IBR Protection Challenges

Framework & Case Studies

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Conference Presentation | Hydro-Quebec, Varennes

Agenda & Framework

1. **DFIG Transformer Inrush**
   CS1
2. **Adaptive Auto-Reclosing**
   CS2
3. **DC Microgrid OC Protection**
   CS3

- Limited SCC
- Bidirectional Flow
- Harmonic Interf.
- Simulated Inertia
- Comm. Dependency
- Storage Dynamics
- Async. Reclosing
- Sympathetic Trip
- Dynamic Imped.

CS1: DFIG System & Harmonic Problem

DFIG Wind Turbine

Collector Transformer (CTr)

FRT Control Options

No FRT | Crowbar | Chopper

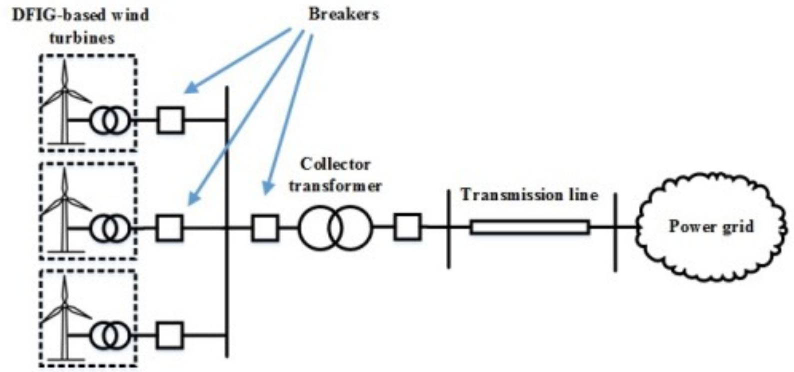


Fig. 1. Overview of a wind farm connected to the power grid.

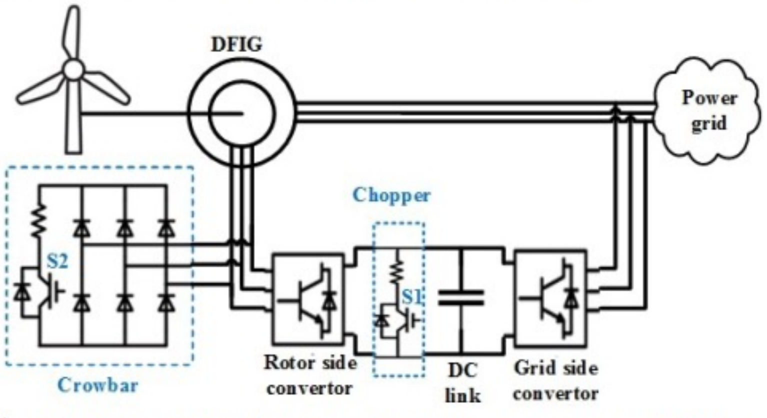


Fig. 2. DFIG-based wind turbine with converter and convertor protections.

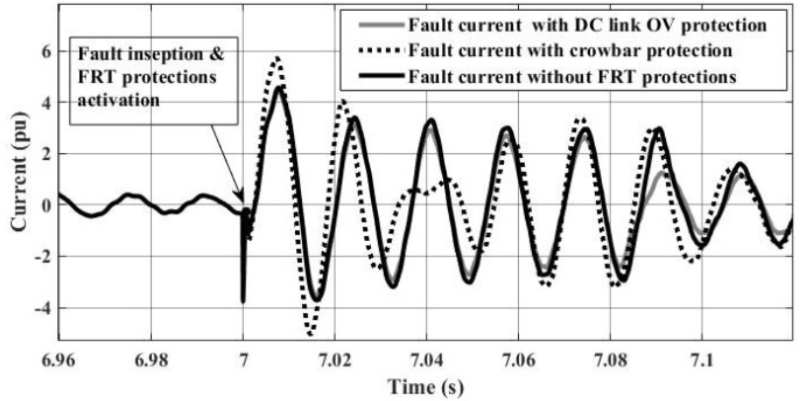


Fig. 5. The CTr internal single-phase short circuit with/without FRT schemes.

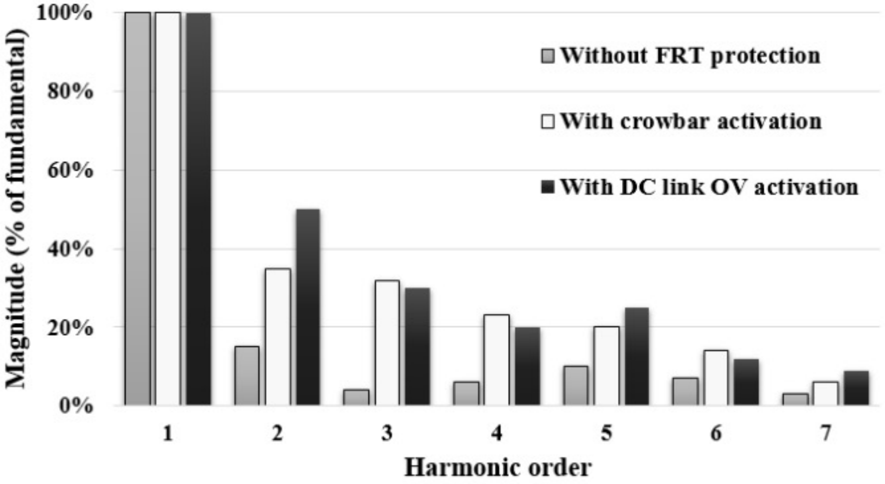


Fig. 6. The CTr internal single-phase short circuit harmonic content.

2nd Harmonic **> 20%** → False Blocking

The Conflict

Internal Fault + **FRT Active** → **High 2nd Harmonic** → **Relay FALSELY BLOCKS**

CS1: Solution (HPS) & HIL Validation

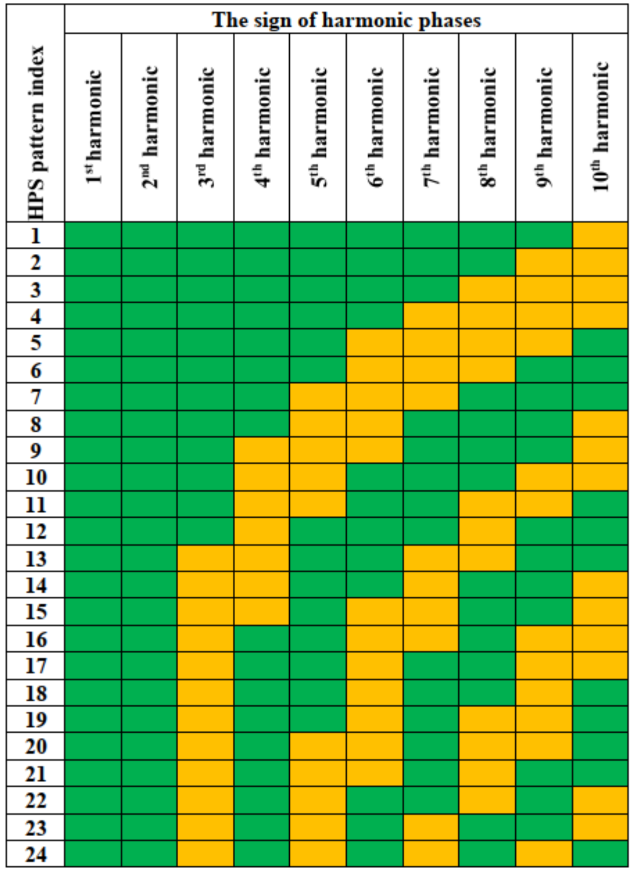
HPS Solution
Harmonic Phase Signs Logic

Analyze Phase Signs (+/-) Harmonics 1-10

Inrush Pattern H1+, H2-

Fault+FRT Pattern Different Signs

The sign of the 1st to 10th harmonic phases (orange for negative and green for positive signs)



Why HIL?

Real-time Constraints
Validate half-cycle execution on F28379D

Interface Testing
Test ADC/DAC channels

Fidelity
Numerical stiffness of FRT/Crowbar switching

Experimental Setup

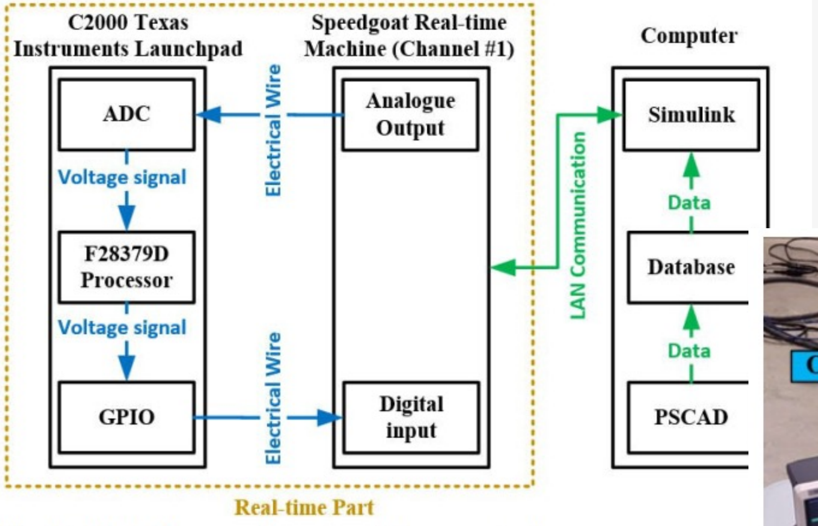


Fig. 18. Block diagram of experimental communication.

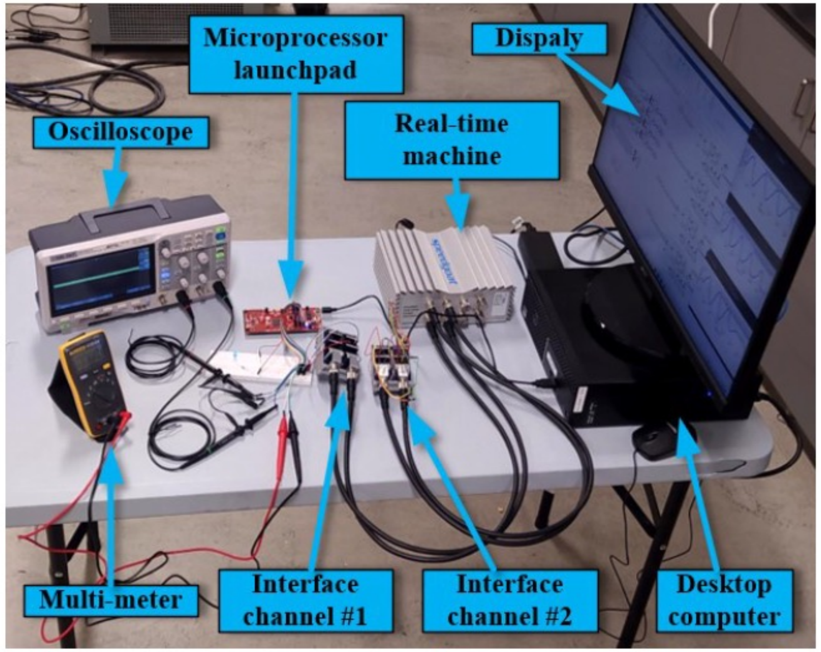


Fig. 19. photograph of setup configuration.

CS1: Experimental Results

Inrush Waveform

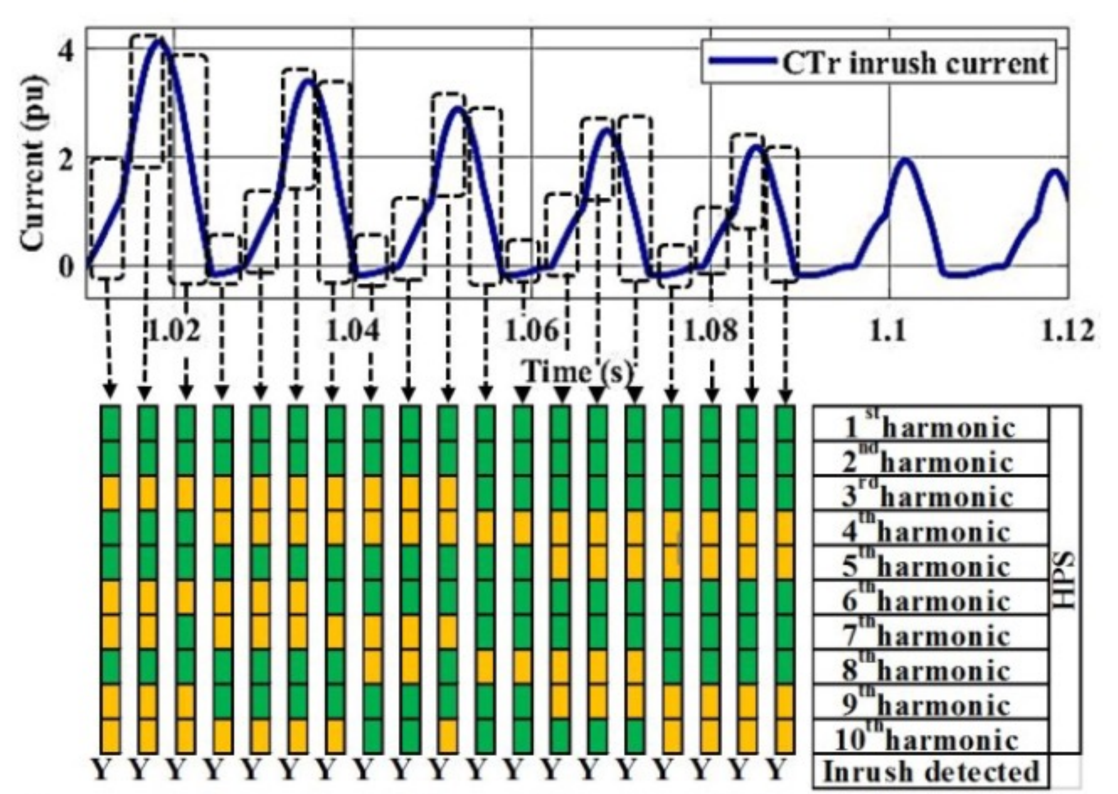


Fig. 13. Inrush current waveform and its HPS calculated.

Fault + Crowbar

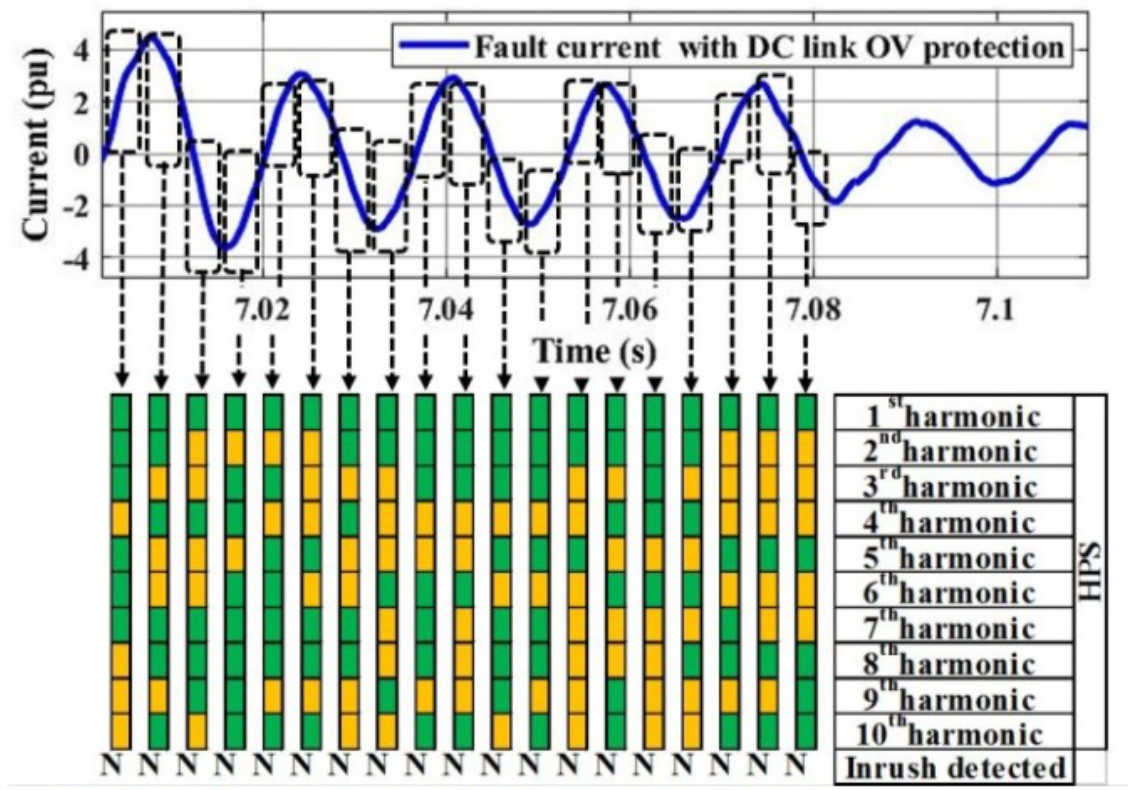


Fig. 16. Fault current and calculated HPS for DC-link OV activation.

Conclusion

HPS method successfully distinguishes fault from inrush even with FRT harmonic interference

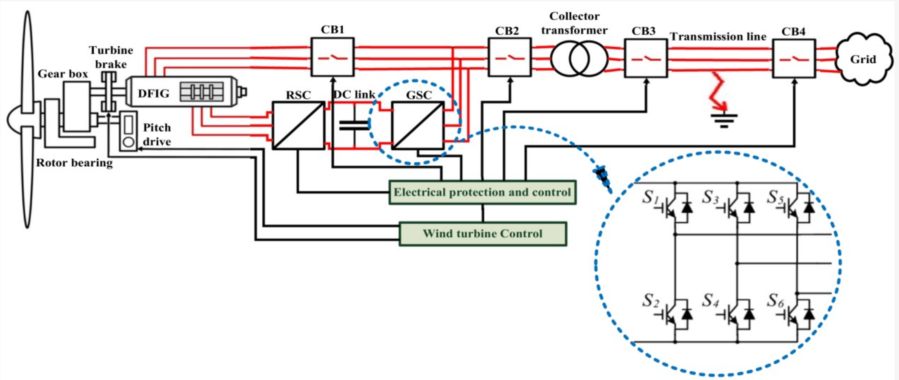
CS2: Wind Farm Auto-Reclosing Problem

System Configuration

Grid-Connected DFIG Wind Turbine

DC-Link Capacitor Energy Source for Pulses

GSC Switching Capability



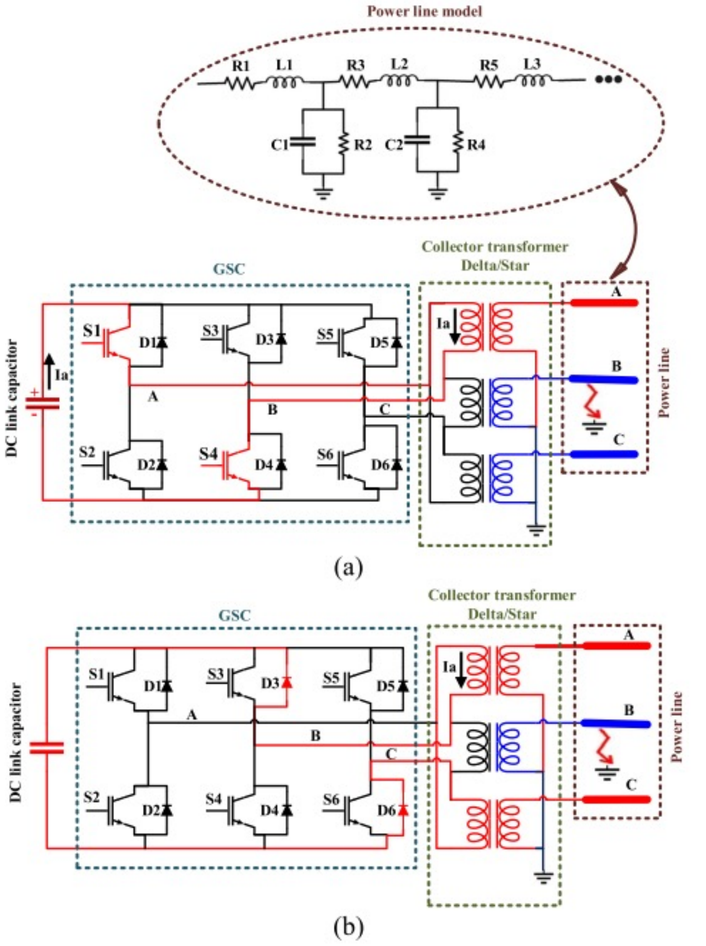


Fig. 4. The GSC switching in indirect pulse application for (a) discharge intervals and (b) charge intervals.

Problem 1: Long Dead Time

Dead Time

6s

Causes Turbine Speed Drop

Mechanical stress & stability issues

Problem 2: Blind Reclosing

No Fault Status Info → **Reclosing on Permanent Fault**

CS2: Solution - Adaptive AR Logic

GSC Switching & Diagnostic Pulse

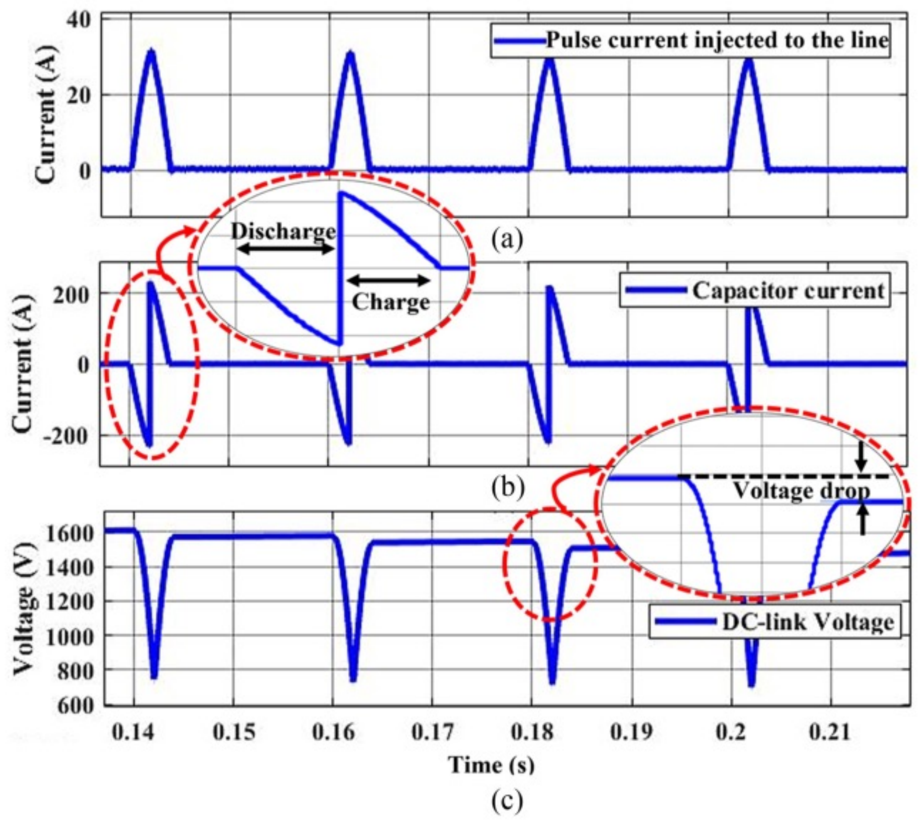


Fig. 8. Pulse waveforms generated by the proposed AR (a) the pulse current injected into the power line, (b) the current flow through the DC-link capacitor, and (c) the DC-link capacitor voltage.

Decision Logic

Correlation Threshold

$r \geq 0.9$

RECLOSE Fault Cleared

HOLD Fault Persistent

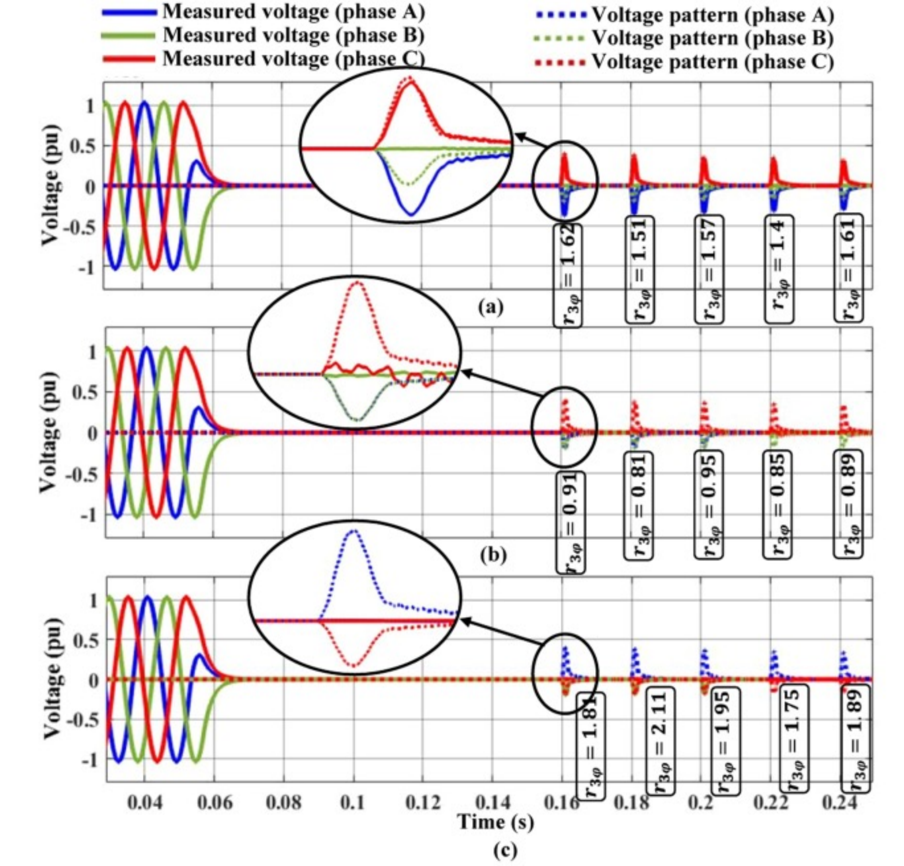
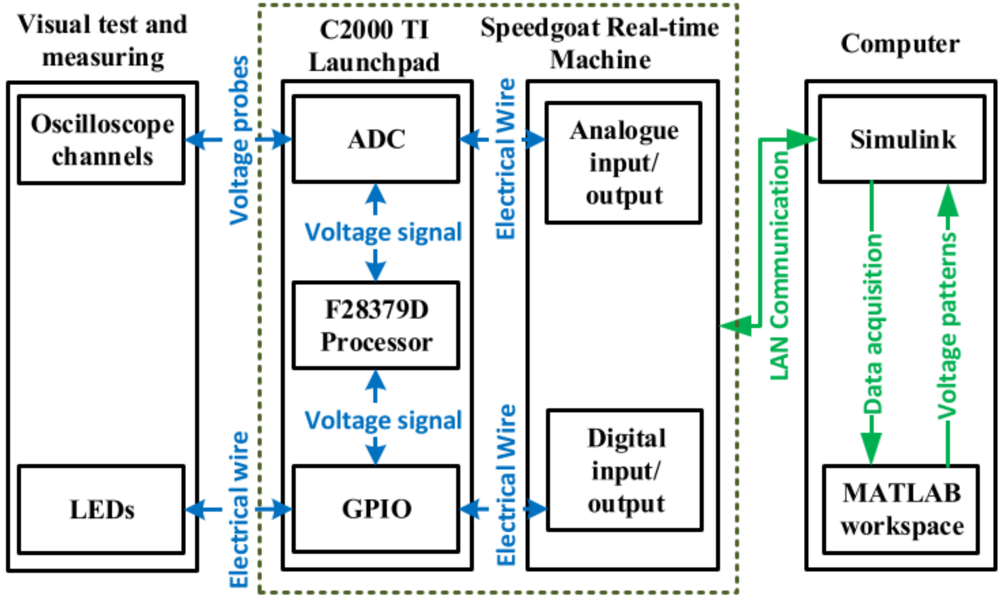
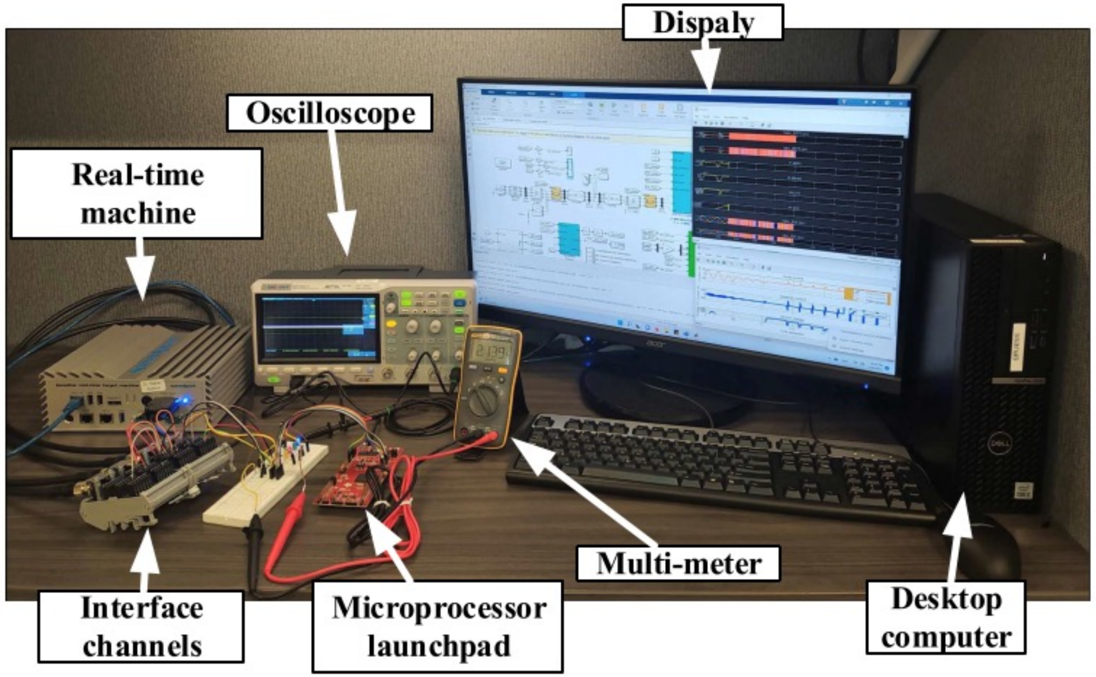


Fig. 9. Adaptive AR process during permanent faults (a) AG fault, (b) AB fault, and (c) ABC fault.

CS2: HIL Testbed & Experimental Results





Experimental Results

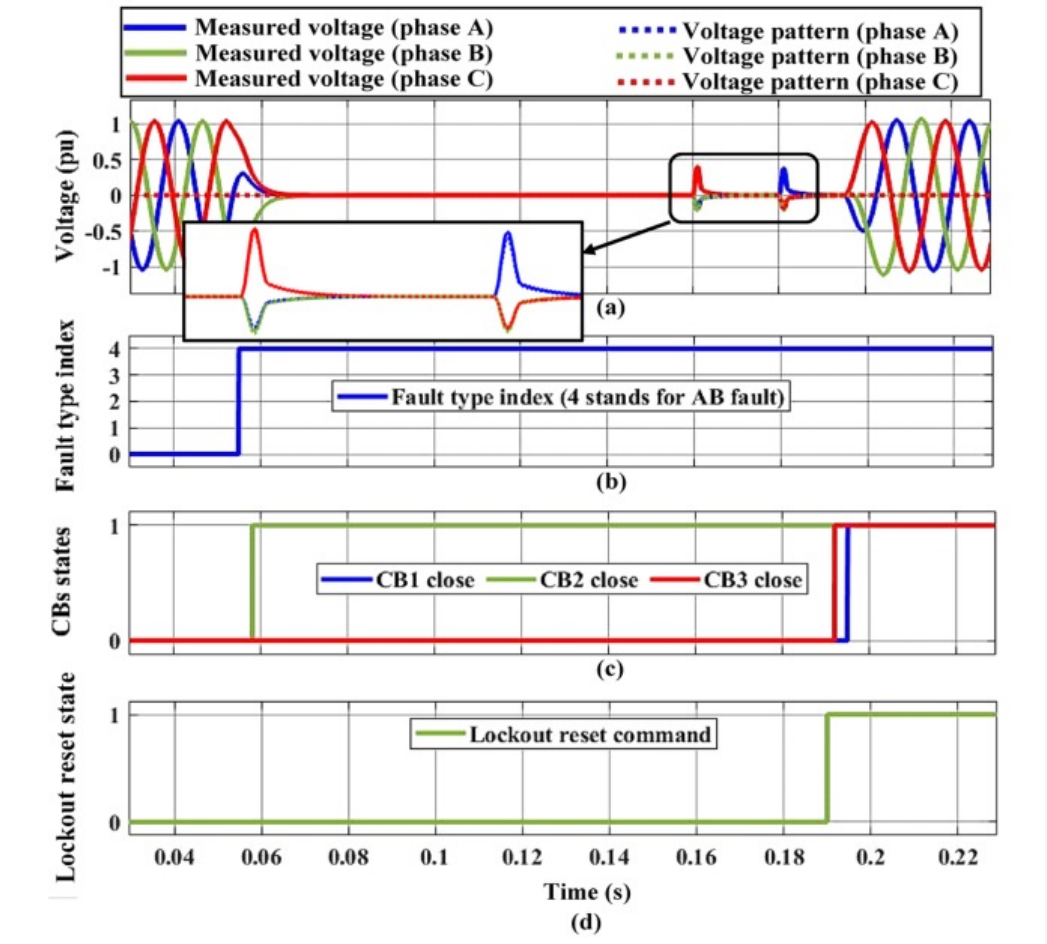
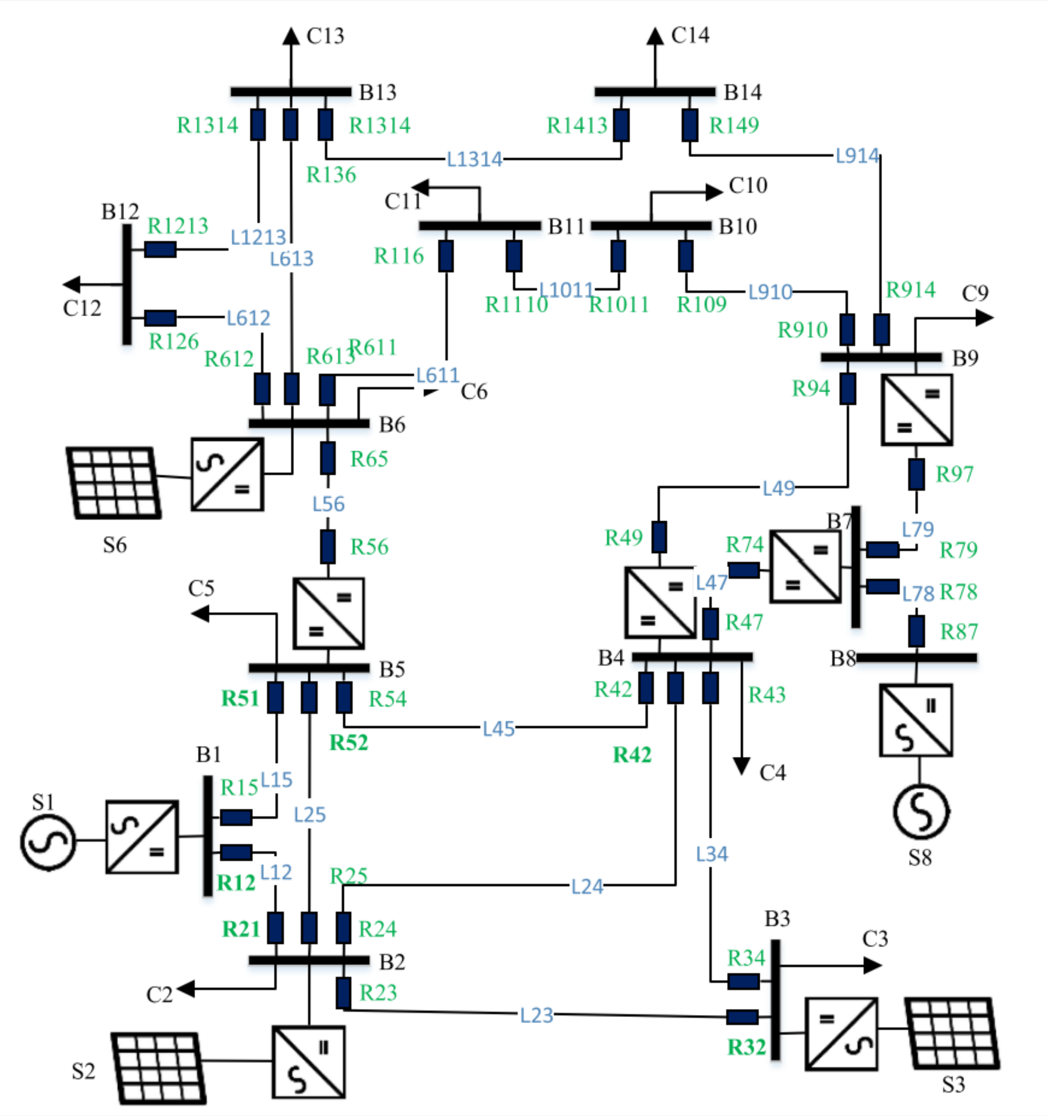


Fig. 13. Experimental test results for a transient AB fault, (a) measured and pattern voltages, (b) fault type signal, (c) CBs close commands signals, and (d) protection lockout reset signal.

CS3: DC Microgrid & OC Problem

DC Microgrid Topology



Problem: Fast Rise Time

Peak Fault Current

2 ms

Standard Time Interval

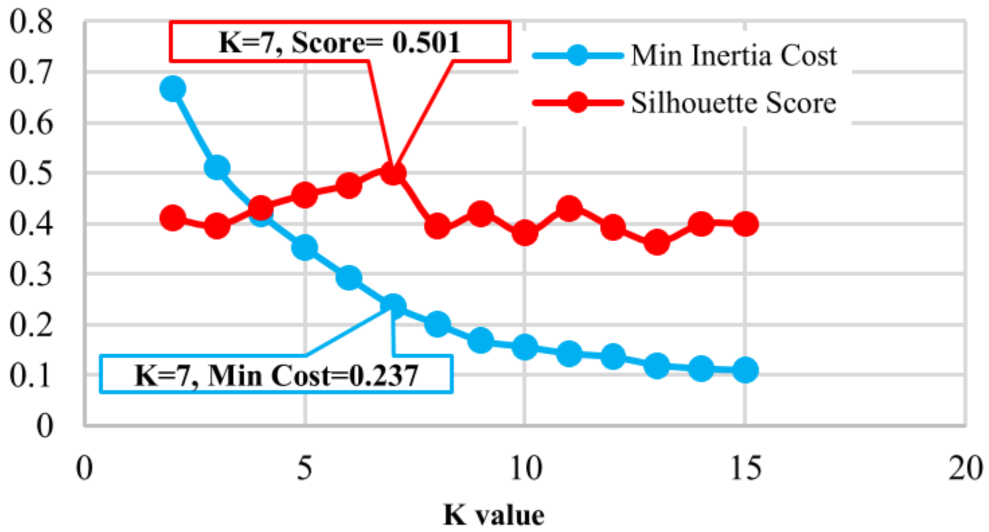
29ms Δt

Extremely Fast Rise Time

Exceeds conventional protection response

Standard OC Coordination Fails

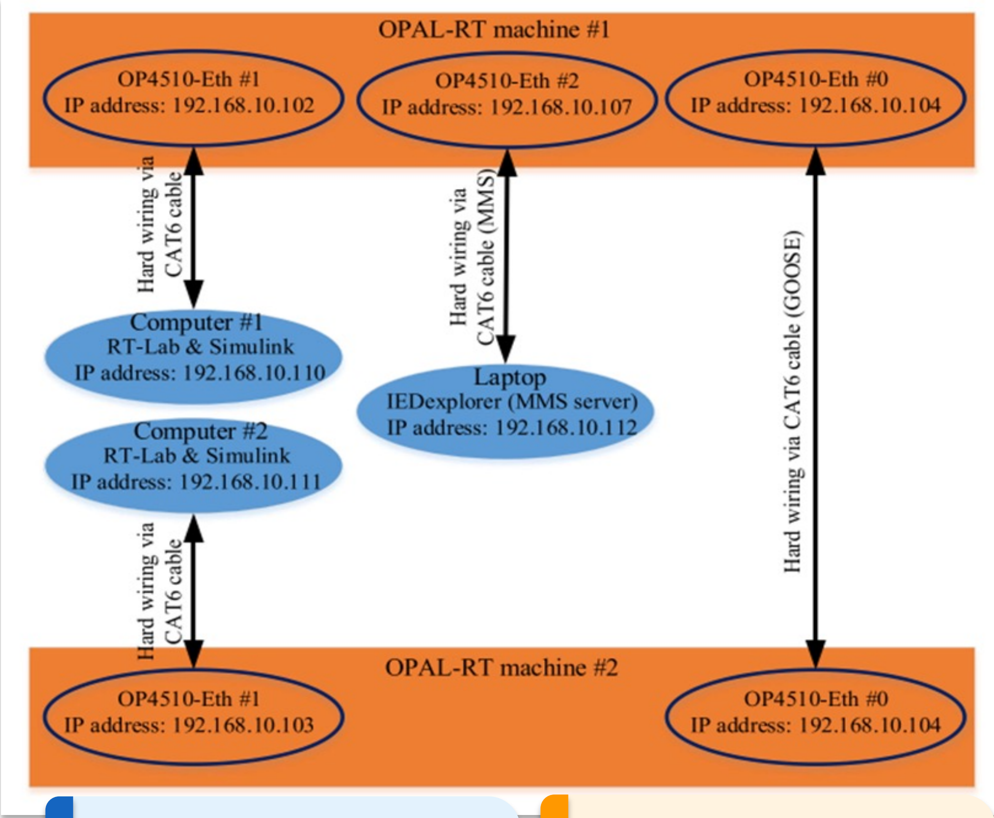
Protection cannot respond in time



CS3: Solution - Adaptive OC + IEC 61850

Network Topology Diagram

OPAL-RT system architecture with dual-machine setup



Realistic Timing

Test algorithms under actual time-critical conditions

Communication Validation

Hardware-in-the-Loop

Dual OPAL-RT machines for authentic testing

Scenario Testing

Two Critical Case Studies

Case Study 1: Normal Operation

Primary Protection

→ Adjacent relays operate before R12

→ R12 monitors and coordinates

→ Selective isolation of fault zone

→ Validates proper coordination mechanism

Case Study 2: Protection Failure

Backup Protection

→ Adjacent relay(s) fail to operate

→ R12 detects failure via GOOSE messages

→ Instantaneous trip within 0.5 ms

→ Demonstrates speed & reliability

Fault Types

- Pole-to-ground faults
- Pole-to-pole faults
- Fault impedance: 0.5 Ω
- Location: L12 & adjacent

CS3: HIL Testbed & Experimental Results

Hardware Implementation

Physical testbed photograph

Power Hardware-in-the-Loop (PHIL)

- **OPAL-RT** real-time simulator
- RT-Lab + MATLAB interface
- **5 kHz** sampling frequency
- IEDexplorer for GOOSE messages

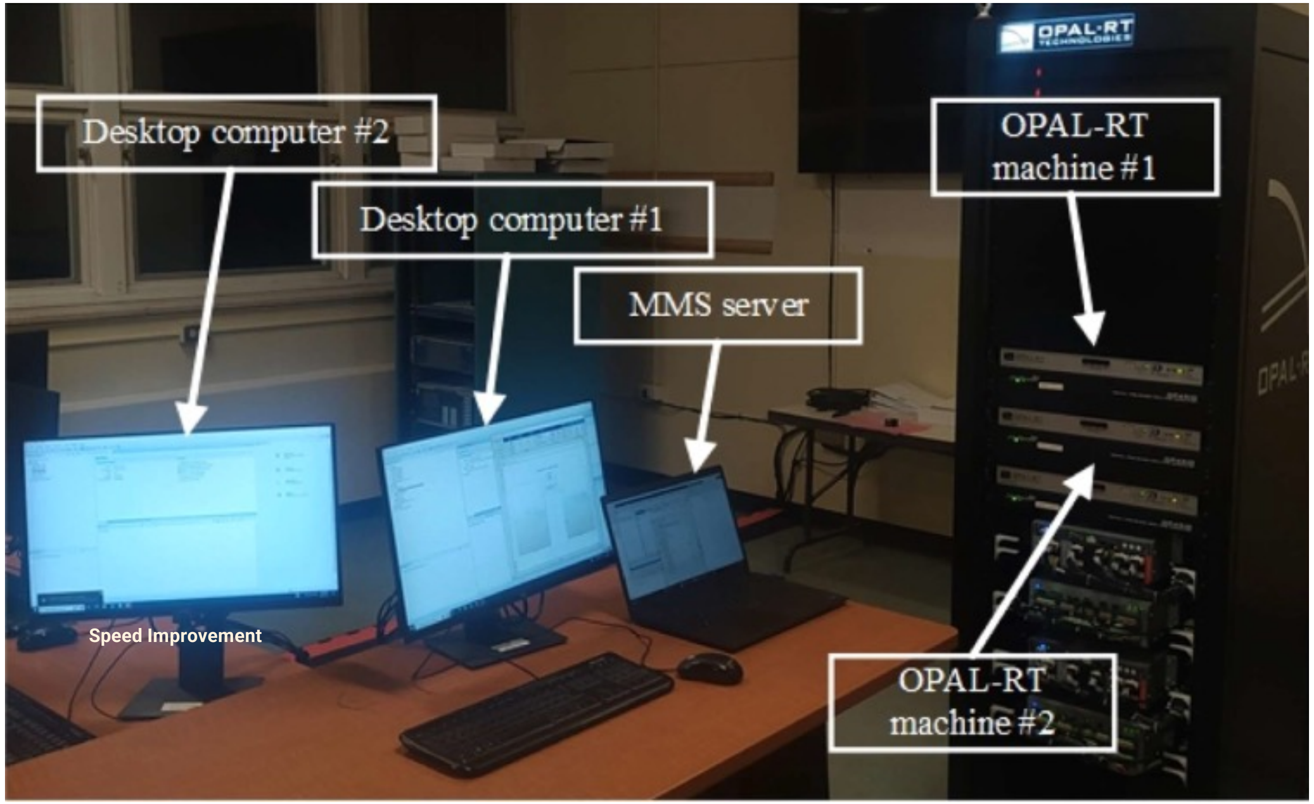
OPAL-RT Real-Time Simulator

Machine #1

Microgrid model & other relays

Machine #2

Relay R12 algorithm implementation



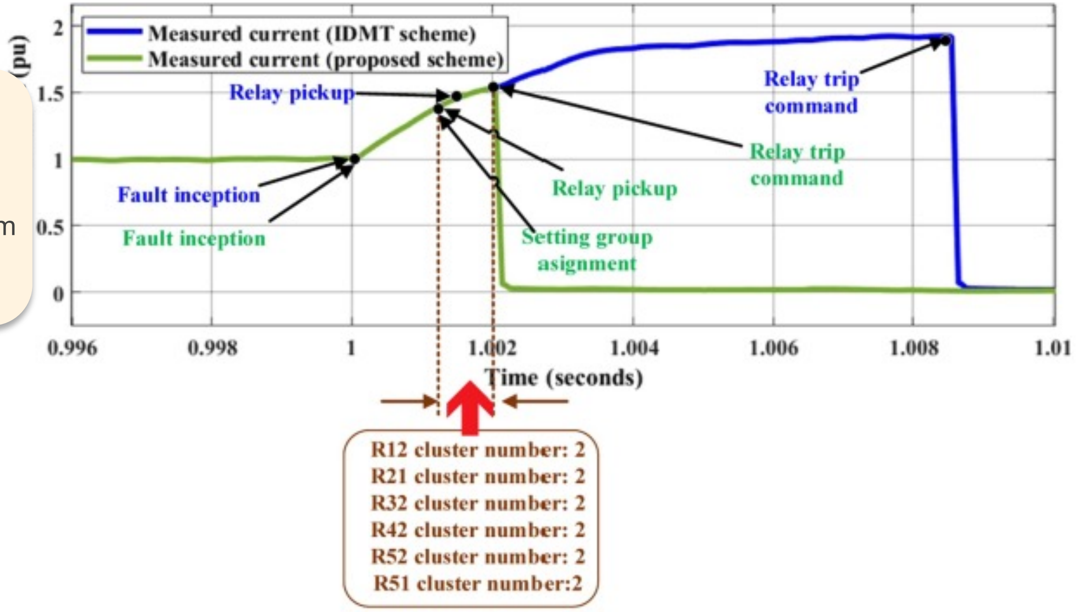


Fig. 10. Current waveform and the OC operation sequences in the case of adjacent relay failure while pole-ground fault occurs at $L12$, while $S2$ and $L23$ are out of service.

Fault location	Sources outages					
	Without outage	S1 outage	S2 outage	S3 outage	S6 outage	S8 outage
L12	N/D	N/D	N/D	N/D	N/D	N/D
L23	0.39 *ms* (11.15 *ms*)	0.34 *ms* (12.11 *ms*)	0.43 *ms* (9.22 *ms*)	0.31 *ms* (15.15 *ms*)	0.29 *ms* (16.91 *ms*)	0.26 *ms* (10.83 *ms*)
L24	0.38 *ms* (15.09 *ms*)	0.41 *ms* (13.15 *ms*)	0.35 *ms* (14.32 *ms*)	0.51 *ms* (16.11 *ms*)	0.45 *ms* (15.53 *ms*)	0.38 *ms* (17.05 *ms*)
L25	0.38 *ms* (9.81 *ms*)	0.52 *ms* (10.21 *ms*)	0.43 *ms* (13.59 *ms*)	0.37 *ms* (12.35 *ms*)	0.44 *ms* (15.38 *ms*)	0.45 *ms* (9.11 *ms*)

Speed Improvement

20×

Protection Failure Response

<0.5 ms

Acknowledgments & Questions

Collaborators

Maher Azzouz
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Laval University

Questions?

Let's discuss IBR protection challenges

Thank You

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