The University of Texas at Austin
Center for Electromechanics

MANAGING POWER SYSTEM FAULTS

Xianyong Feng, PhD
Center for Electromechanics
The University of Texas at Austin
November 14, 2017

Outline

1. Overview
2. Methodology
3. Case Studies
4. Conclusion

Power System Fault Management

Detection
- Real-time monitoring
- Detect electrical abnormal
- Fault type identification (permanent or temporary)

Location
- Quickly and accurately locate fault
- Minimize system impact

Isolation
- Open protective device
- Minimize load interruption

Restoration
- Quick recovery
- Restore interrupted loads to normal

Power System Protection Research

- DC distribution system protection
  1. Ultra-fast dc fault protection [1], [2]
  2. Power converter fault current handling [3]
  3. Meshed dc network short-circuit fault current analysis [4]
- Protection study for AC system with high penetration DERs
  1. Intelligent sensor development
  2. Fault type identification
  3. Fault location
  4. Islanding detection
  5. Optimal sensor placement

1. X. Feng, et.al., "Fault inductance based protection for DC distribution systems,“ *Proc. IET 13th Conference on Development of Power System Protection*, March 2016.
2. X. Feng, et.al., “A novel fault location method for DC distribution protection,” *IEEE Trans. Industrial Applications*, vol. 53, no. 3, pp. 1834-1840, May-June, 2017.
3. L. Qi, J. Pan, X. Huang, and X. Feng, “Solid state fault current limiting for dc distribution protection,” *Proc. of Electric Ship Technology Symposium*, Aug. 2017, pp. 187-191.
4. X. Feng, et.al., “Estimation of short circuit currents in mesh DC networks,” *Proc. IEEE PES General Meeting*, July 2014.

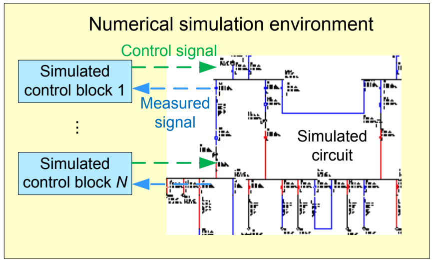
CEM Approach - Protection Control

Simulation Test:

- New protection strategies are initially implemented in modeling software and verified in numerical environment

Tools:

1. Matlab / Simulink
2. PSCAD
3. ETAP
4. OpenDSS



- The protection algorithms are implemented numerically
- The performance is evaluated and optimized offline

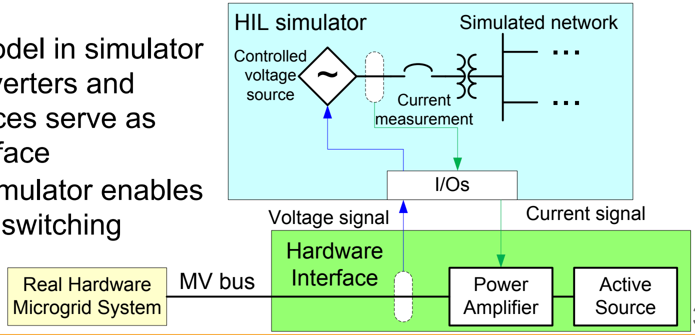
1

Power Hardware-in-the-Loop (PHIL) Simulation Test:

- Implement the interface between HIL simulator and real power systems

Features:

1. Network model in simulator
2. Power converters and active sources serve as power interface
3. NI FPGA simulator enables the fast PE switching



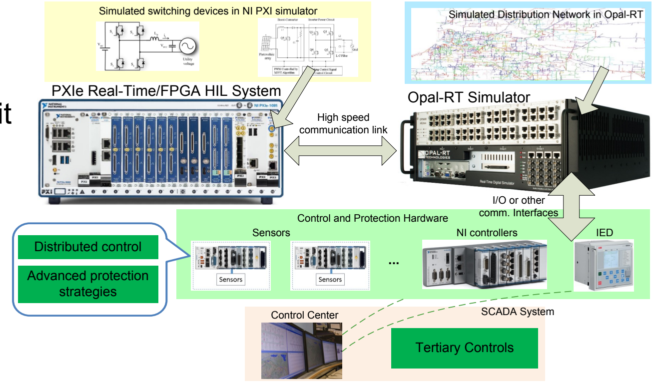
3

Control Hardware-in-the-Loop (CHIL) Simulation Test:

- Protection strategies are implemented in hardware controllers
- The controller is validated in the HIL simulation environment

Procedure:

1. Model the circuit
2. Implement control strategy in hardware
3. Configure the interface
4. Perform HIL tests



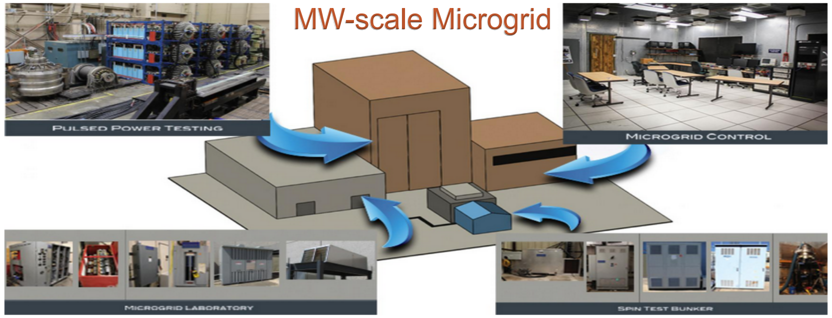
2

Real Hardware Test and Field Demonstration:

The protection strategy test in real microgrid.

Benefits:

1. Obtain validated engineering data
2. Demonstrate system performance in the real operation environment



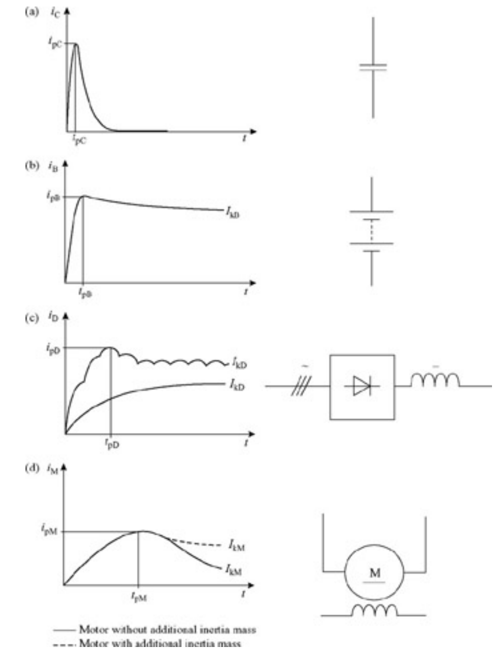
4

DC Distribution System Protection

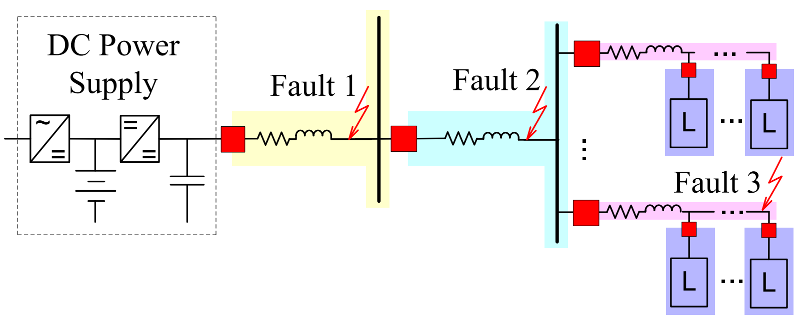
DC protection challenges

1. No fault current zero-crossing
2. Lower line impedance
3. High di/dt
4. Power electrics device can not tolerate high fault current
5. Fast capacitor discharge

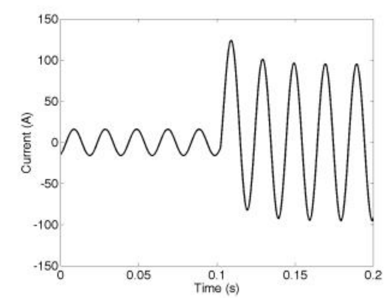
DC fault current



DC distribution system example



AC fault current



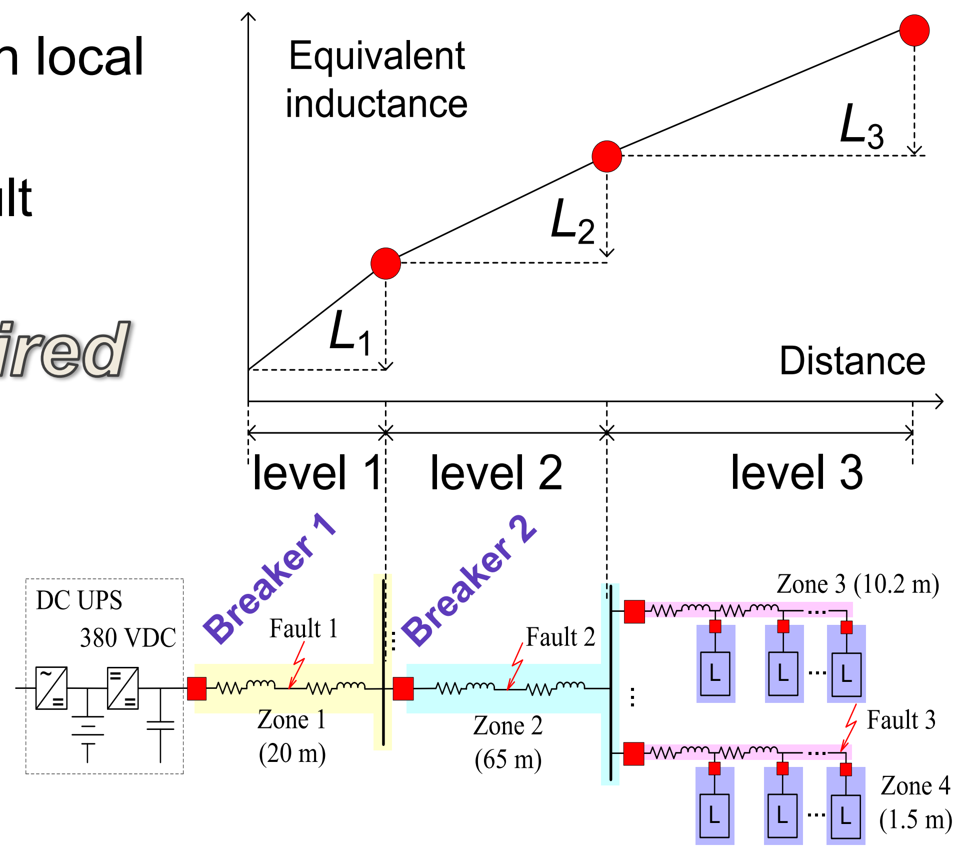
Fast DC Fault Location Algorithm

Inductance-based dc fault location*

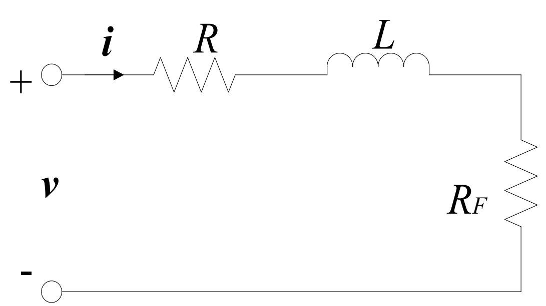
1. Estimate fault inductance with local measured $v(t)$ and $i(t)$
2. Use estimated L to locate fault

No communication required

Line inductance distribution



Equivalent fault circuit

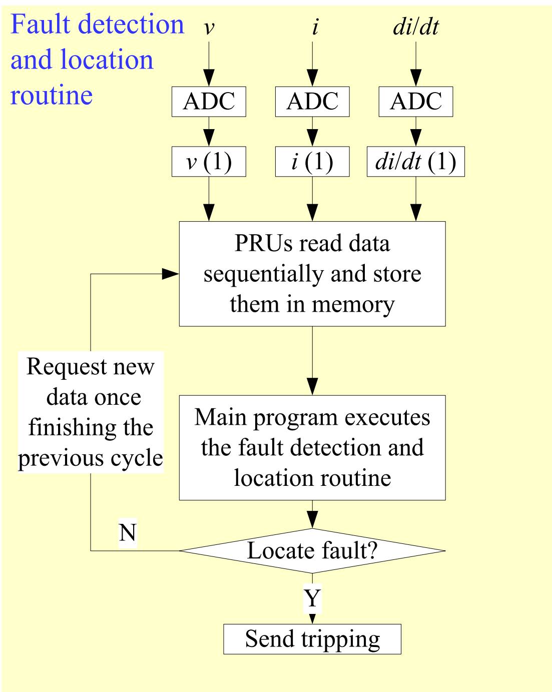


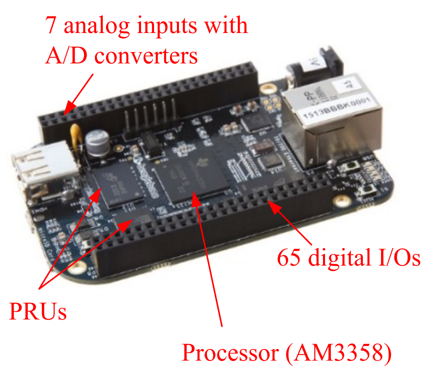
*X. Feng, et.al., “A novel fault location method for dc distribution protection,” *IEEE Trans. Industrial Applications*, vol. 53, no. 3, May-June, 2017.

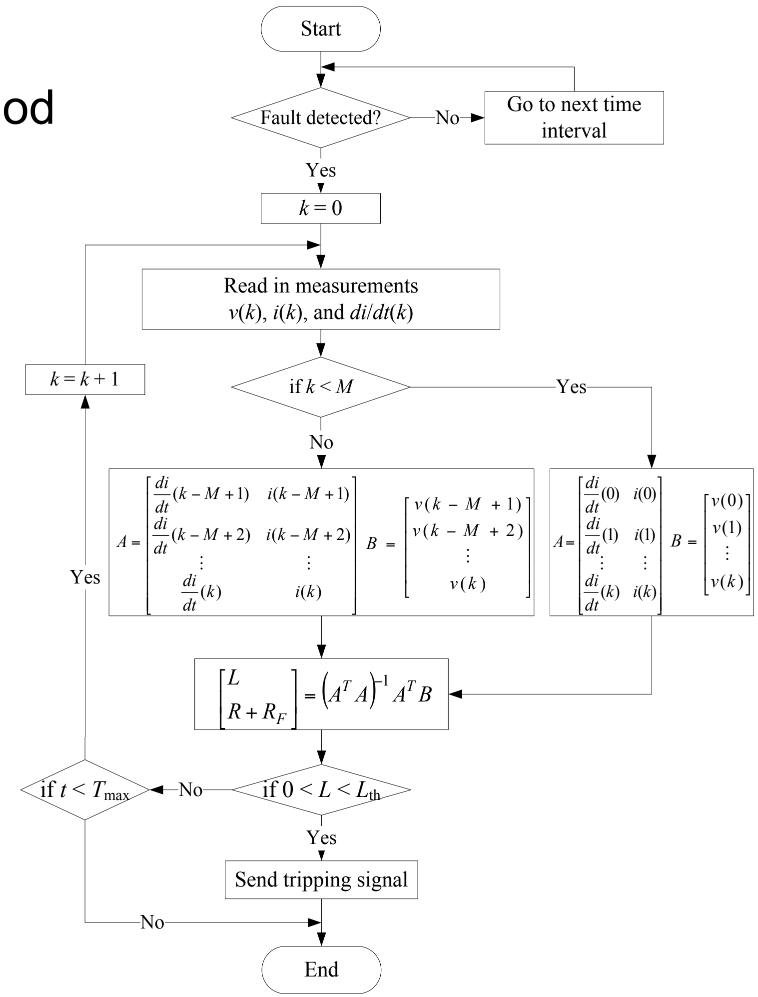
Protection Control Prototype

Protection strategy design

1. Online moving-window least square method
2. Algorithm on embedded controller



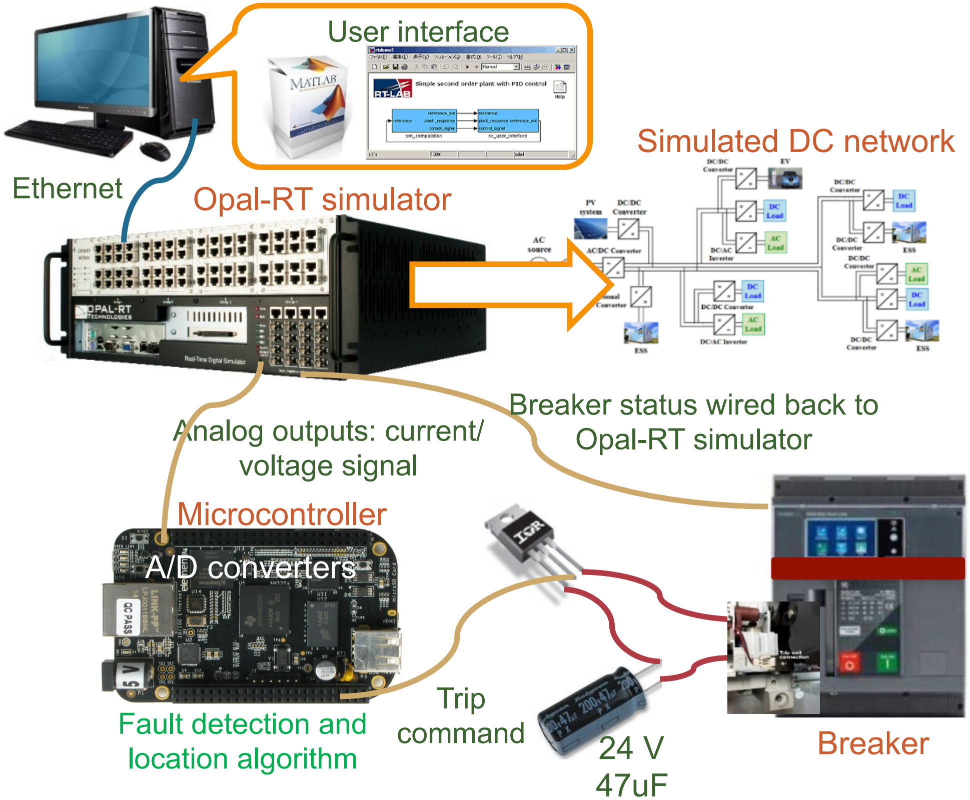




Protection Algorithm Test

Control-HIL test

1. Opal-RT simulator
   - Simulated a 380 V dc system
   - Convert *v*(*t*)/*i*(*t*) to analog
   - Read in breaker status
2. Embedded controller
   - Read in *v*(*t*)/*i*(*t*) signals
   - Execute prot. algorithm
   - Send a trip signal for internal fault

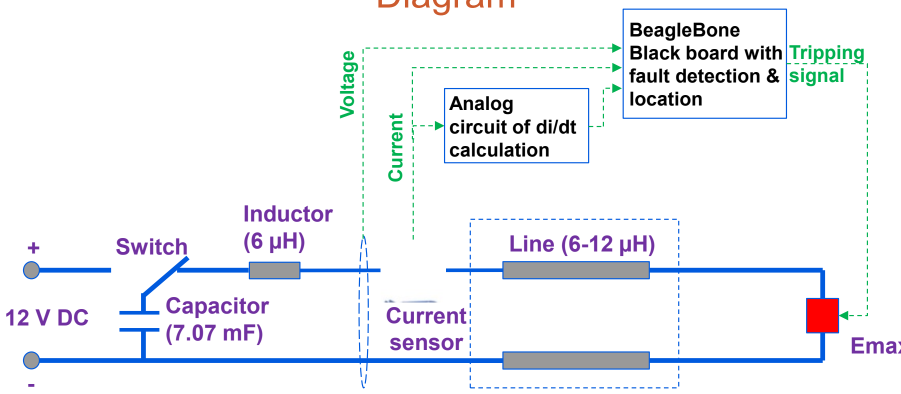


Protection Algorithm Test

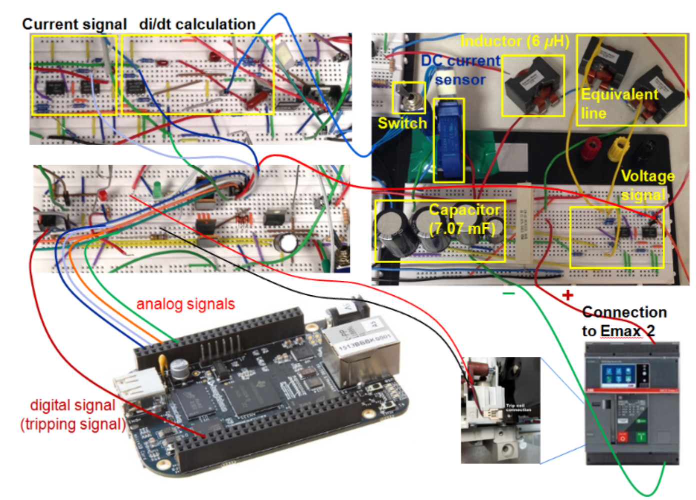
Hardware test

1. Low voltage circuit
   - 7.07 mF capacitor is charged to 12 V
   - Inductors are used to emulate lines
   - Short-circuit fault is created by closing a breaker
2. Embedded controller
   - Read in *v*(*t*), *i*(*t*), *di*/*dt*
   - Execute prot. algorithm
   - Send a trip signal for internal fault

Diagram



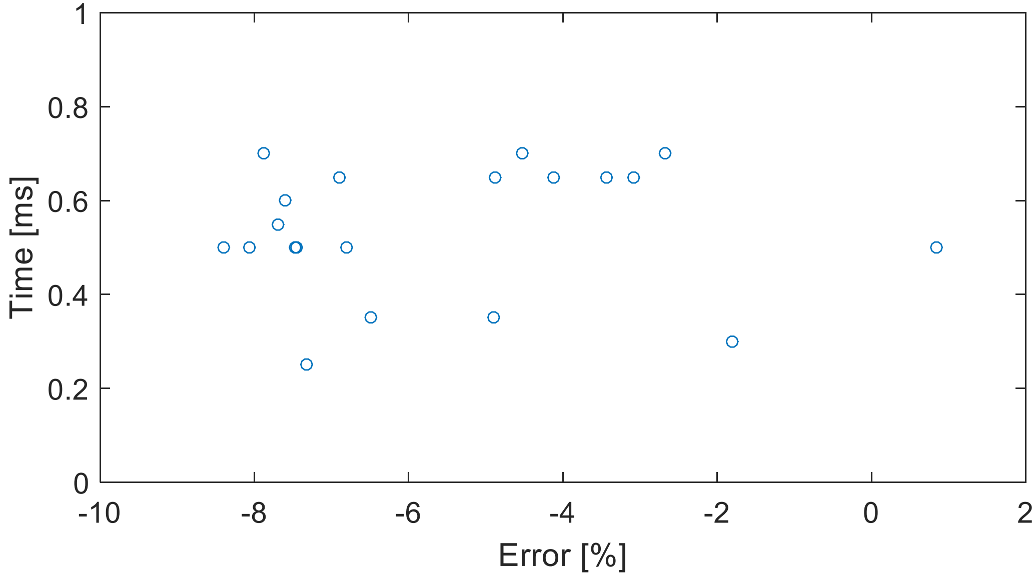
Test Circuit

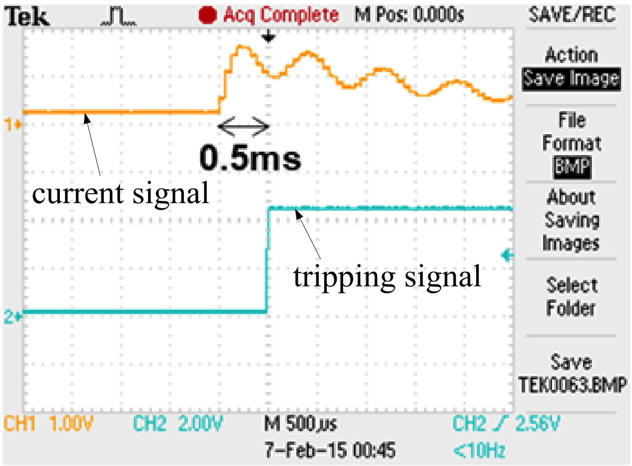


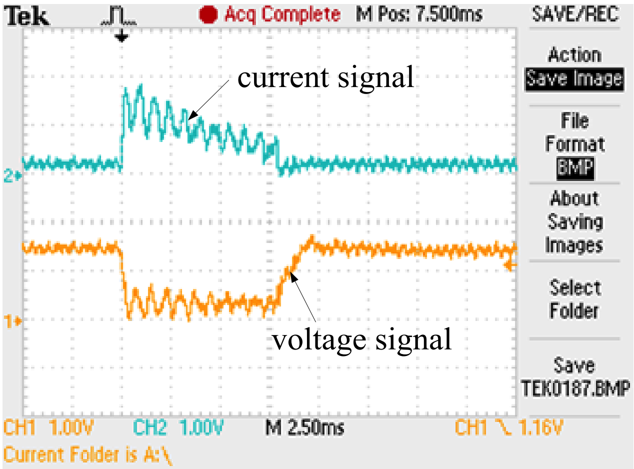
Protection Algorithm Test Results

Control-HIL test results

1. *L* estimation error < ***8.4%***
2. Fault detection/location time < ***0.7 ms***

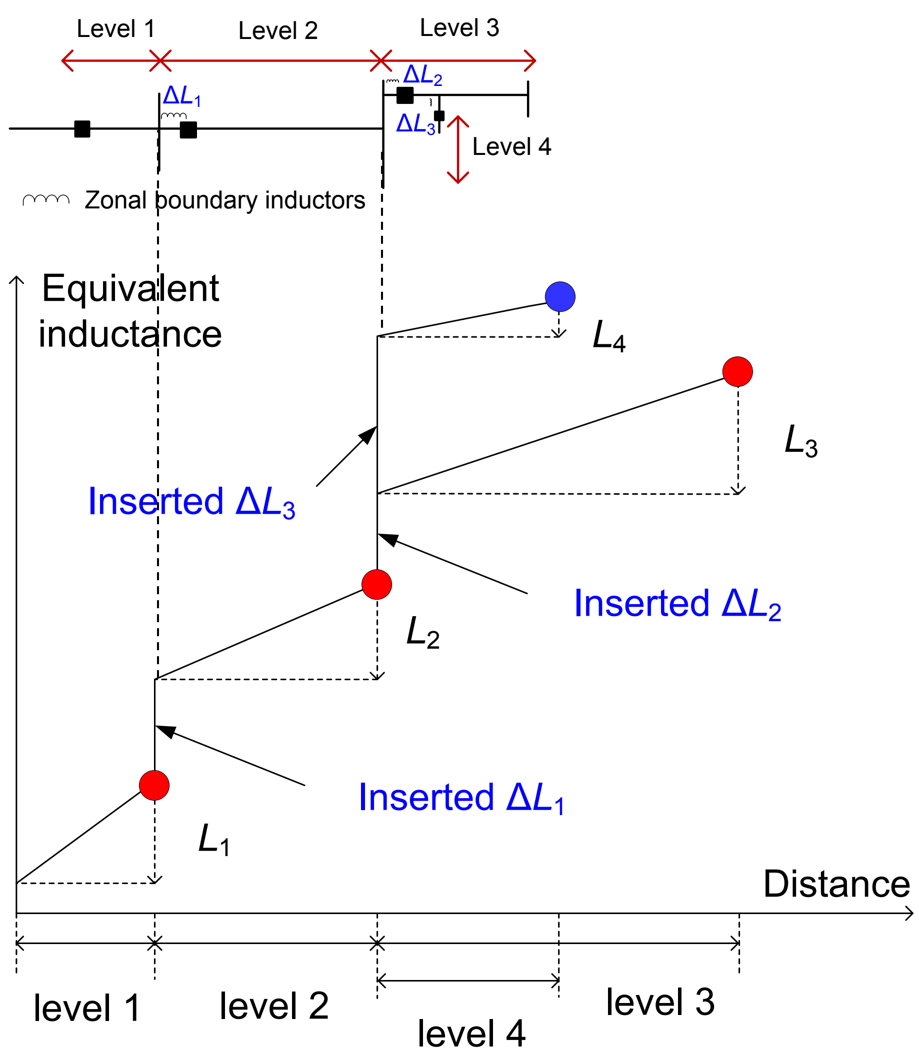




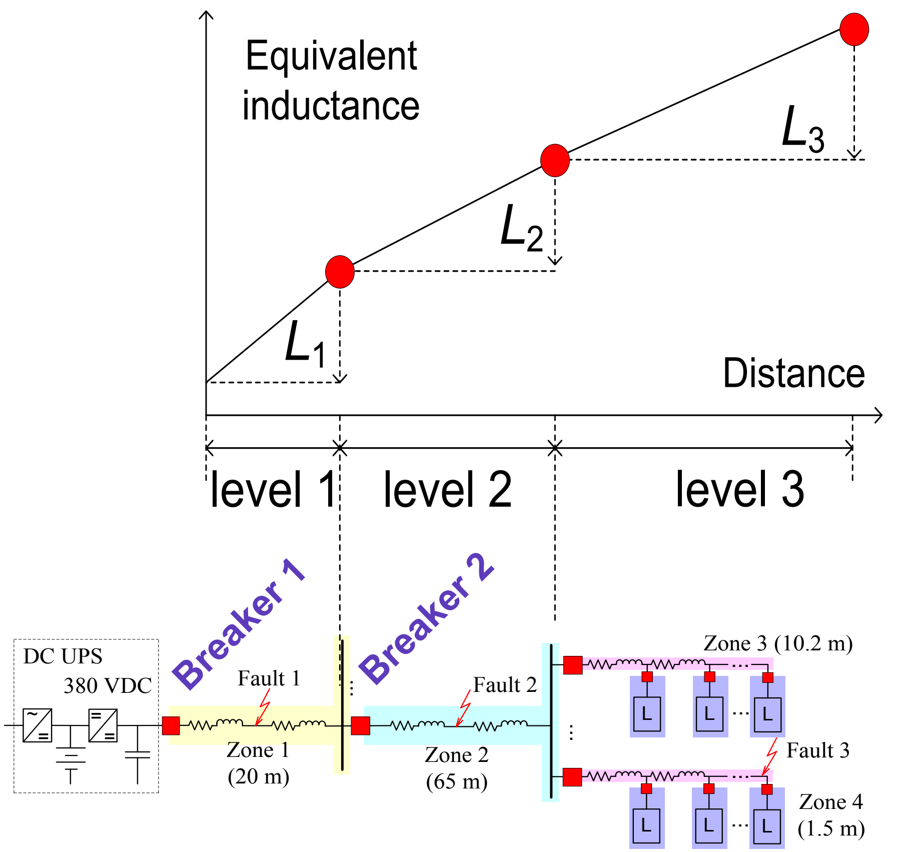


Protection Algorithm Improvement

Boundary Inductor



No boundary inductor



Result Summary

1. The prot. method uses local measurements only to locate fault
   - Detection and location time < *0.7 ms*
   - *L* estimation error in HIL test < *8.4%*
   - *L* estimation error in hardware test < *20%*
2. The prot. Method accurately locates short-circuit faults if:
   - Voltage measurement error < *0.5%*
   - Current measurement error < *1%*
3. Boundary inductors improve prot. selectivity

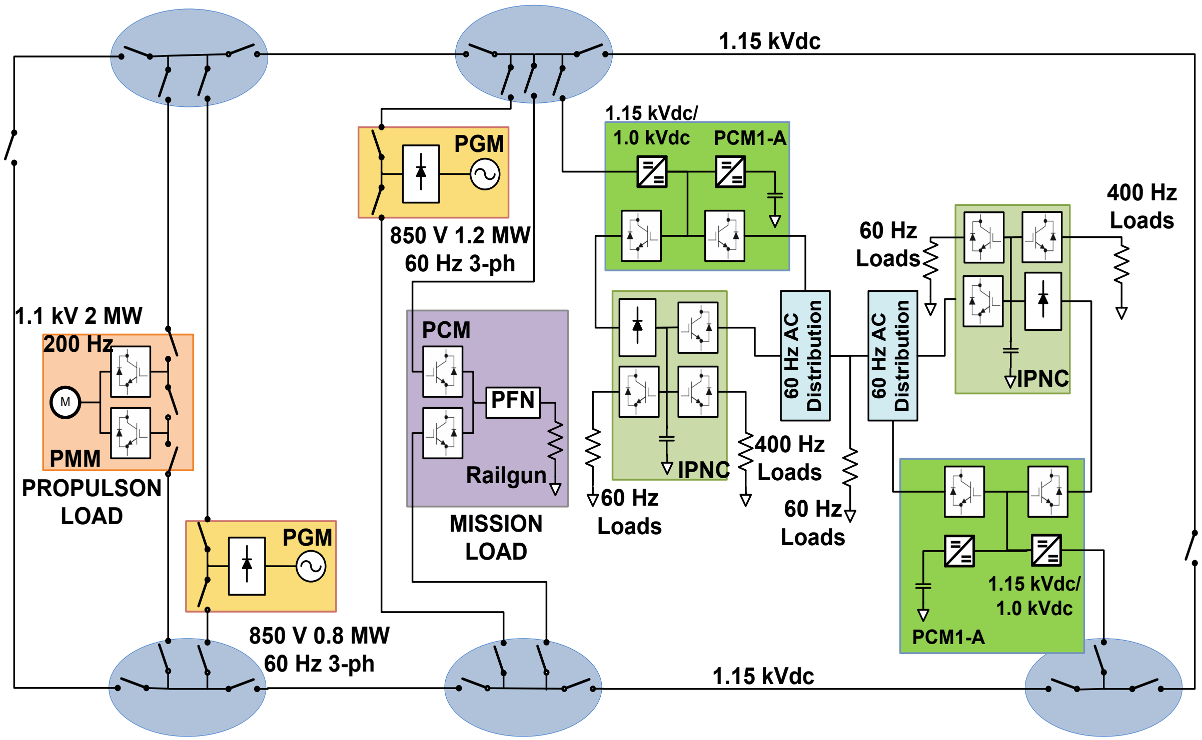
- Ongoing work:

1. Protection algorithm test on real MV dc microgrid

MVDC Shipboard System Protection

System Description

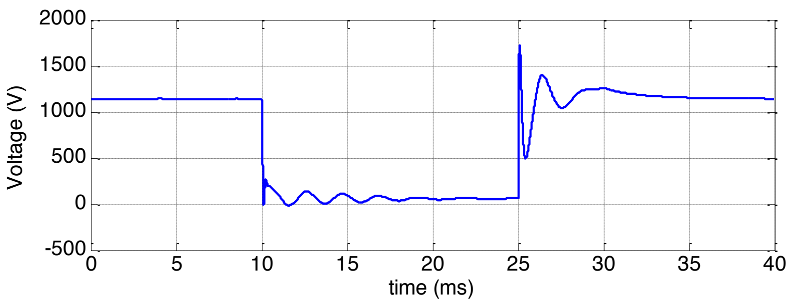
1. Two PGMs
   - FCL in dc-dc converters
2. One propulsion load
   - VFD + motor
3. One pulse load
   - High *di*/*dt*
4. DC circuit breakers
   - Isolate fault
5. Protection strategy*
   - FCL + diff. protection

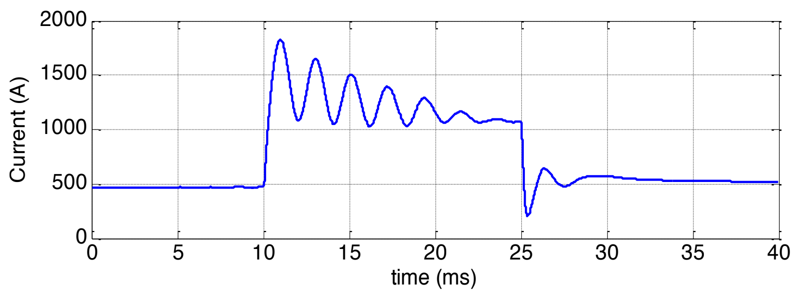


*S. Strank, et. al., "Experimental test bed to de-risk the navy advanced development model," *Proc. of Electric Ship Technology Symposium*, Arlington, VA, Aug. 2017, pp. 352-358.

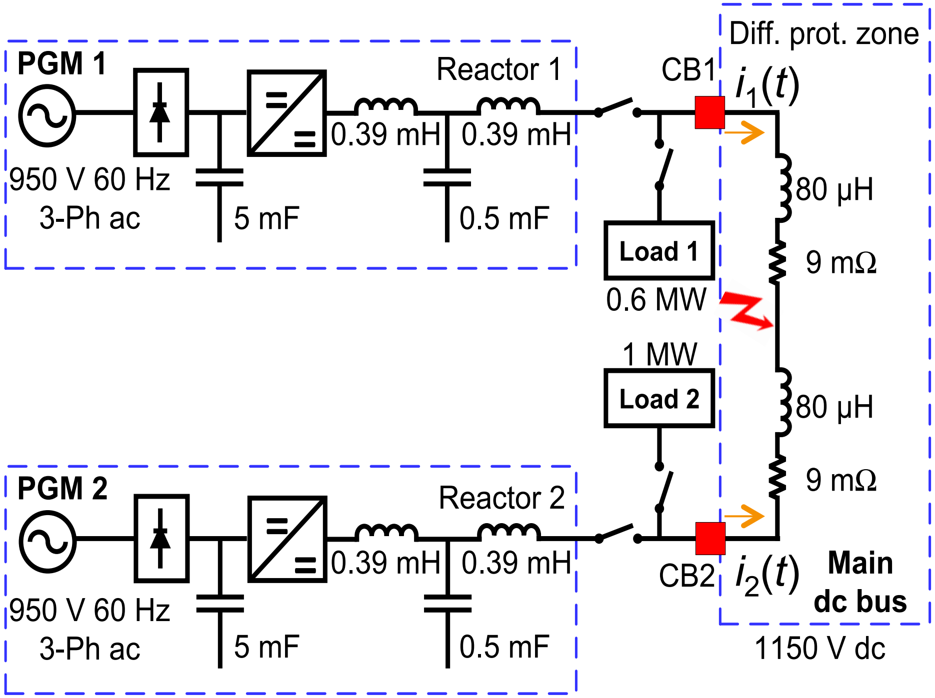
MVDC Shipboard System Protection

- Main results
  1. Fault: 10-25 ms, 20 mΩ, on dc bus
  2. Prot. strategy: FCL + diff. prot.
- Ongoing work
  1. Validate the protection method on real dc microgrid



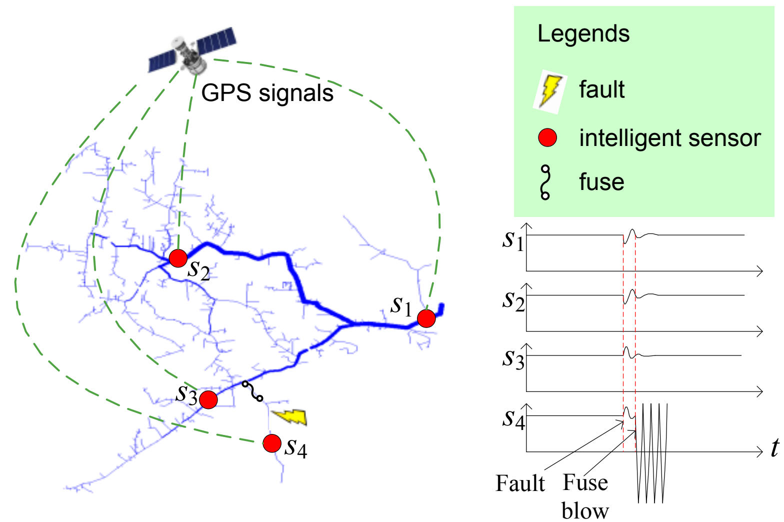


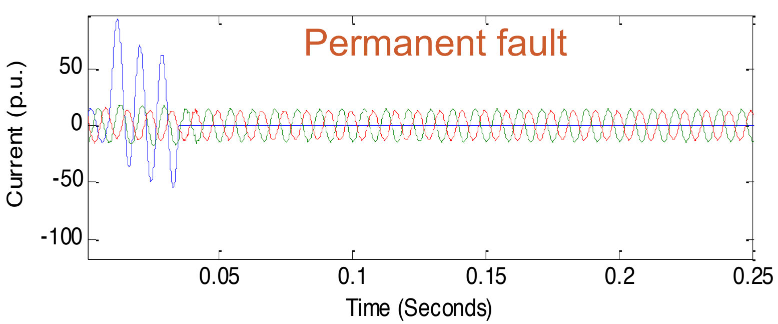
Current differential: $i_1(t) + i_2(t)$

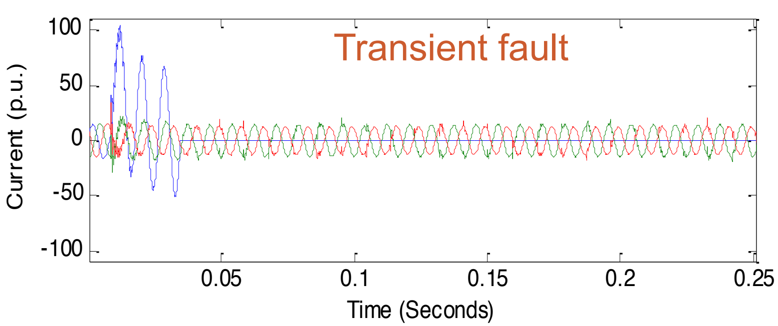


AC Distribution System Protection

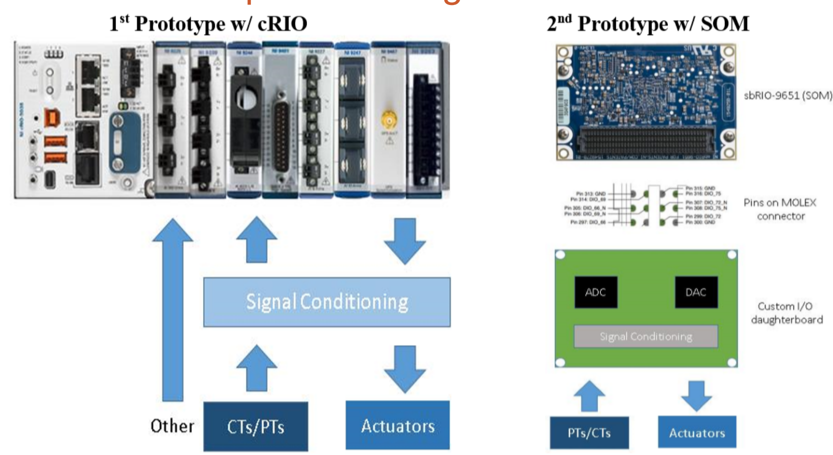
- Supported by DOE
- Fault type identification
  - Permanent or temporary
- Fault location
- Islanding detection
- Optimal sensor placement







Proposed intelligent sensors



AC Distribution System Protection

- Impedance fault location
  1. Requirement
     - Network model
     - Fault waveforms
  2. Benefit
     - Locate fault segment
     - Do not need synch.
- Traveling wave method
  1. Requirement
     - GPS synchronization
     - High bandwidth sensor
     - Fast processing speed
  2. Benefit
     - Incipient fault location (sub-cycle fault)
     - Simple algorithm

Conclusion

1. Fault management is critical for power system safety and reliability
2. Our dc prot. approach reduces fault clearing time and system recovery time
3. The fast prot. method significantly improves power system resilience

Thanks for your attention

Question?

Contact information:

Xianyong Feng, PhD
Center for Electromechanics
The University of Texas at Austin
Email: x.feng@cem.utexas.edu
Phone: 1-512-232-1623