Without Operation \| Correct | Send Omission \| Correct | Correct Selection of Faulty Phase | - |
| Case 6 | Correct with Anomaly | Operation Z1 \| Correct | Without Operation \| Incorrect | Send Omission \| Incorrect | Without Operation \| Correct | Send Omission \| Correct | Correct Selection of Faulty Phase | - |
| Case 7 | Correct with Anomaly | Operation Z1 \| Correct | Without Operation \| Incorrect | Send Omission \| Incorrect | Without Operation \| Incorrect | Send Omission \| Incorrect | Correct Selection of Faulty Phase | - |
| Case 8 | Correct with Anomaly | Without Operation Z1 \| Correct | Without Operation \| Incorrect | Send Omission \| Incorrect | Operation \| Correct | Send \| Correct | Incorrect Selection of Faulty Phase | Three Phase Operation |
| Case 9 | Correct with Anomaly | Operation Z1 \| Correct | Without Operation \| Incorrect | Send Omission \| Incorrect | Without Operation \| Incorrect | Send \| Correct | Incorrect Selection of Faulty Phase | Three Phase Operation |

16 min. for 30 events

6 s for analytics & reporting

## Conclusions

- A successful implementation of an automatic test bed for distance relays was achieved along with automated analysis and classification of events
- Great value in effort and time saving is foreseen
- Due to the fast diagnosis and time saving, more test scenarios could be implemented. This would lead to better relay settings and protection logics to increasing security and reliability


## Future work

- Expand the knowledge data base with more binary signals and include response time for the DT algorithm to cover more possible relay behaviors
- Create the ability to test multiple relay brands
- Develop the test bed for transformer, generator and differential protections
- Turn this prototype into a IEC61850 test bed to help TSOs address the substation digitalization