A Comparison of IEC 61850-Based Digital-HIL and Analog-HIL Schemes

Omar Alamr

Arab Potash Co., Mutah University

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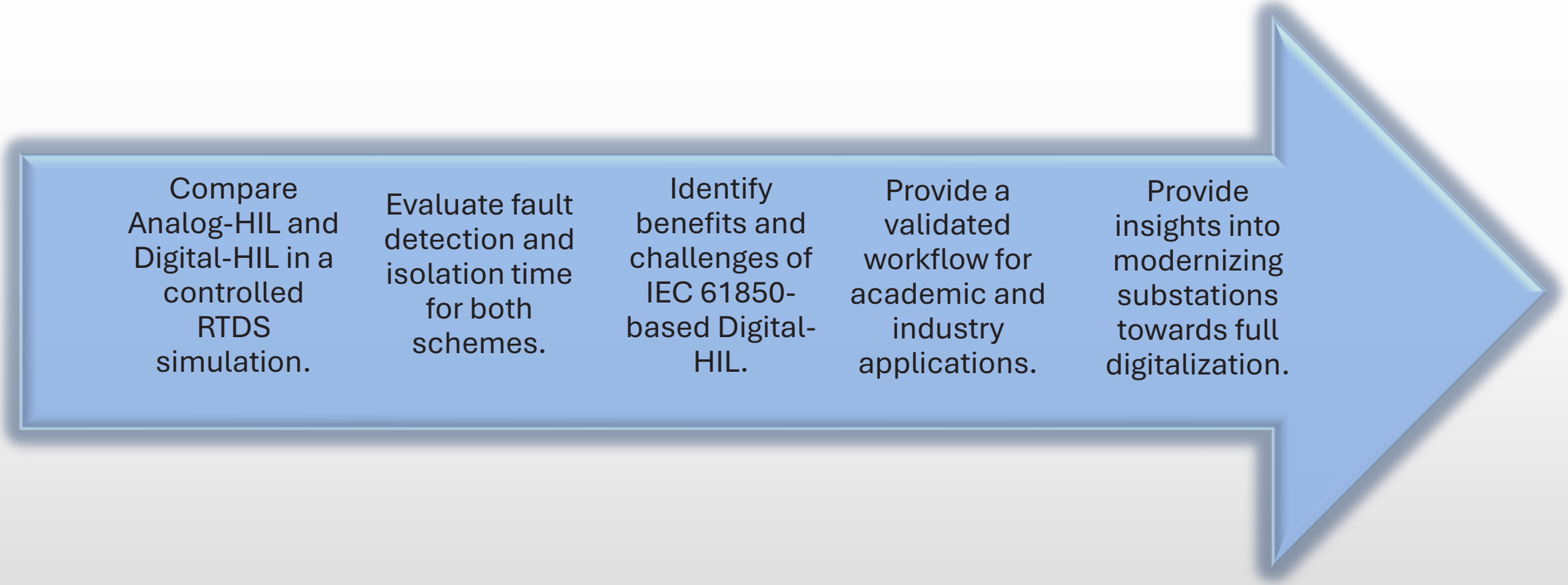
Introduction

- Growing need for accurate and safe protection system testing.
- RTDS simulators are critical tools in real-time simulation.
- Digital substations and IEC 61850 are reshaping how we connect, test, and validate relays.
- This work presents:
- Full digital substation implementation using RTDS and ABB REX640.
- A comparative study between Digital-HIL and Analog-HIL schemes.

Research Objectives

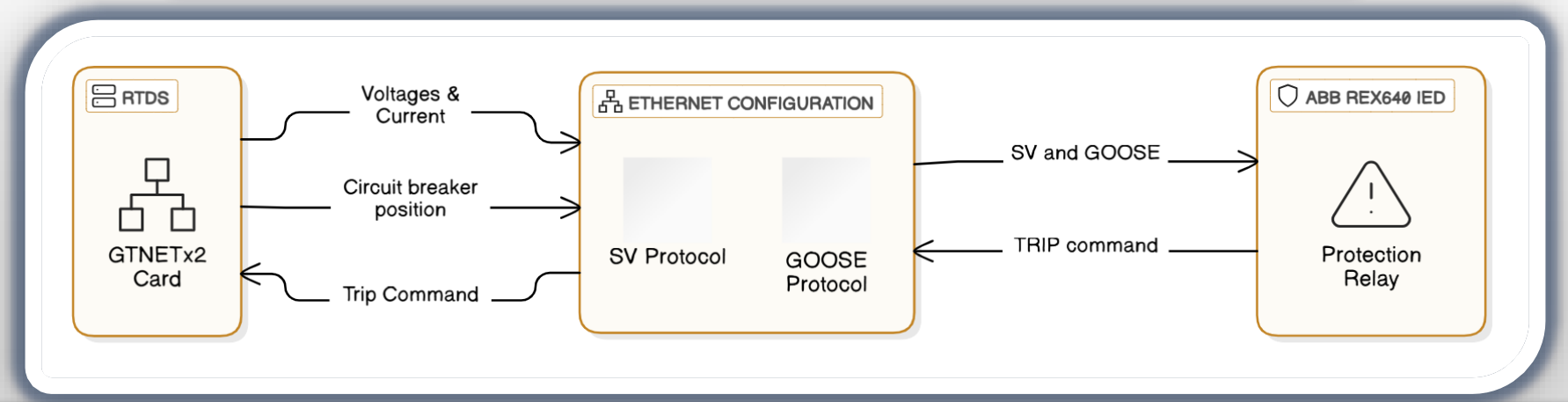


IEC 61850 and Digital Substations Overview

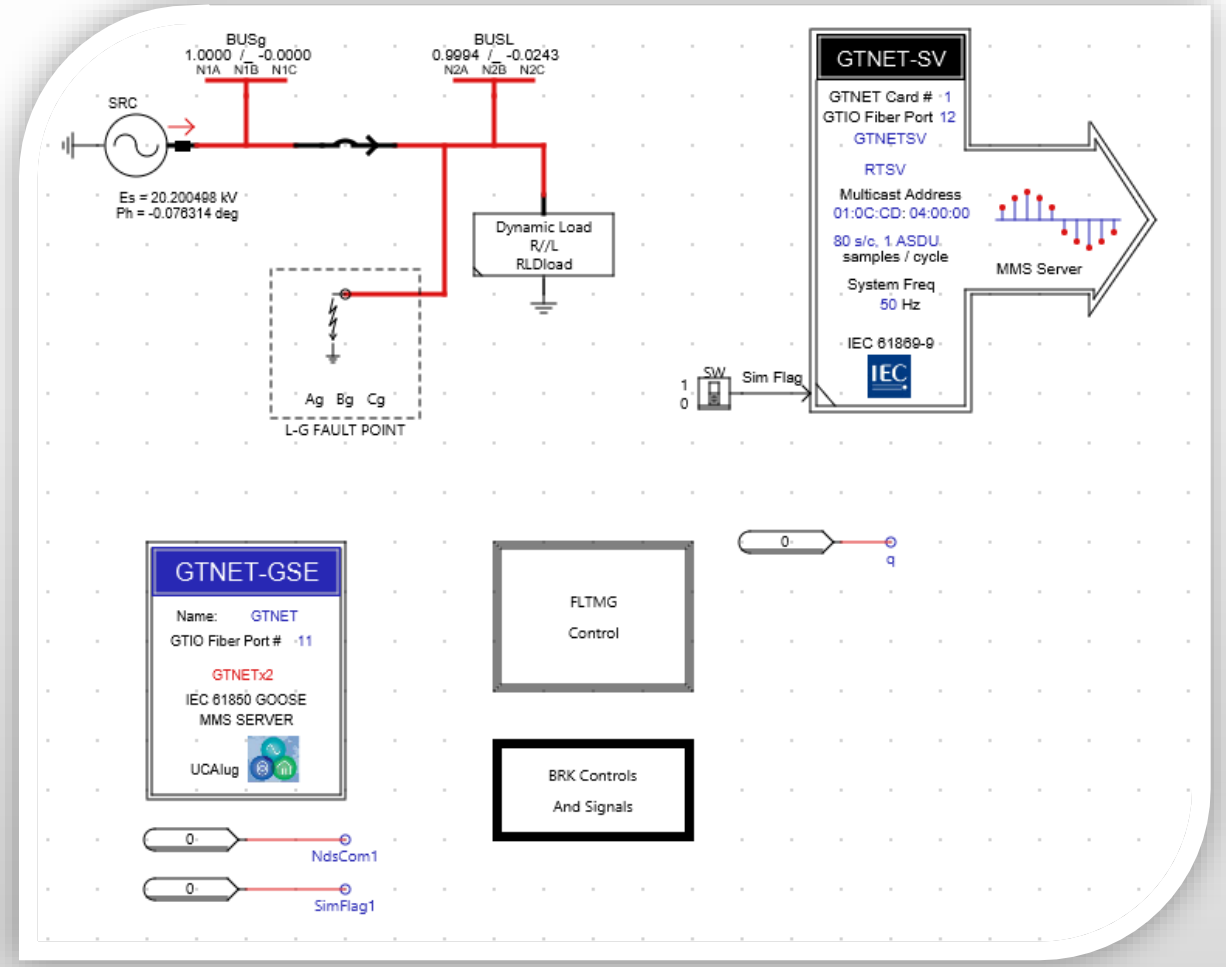
IEC 61850 Communicate	Key protocol components:	Benefits:
• Fast • Standard-based • Interoperability	• Sampled Values (SV) • GOOSE Messaging • SCL Files (SCD, CID, ICD)	• Reduces wiring • Increases speed • Enables flexibility.

Full Digital Substation Architecture

- RTDS (with GTNETx2 card) connected to ABB REX640 IED.
- Ethernet-based configuration for SV and GOOSE.
- Protection relay receives Voltage and current values using Ethernet.
- Trip command from IED received by RTDS to open the breaker.
- Protection relay receives the circuit breaker position feedback by GOOSE messaging.



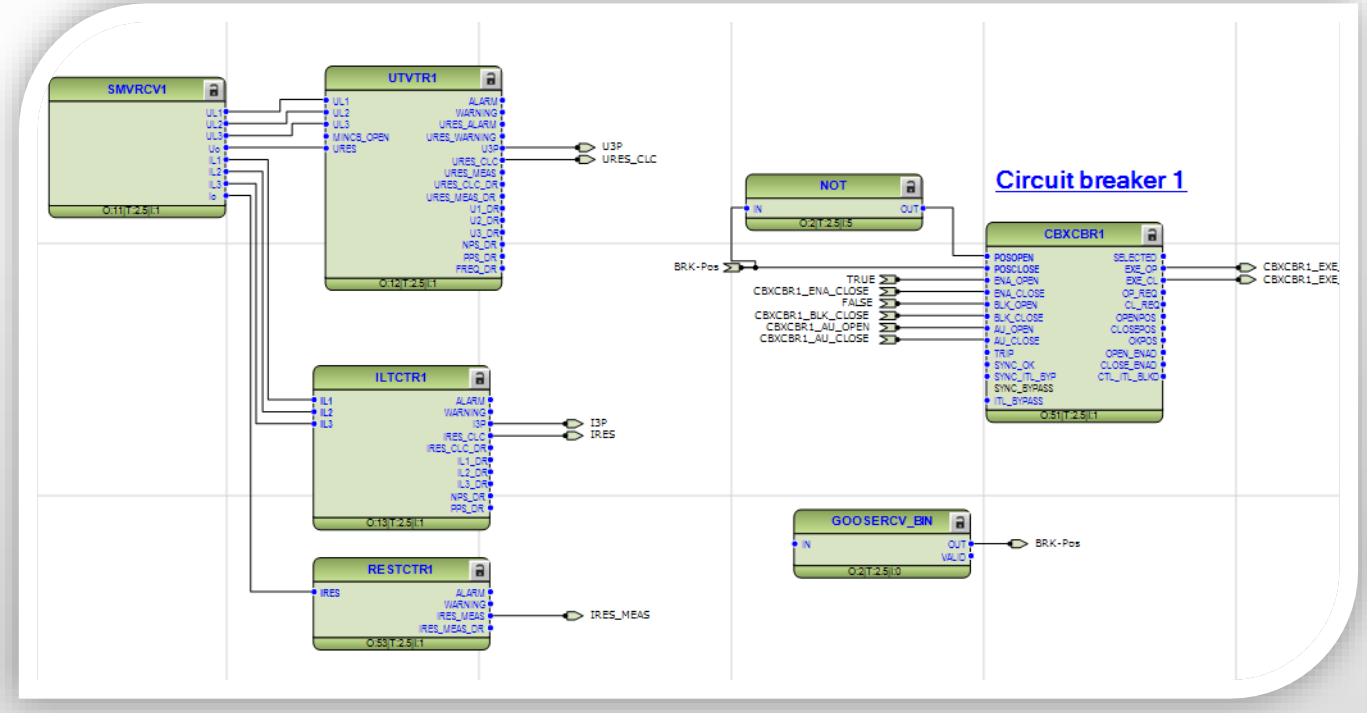
RTDS & RSCAD Setup



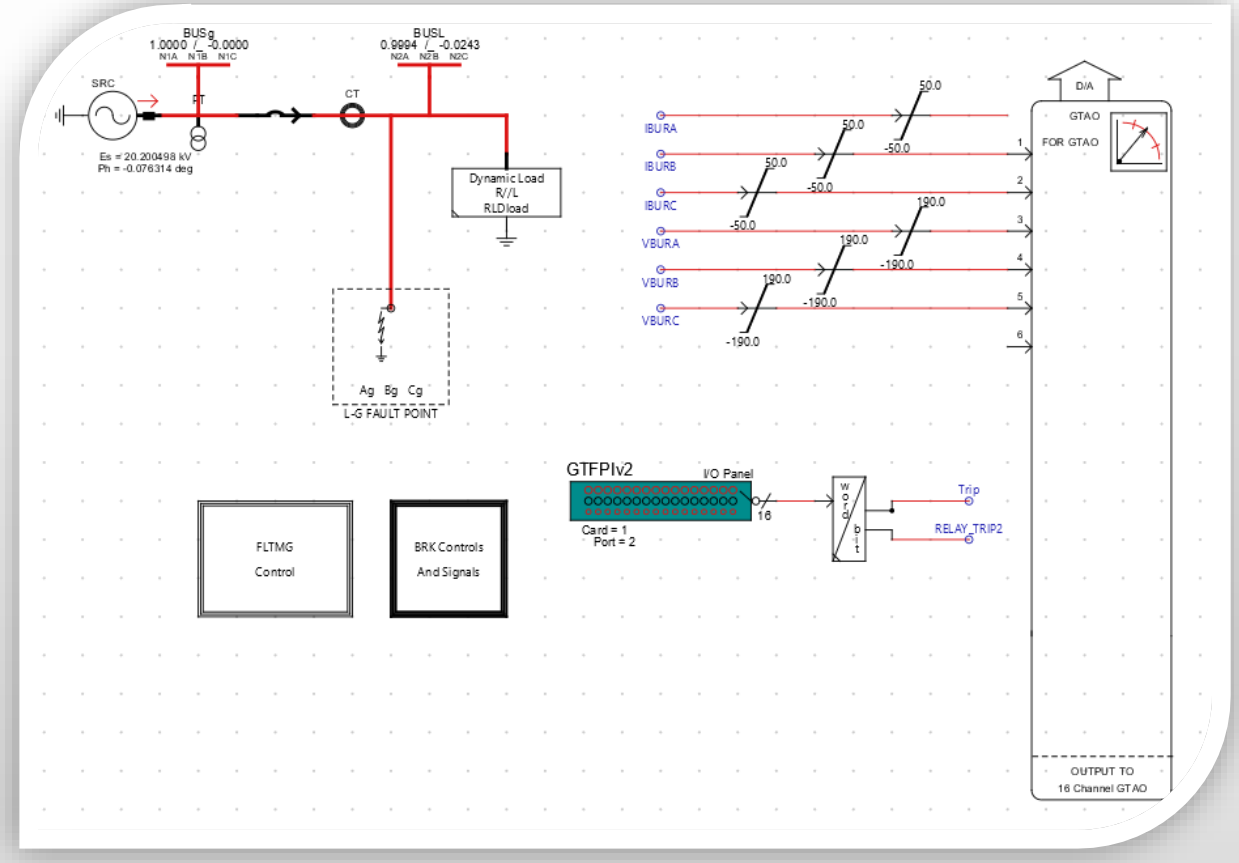
- SV stream built using RSCAD Sampled Values component.
- GOOSE messaging via ICT tool.
- Logical nodes (i.e. GGIO) configured for breaker control and trip logic.
- CID files exported and used in PCM600 and IET600 for interoperability.

IED Configuration – ABB REX640

- SV Receiver (SMVRCV1) receives the Voltage and current data from RTDS.
- GOOSE Receiver (GOOSEREC_BIN) receives Breaker position feedback.
- Trip logic implemented using TRPPTRC1, connected to CB function.
- Uses GOOSE message to trigger breaker trip in RSCAD.



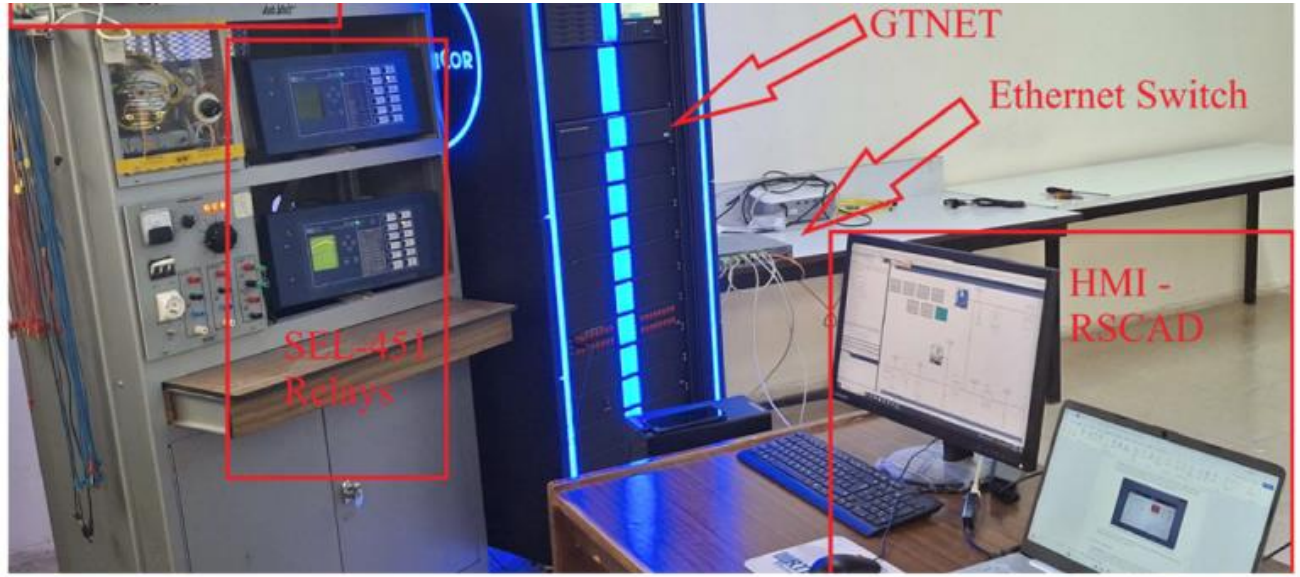
Analog-HIL Configuration



- GTAO card sends ±10 V analog signals to SEL-451.
- Relay sends binary trip back to RTDS via GTFPI.
- Requires careful scaling and calibration of voltage/current levels.
- Mutah lab lacked amplifiers; used low-voltage panel of SEL-451 directly, so the GTAO must give ±3 volts only.

Mutah university lab setup

- RTDS, RSCAD
- PCM600, IET600, ITT600.
- 2x ABB REX640 IEDs.
- 1x ABB REF615 IED.
- 2x SEL-451 Relays.
- DC power source for the REXs.



Unified Simulation Scenario

- 20 kV Source + Circuit Breaker + 2 MW Load.
- Both relays set to instantaneous overcurrent. Time delay: 0.
- Pickup: 200 A, CT ratio 200:1.
- Faults applied:

1-phase fault at 0°

3-phase fault at 0°

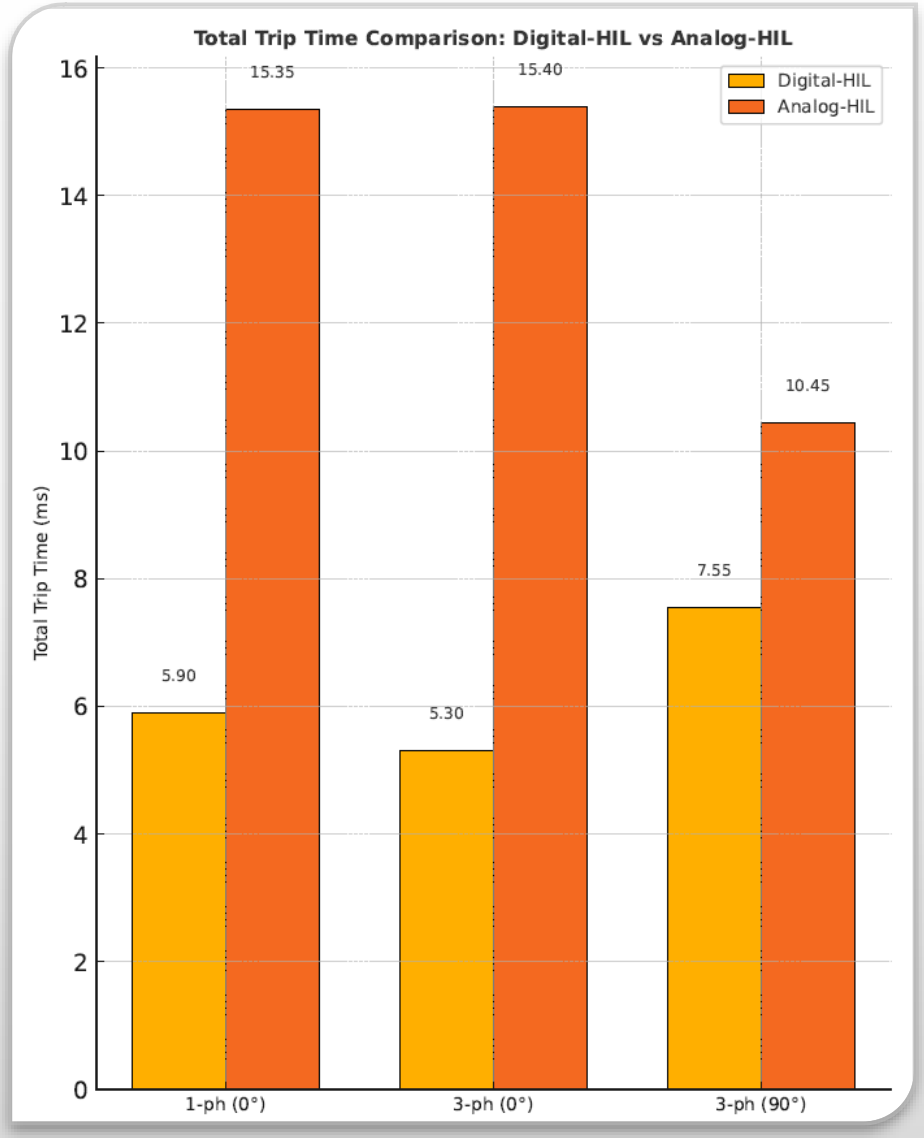
3-phase fault at 90°

Results

Digital-HIL	Analog-HIL
1-phase (0°): 5.9 ms	1-phase (0°): 15.35 ms
3-phase (0°): 5.3 ms	3-phase (0°): 15.40 ms
3-phase (90°): 7.55 ms	3-phase (90°): 10.45 ms

Comparative Analysis

- Digital-HIL outperforms Analog-HIL by up to 65.6%.
- Lower latency, fewer dependencies, higher accuracy.
- Analog-HIL requires amplifiers, scaling, and introduces risk.



Discussion

- Digital-HIL is ideal for real-time, flexible testing environments.
- Especially beneficial for low-inertia systems and DER-rich microgrids.
- Analog-HIL still useful for legacy systems, but gradual migration recommended.
- The full digital substation model offers education, training, and R&D value.

Conclusion

- RTDS enables accurate, real-time substation simulation.
- IEC 61850 Digital-HIL is faster, safer, and more scalable than Analog methods.
- The presented framework demonstrates a full HIL validation platform for academia and utilities.

Acknowledgments & References

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Thank You!

- Questions?

+962-796016265

+962-779939344

Omar.am@arabpotash.com

OmarA.Alamr@outlook.com

- Research interests:

1. Smart Grid applications
2. Microgrids protection and control
3. Real-time simulations and digital substation automation