Hardware-in-the-Loop Testing of a Completely Digital IEC 61850-Based Teleprotection Scheme Using the RTDS Simulator

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RTDS Applications and Technology Conference

May 16-19, 2017

Winnipeg, Canada

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PRESENTATION OUTLINE

- Background
- Objectives
- Methodology
- Experimental Results
- Conclusion
- Bibliography

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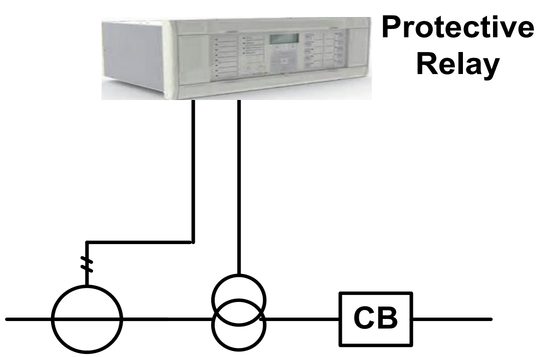
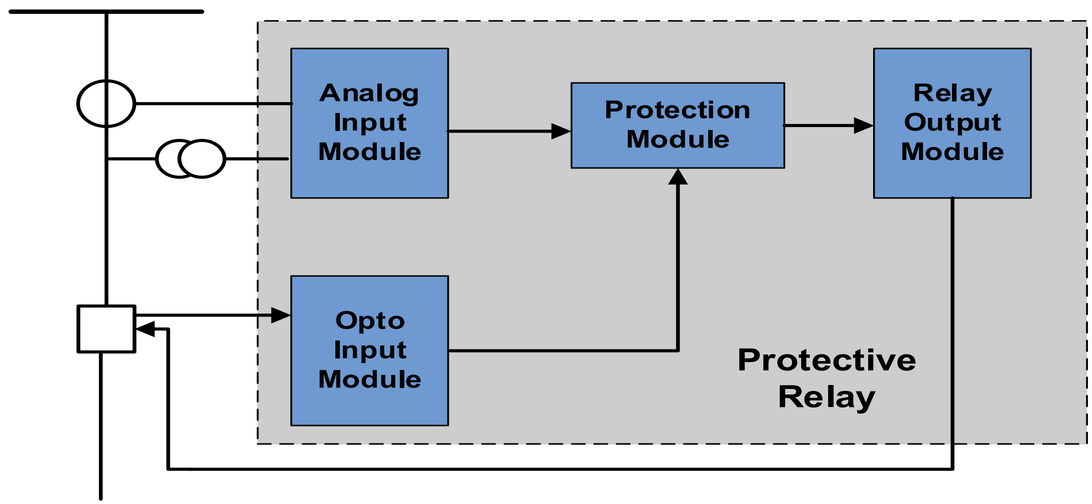
BACKGROUND

Protection in conventional power systems

- Analogue current and voltage inputs from CTs and VTs
- Analogue inputs protection relays
- Inter-wiring required



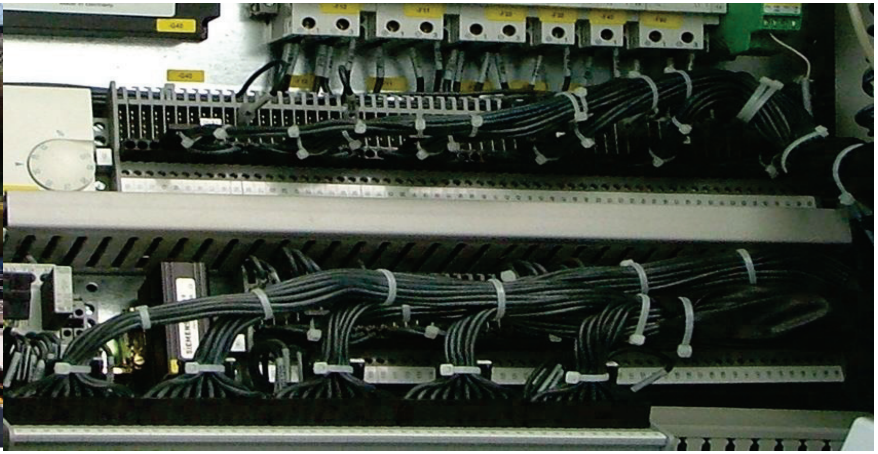
Traditional Hardwired Inputs



BACKGROUND

Shortcomings:

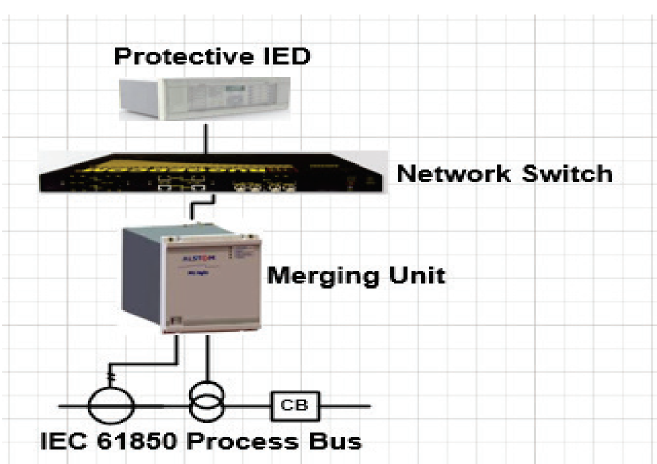
- Multiple cable runs between CTs/VTs and relays
- Inter-wiring amongst devices is required
- Multiple protocols are in use
- Interoperability between multi-vendor devices is difficult
- Expensive protocol converters required
- Lack of harmonization and standardization
- Reconfiguration and maintenance difficult

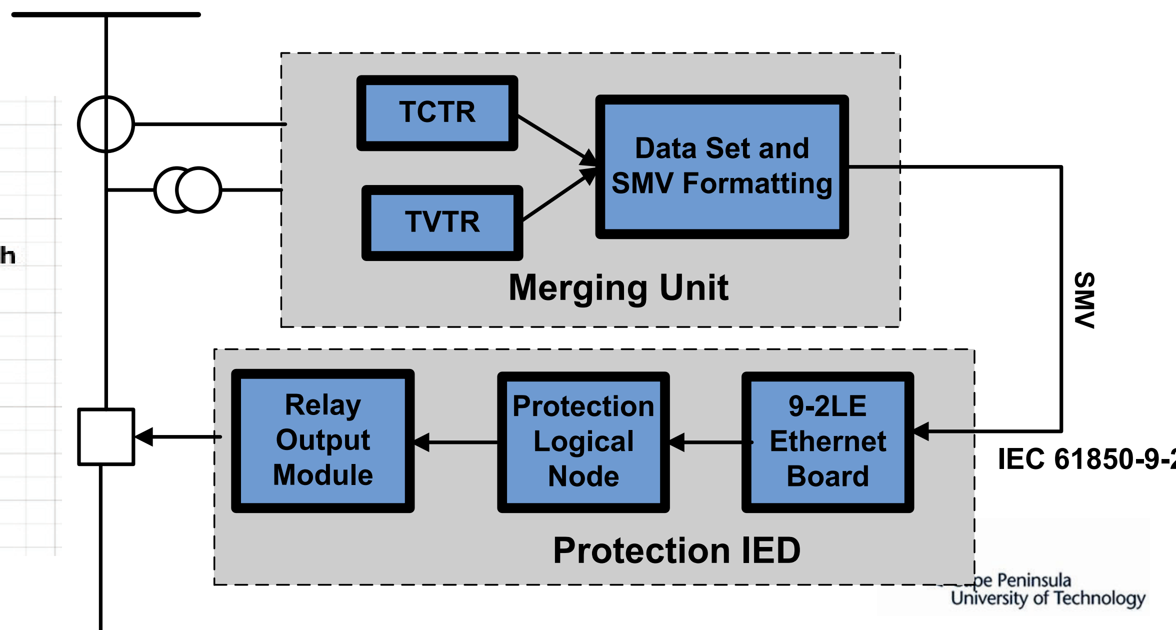


BACKGROUND

Protection in a completely digital power system

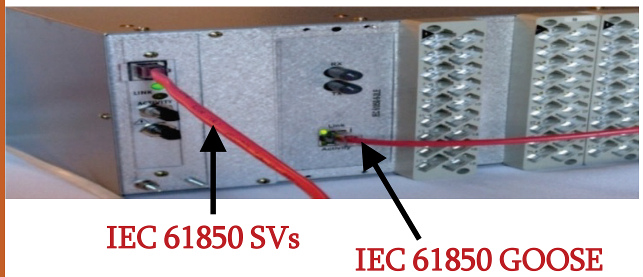
- Digitized current and voltage inputs from NCITs/Merging Units (MUs)
  - NCITs: Optical sensor loops/capacitive voltage dividers
  - MUs: LNs, merging of V & I datasets, and frame formatting
  - P/M: 80 samples/cyc., PQ: 256 samples/cyc. (IEC 61850-9-2LE)
- Protection relays with digital interface
- Communication-based link between the process/bay/station levels





BACKGROUND

- Digital substations
- Conventional substations



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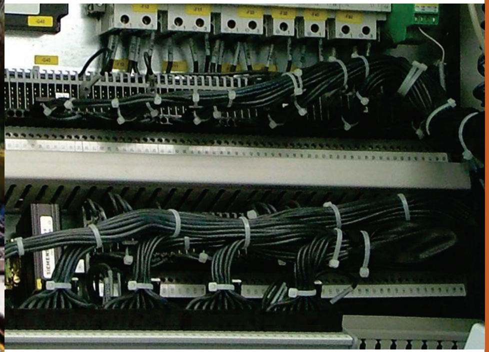

Advantages of IEC 618550-based digital substations:

- Allows for standardization & interoperability
- Less cabling required from CTs/VTs & between devices
- Lifecycle cost savings
- Less installation and outage time
- Increased safety
- Easy reconfiguration and maintenance

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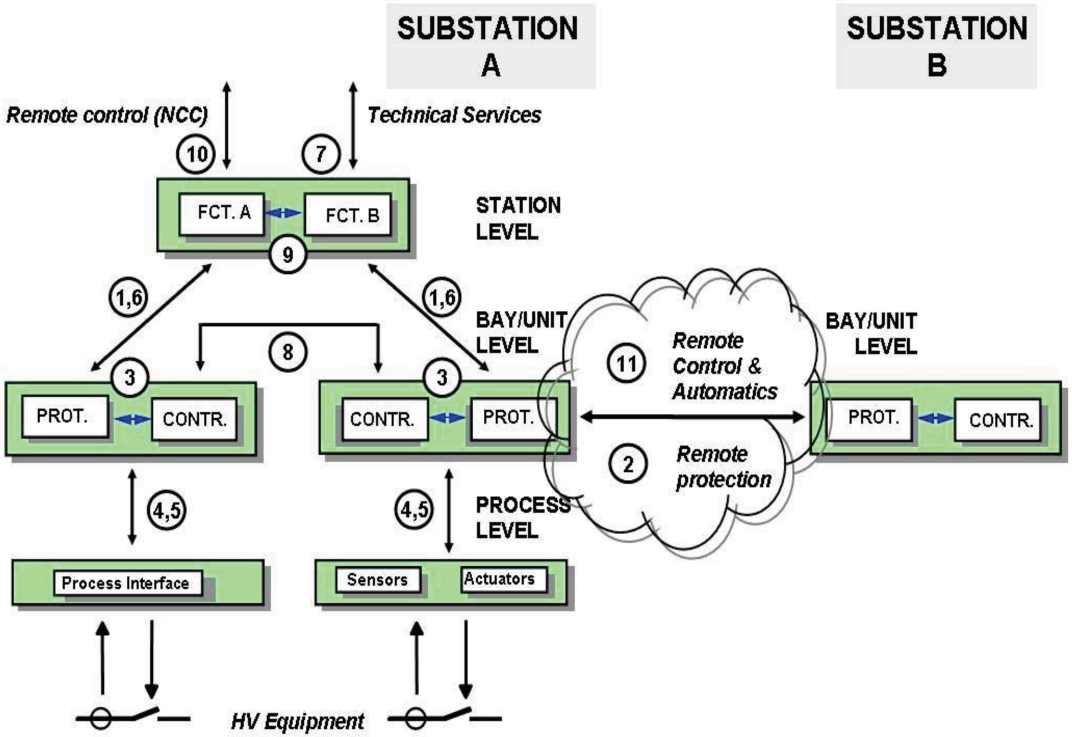
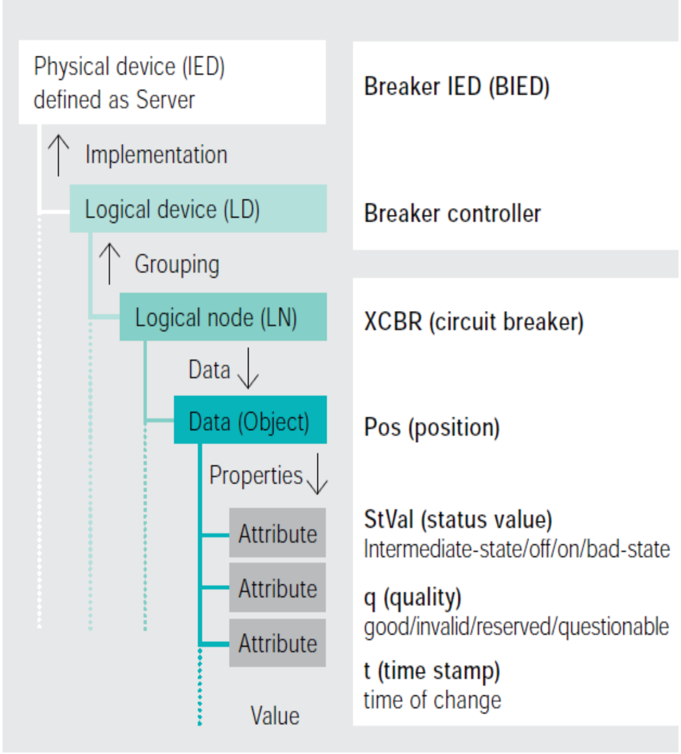
BACKGROUND

IEC 61850: Automation and control in power systems

- Object-oriented data modelling
  - Logical device| logical nodes| data objects| data attributes
- Substation configuration language (SCL)



Substation automation logical interfaces and levels



Hierarchical data model

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BACKGROUND

Features of tele-protection schemes

- Substation-to-Substation (SS-SS) exchange of information by relays
- High-speed simultaneous fault clearing compared to time-stepped distance protection

Benefits of tele-protection schemes

- Improves system stability (power transfer) of healthy lines
- Reduces voltage sag duration
- Reduces damage to insulators/through-fault duty time on transformers
- Permits quicker reclosing

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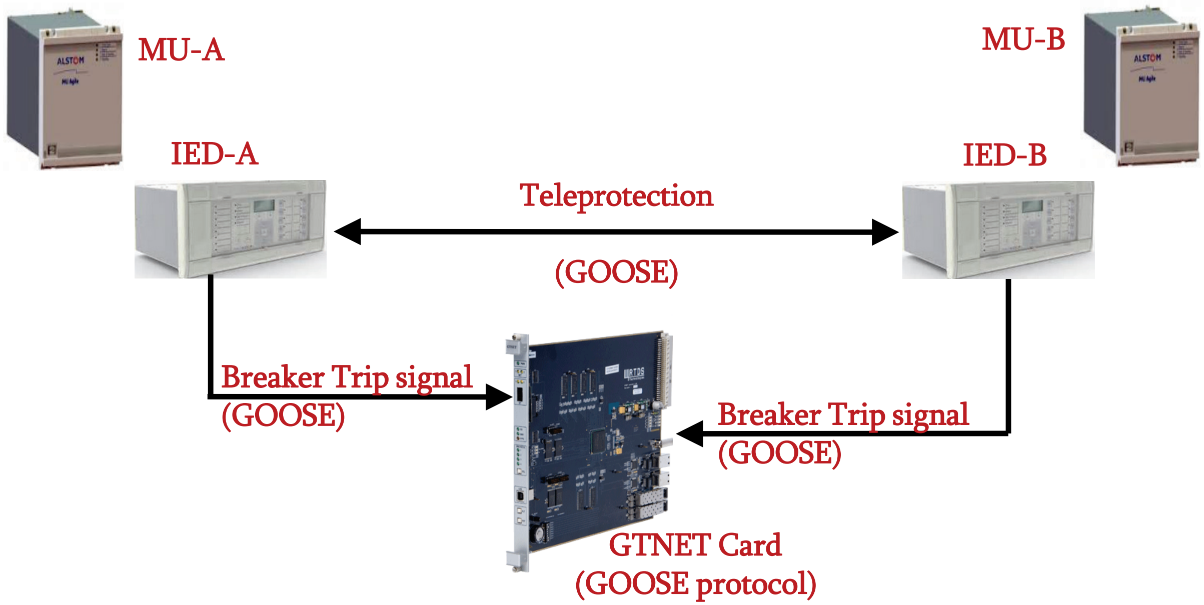
OBJECTIVES

Teleprotection (POTT) Scheme Logic



Pictorial layout of the objective

- Use IEC 61850-9-2LE inputs
- Use an over-reaching Zone-2 distance element
- Send a key (POTT TX) via GOOSE to the remote end
- Transfer trip is supervised by the over-reaching (Zone-2) element of the remote end
- Issue breaker trip signals using IEC 61850-8-1 GOOSE messages

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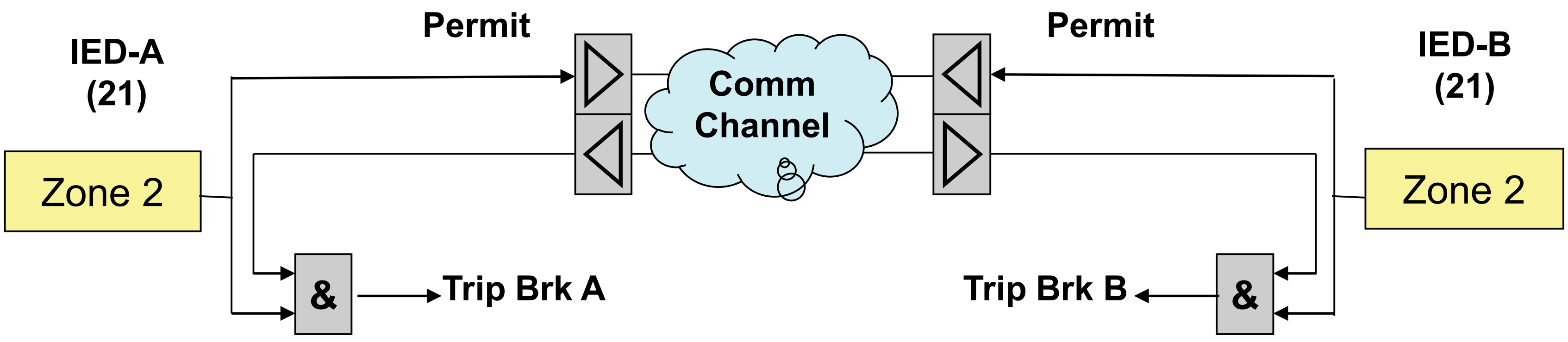
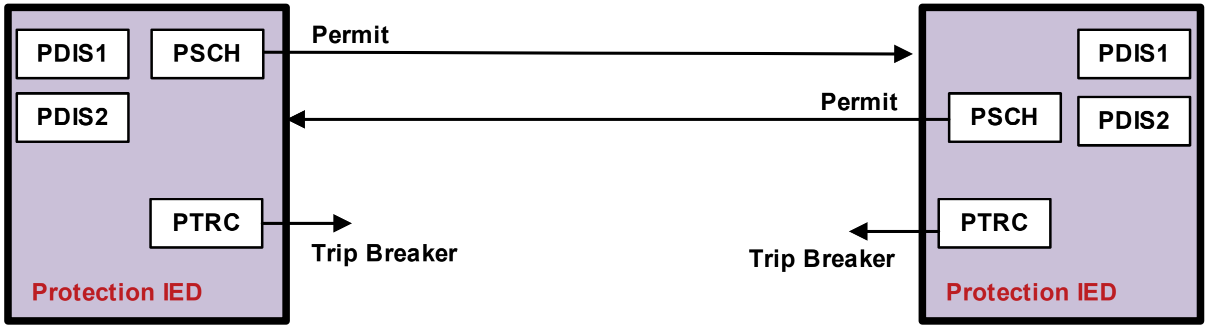
OBJECTIVES

Teleprotection (POTT) Scheme Logic



POTT scheme logic



POTT scheme logic using IEC 61850 logical nodes

OBJECTIVES

Objectives

- **Conformance testing**

- **Performance testing**
  - Testing of the MU measurement (accuracy) function
  - Testing of the protection function (speed, dependability, security)

- **Interoperability testing**

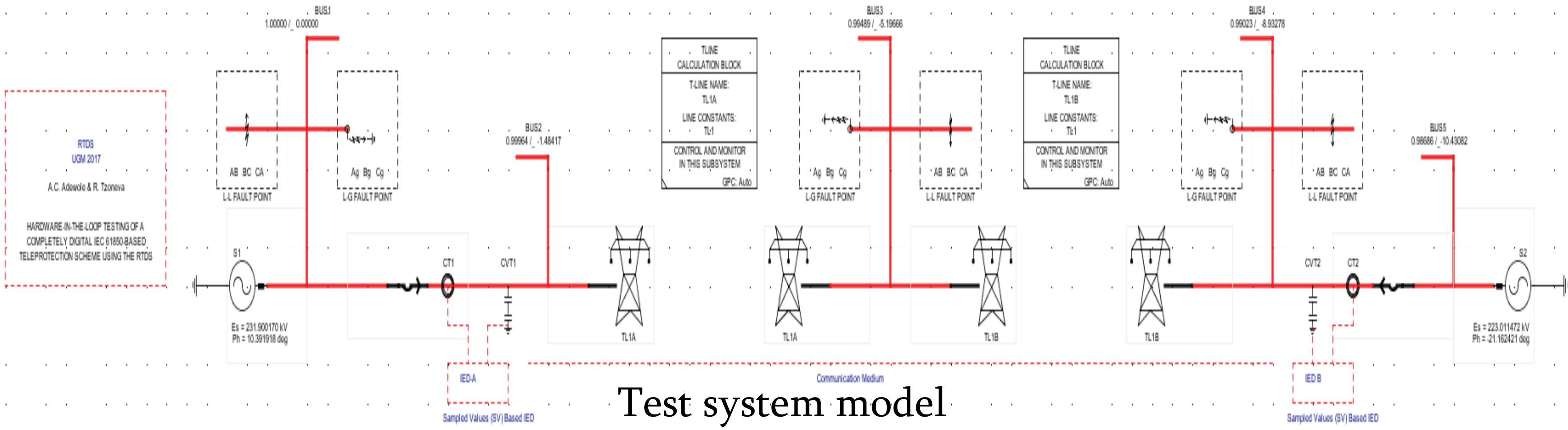
- **Interchangeability testing**

METHODOLOGY

- Test system modelling in RSCAD
- Three case study setups using industrial-grade hardware
- System engineering process
- Hardware-in-the-loop simulations using the RTDS

METHODOLOGY

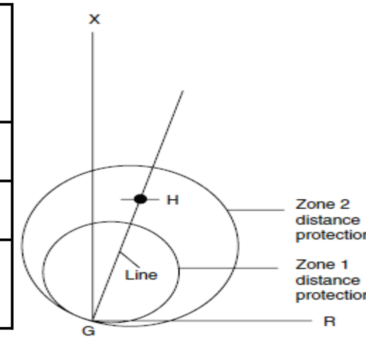
Test System Modelling



Test system model

Protection zones and zone times

Protection Zones	Zone Phase and Ground Reach Settings	Time Delay /(ms)
Zone-1 (forward)	80% of Line-1	0
Zone-2 (forward)	(Line-1 impedance) + 20% Line- 2 impedance	200
Zone-3 (reverse)	20% of Line-1	400



Simulation parameters

Fault Location /(%)	20, 40, 60, 75, 115 (forward), 20 (reverse)
Fault Resistance /(Ω)	0.1, 1.0, 5.0, 10.0
Fault Type	Phase-to-Ground (A-G), Phase-to-Phase (AB) and Three Phase (3 Ph.)

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METHODOLOGY

Testbed setup for 3 case studies

- RTDS

- Two merging units from the same vendor
  - Same model used

- Two IEDs from the same vendor
  - Same model used
  - Distance protection function (Mho characteristics)
  - Zones 1-3 elements (forward and reverse directionality)

- Communication network switches

- GPS satellite clock

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METHODOLOGY

Testbed at CSAEMS-CPUT

Implemented testbed for hardware-in-the-loop simulations

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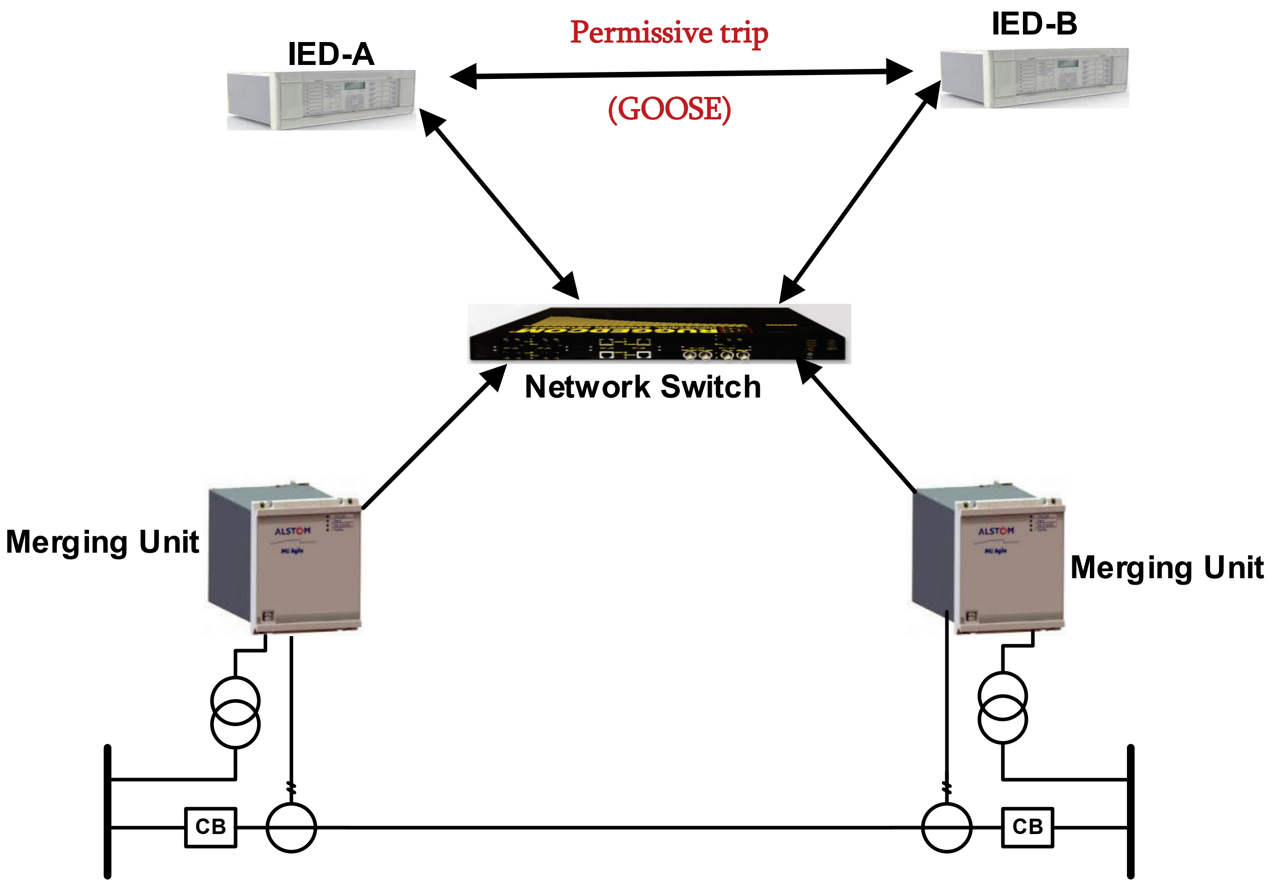
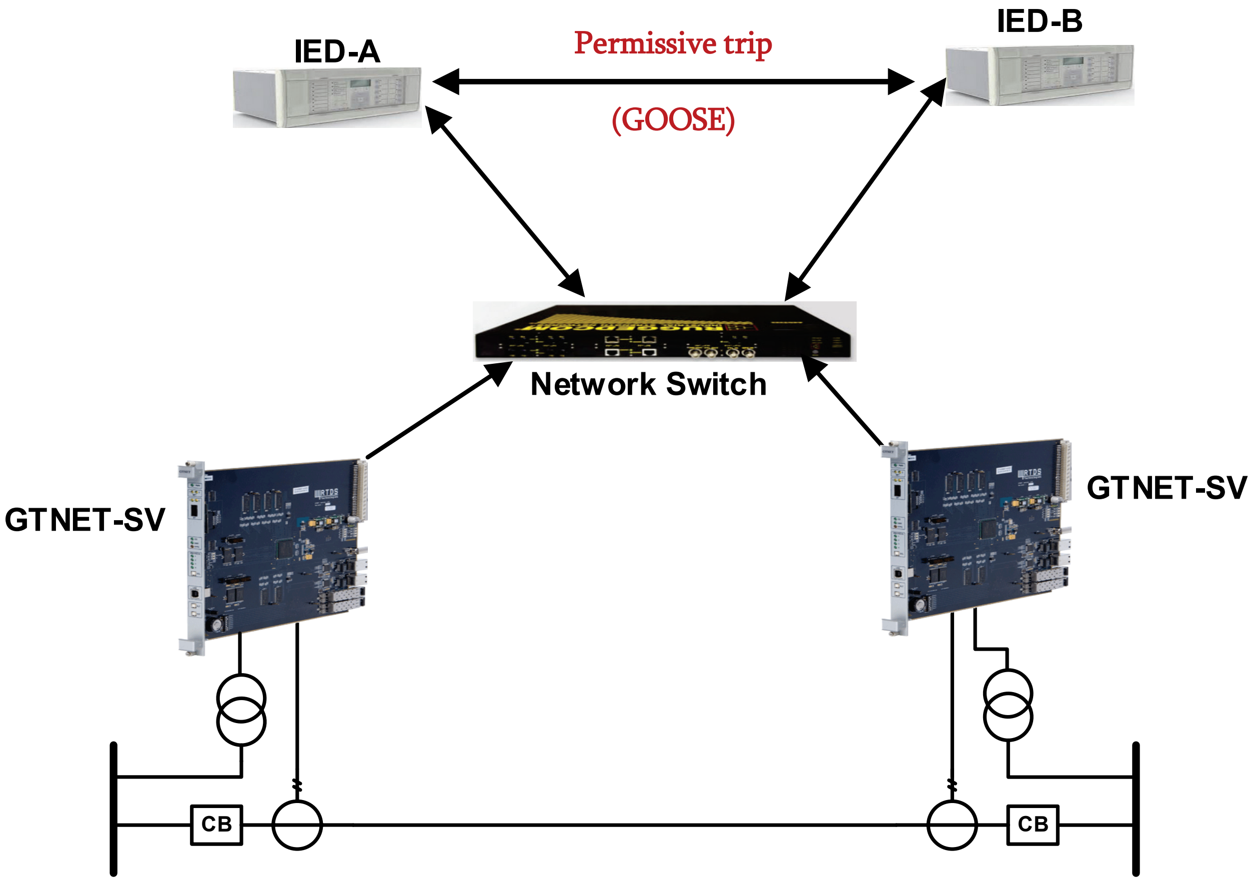
METHODOLOGY

Case Study-1



METHODOLOGY

Case Study-2



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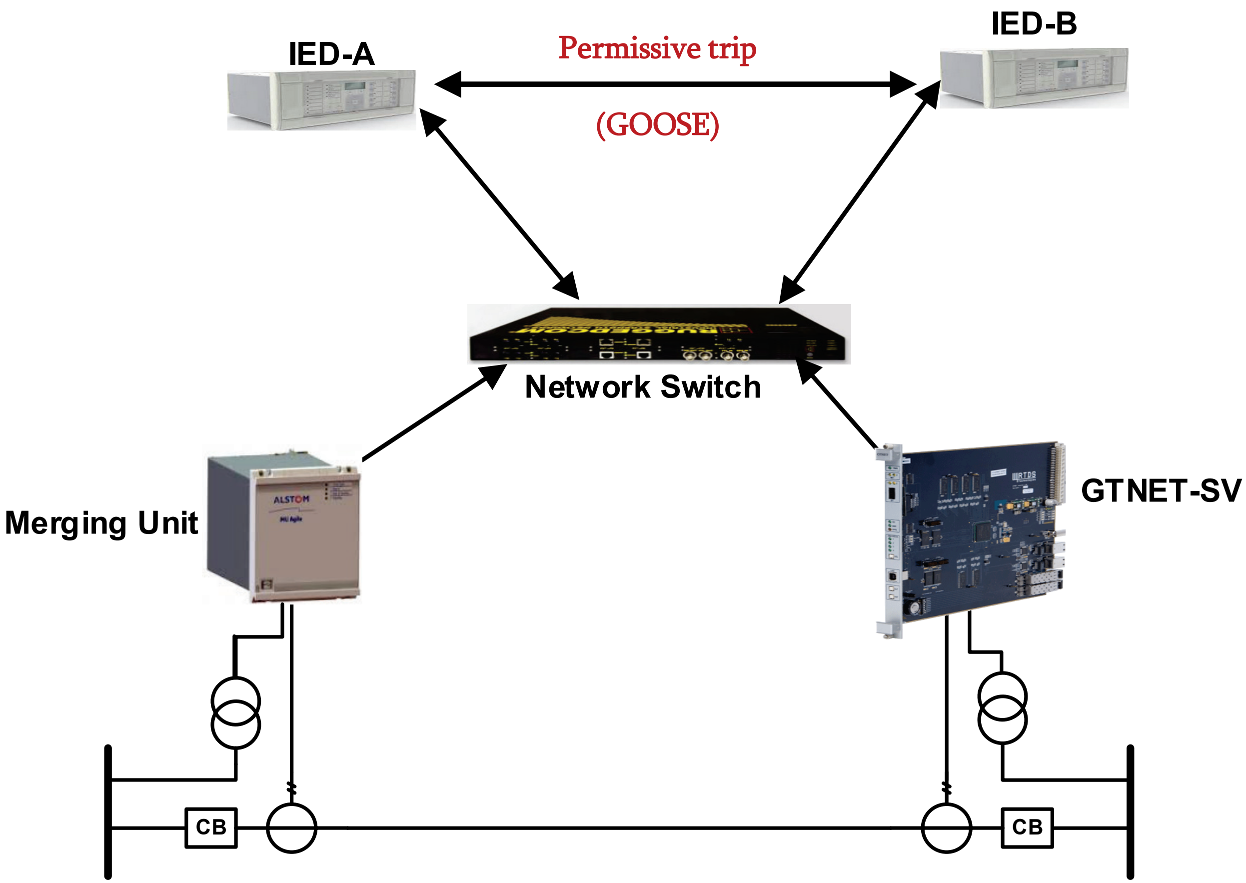
METHODOLOGY

Case Study-3



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RESULTS

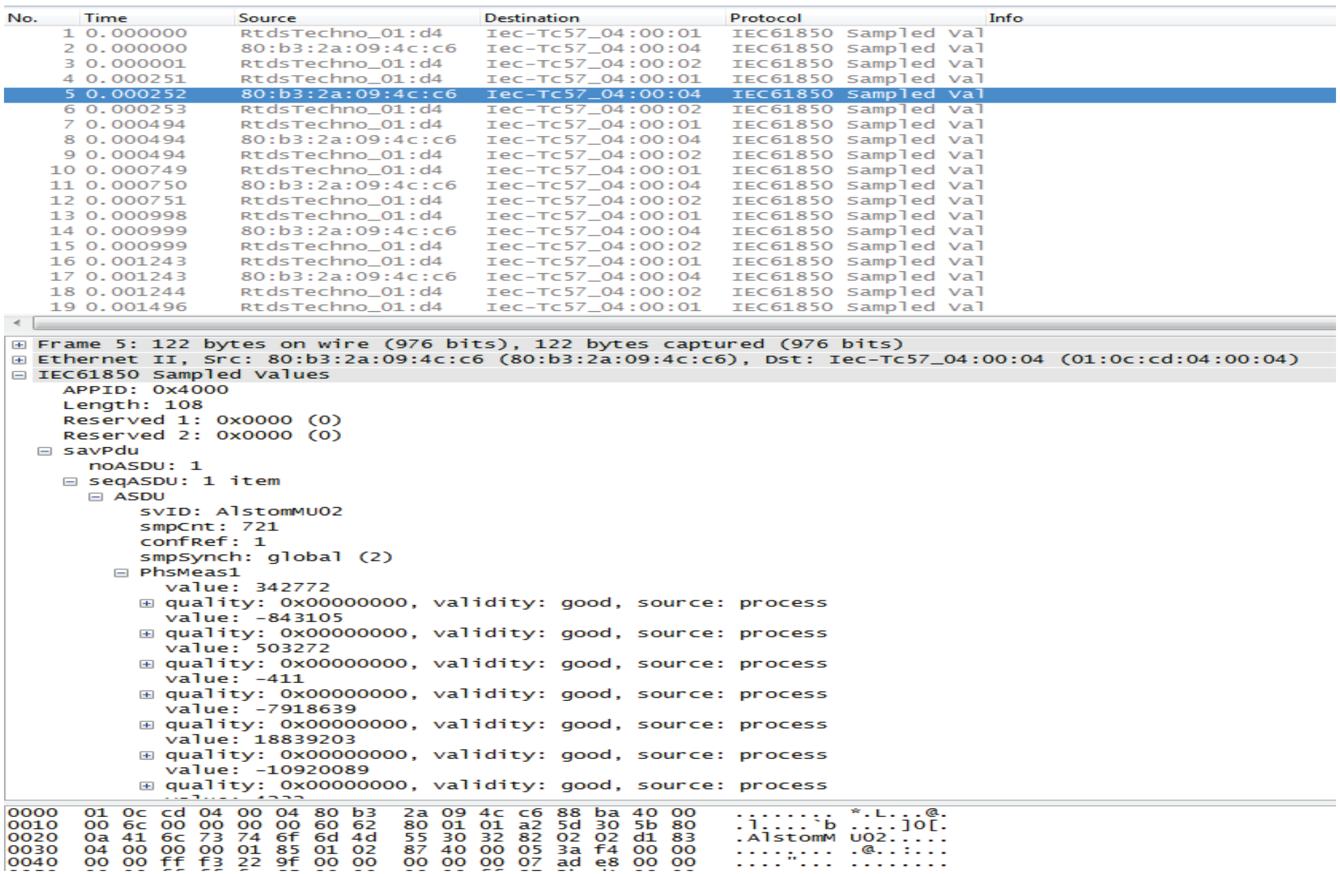
Measurement accuracy

Line currents: Maximum relative error

- Sampled Values from MU: 0.13% | GTNET-SV: 0.067%

Voltages:

- Sampled Values from MU: 0.81% | GTNET-SV: 0.021%



Sample values capture using Wireshark network analyzer

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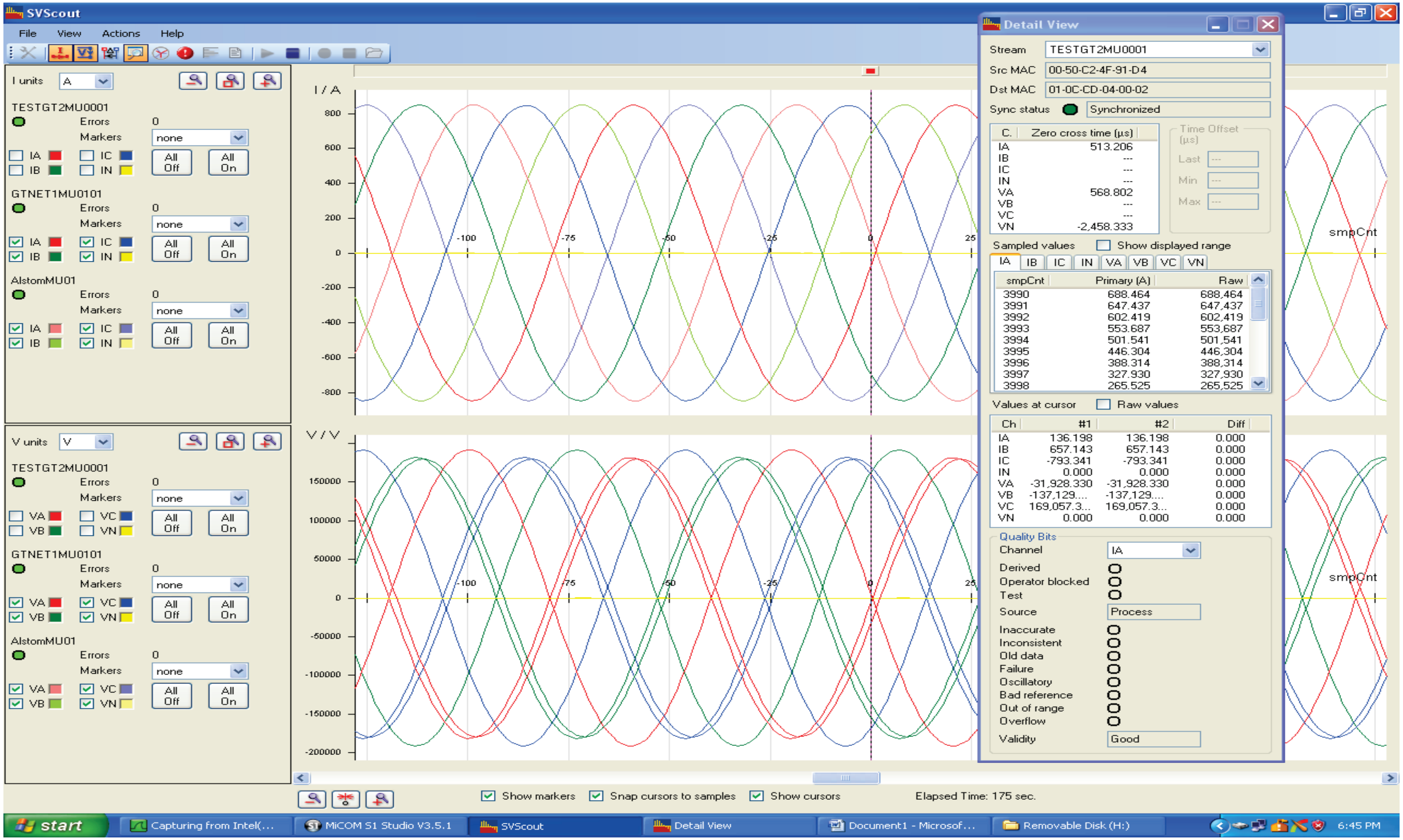
RESULTS

Measurement Analysis: MU with GTNET-SV as reference



SV capture using SVScout

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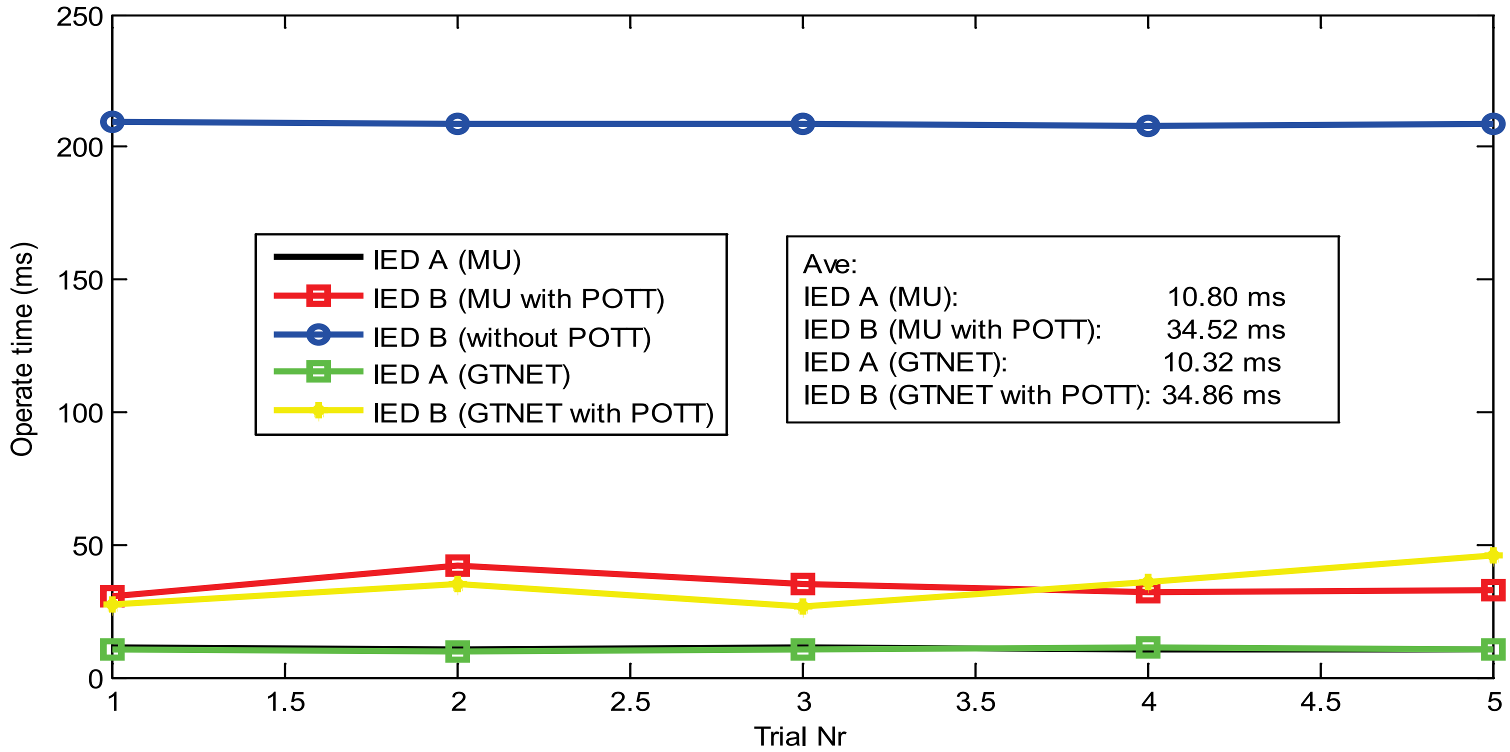
RESULTS

IEC 61850-GOOSE Based POTT using SVs from 2 MiCOM & 2 RTDS GTNET MUs (A-G Fault)

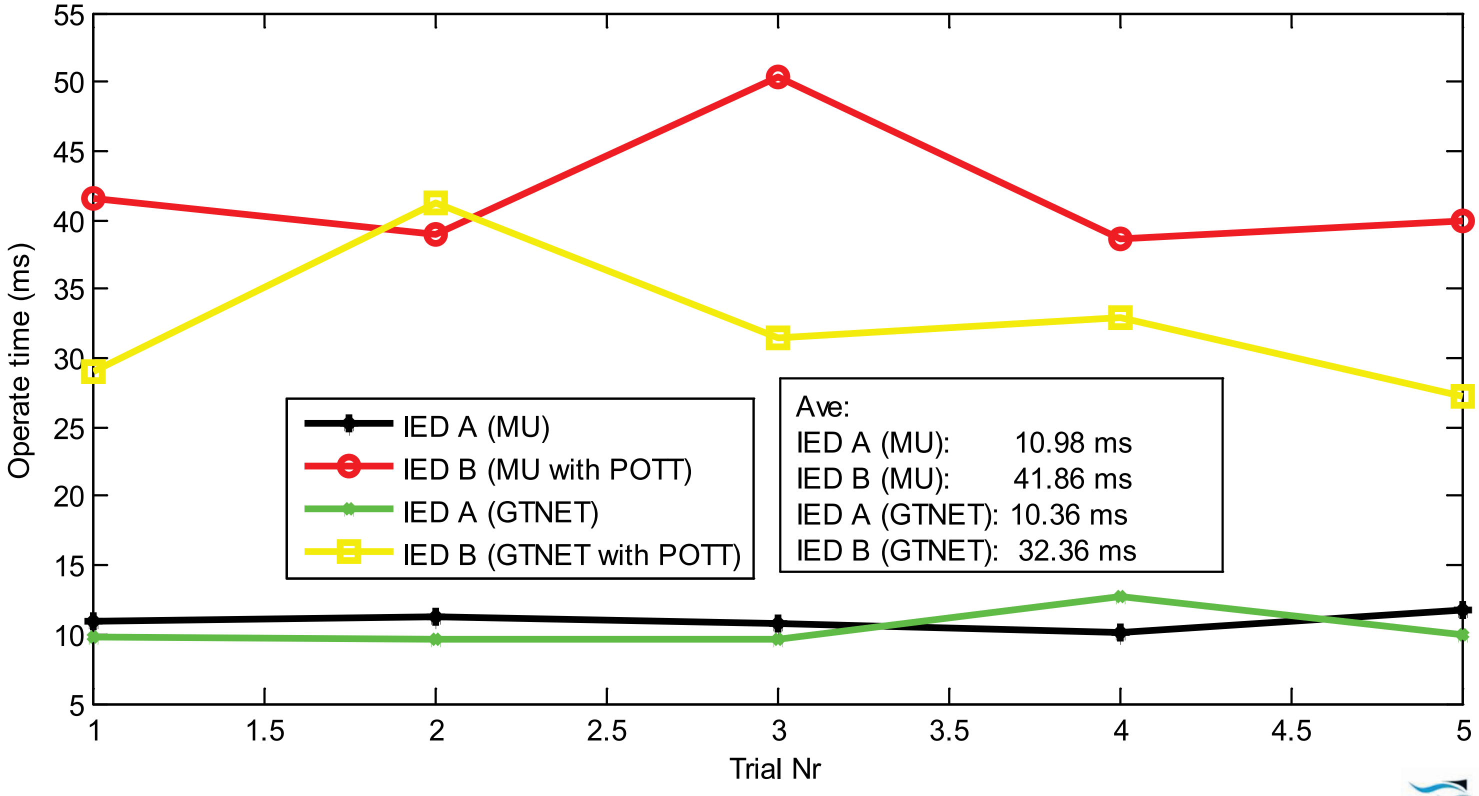
- Relay Operate Time: Time from fault inception to when a trip signal was issued



Trip time for IEC 61850-based POTT

RESULTS

IEC 61850-GOOSE Based POTT using SVs from 2 MiCOM & 2 RTDS GTNET MUs (3 Phase fault)



Trip time for IEC 61850-based POTT

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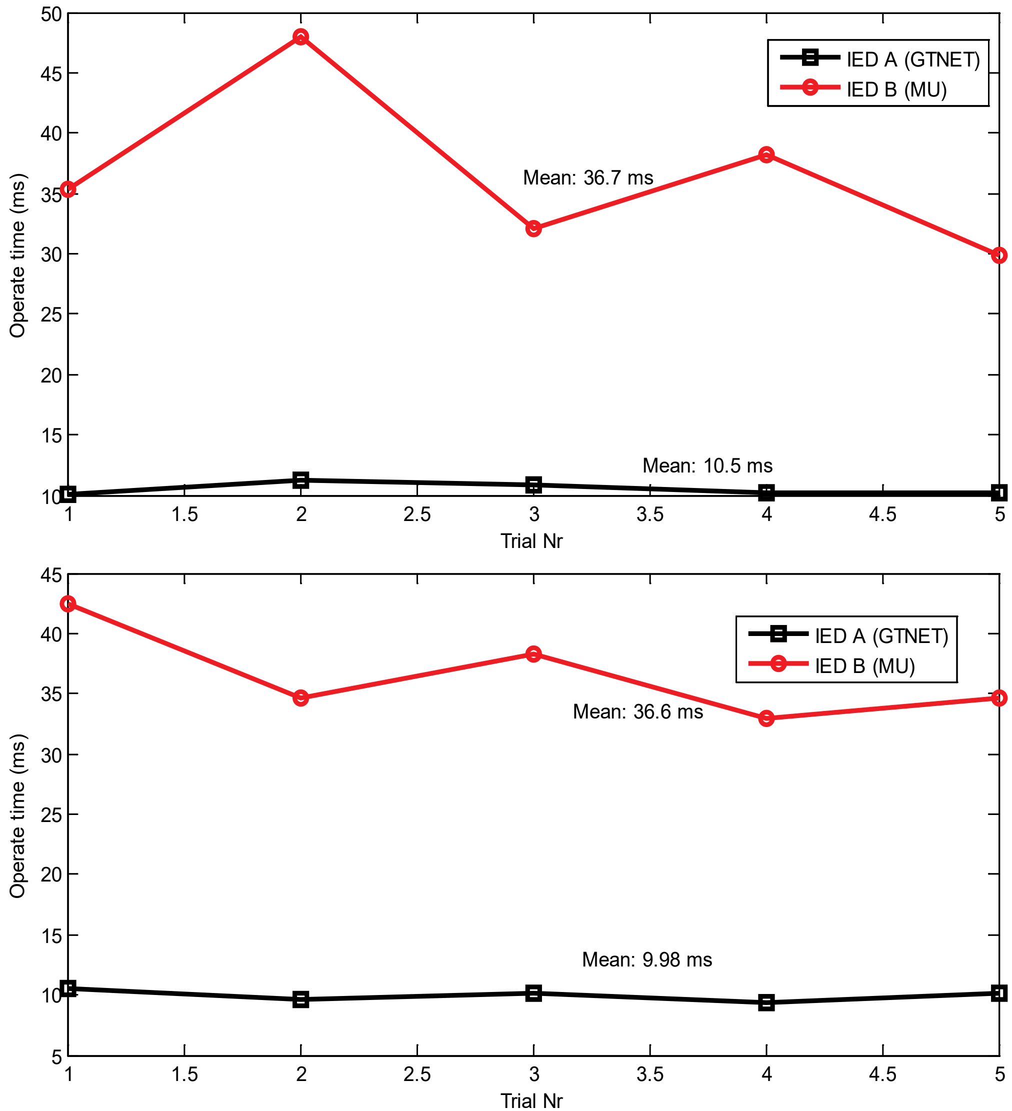
RESULTS

Interchangeability

GOOSE Based POTT using SVs from 1 MiCOM & 1 RTDS GTNET MUs



Trip time for IEC 61850-based POTT (A-G & 3 ph faults)

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CONCLUSION

- Validation of product and system functionality
- Conformance testing
- Functional testing:
  - IED measurement accuracy
  - Speed
  - Security
  - Dependability tests carried out
- IEC 61850 interoperability testing
- IEC 61850 interchangeability testing

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Thank you

Questions?

Bibliography

- Adewole, A.C., Tzoneva, R. (2014). Impact of IEC 61850-9-2 Standard-Based Process Bus on the Operating Performance of Protection IEDS: Comparative Study. 19th IFAC World Congress (IFAC WC 2014), Cape Town, South Africa, August 24-29, 2014, pp. 2245-2252.
- Arnold, T., Adewole, A.C., Tzoneva, R. (2015) Performance Testing and Assessment of Multi-Vendor Protection Schemes Using Proprietary Protocols and the IEC 61850 Standard. Industrial and Commercial Use of Electricity (ICUE) Conference, 17-19 August 2015, Cape Town, South Africa, pp. 284-290.