The University of Texas at Austin
Center for Electromechanics

INTELLIGENT CONTROL FOR MICROGRID

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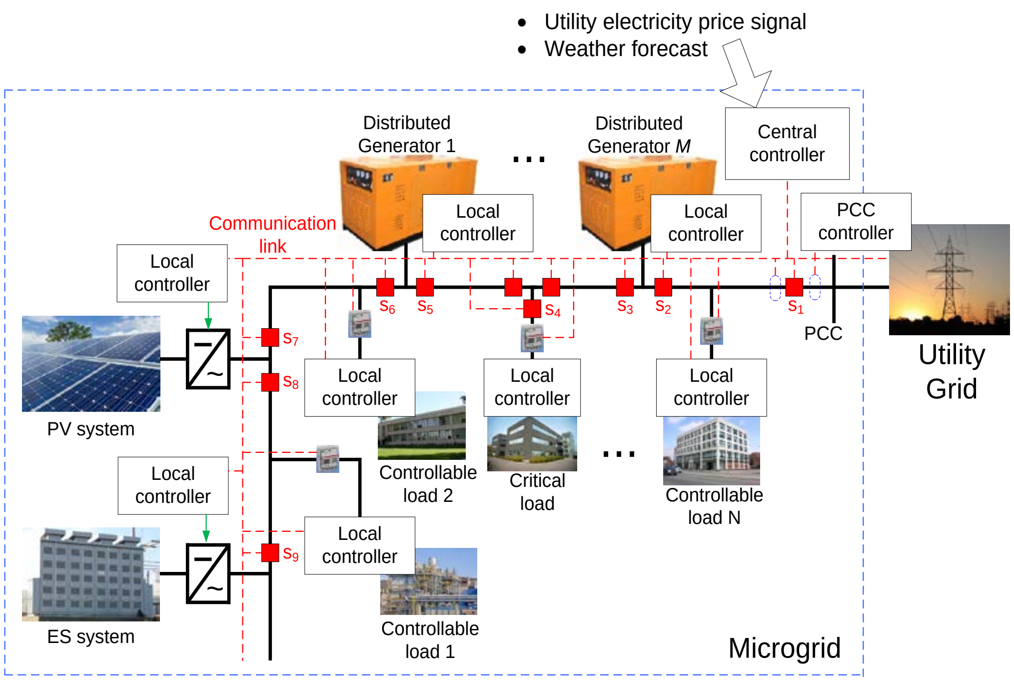
Outline

- Microgrid Overview
- MPC-based Microgrid Energy Management
- DC Microgrid Protection
- Summary

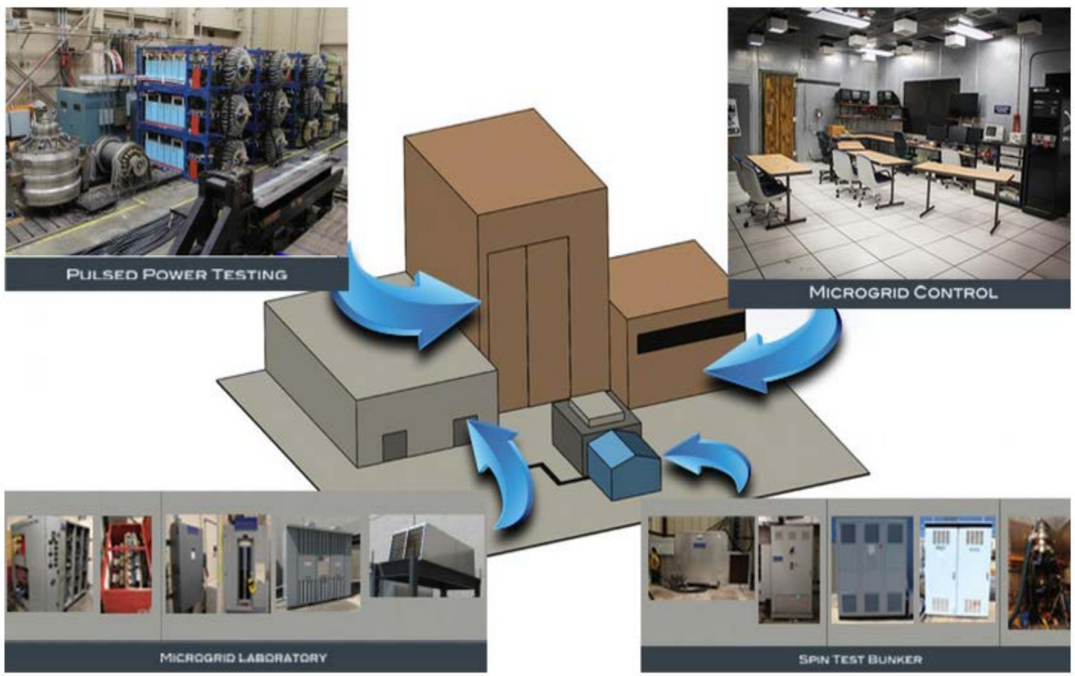
Introduction

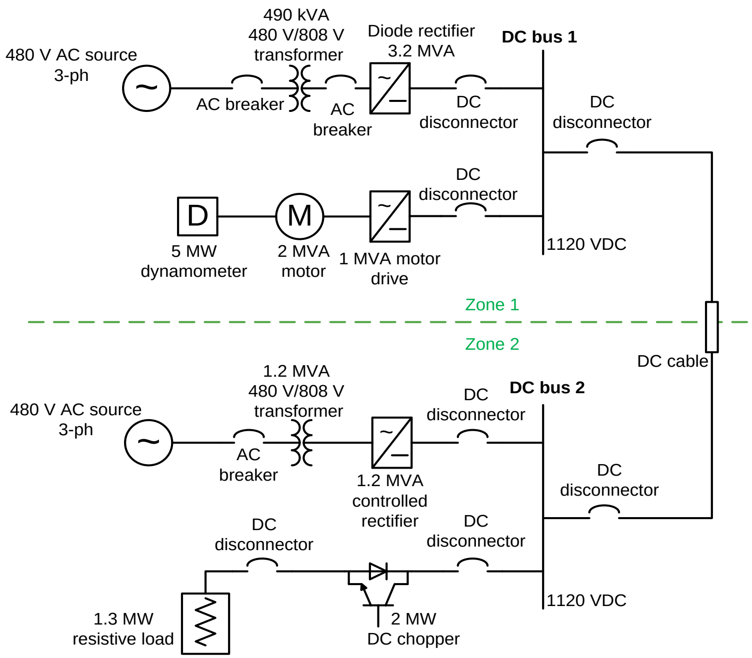
- *Microgrid Definition*: A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.



Introduction

- MW dc microgrid at CEM in UT-Austin



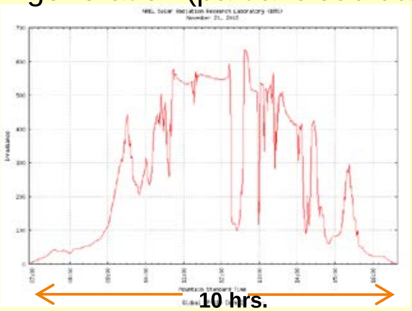


Challenge and Opportunity

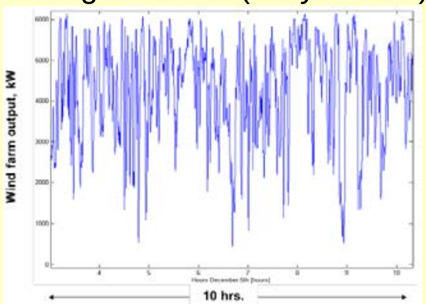
1. High Penetration DER
   - Accommodate high penetration intermittent DERs
2. Energy Efficiency
   - Reduce operational cost
   - Reduce emission
3. Reliability and Resilience
   - Improve system stability
   - Reliable fault ride-through and protection
   - Seamless mode transitions

Renewable Intermittency

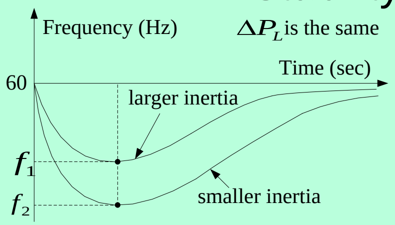
PV generation (partial cloud day)



Wind generation (daily curves)

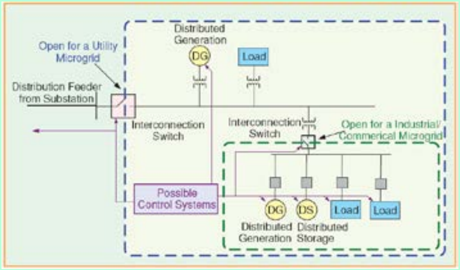


Stability and Resilience

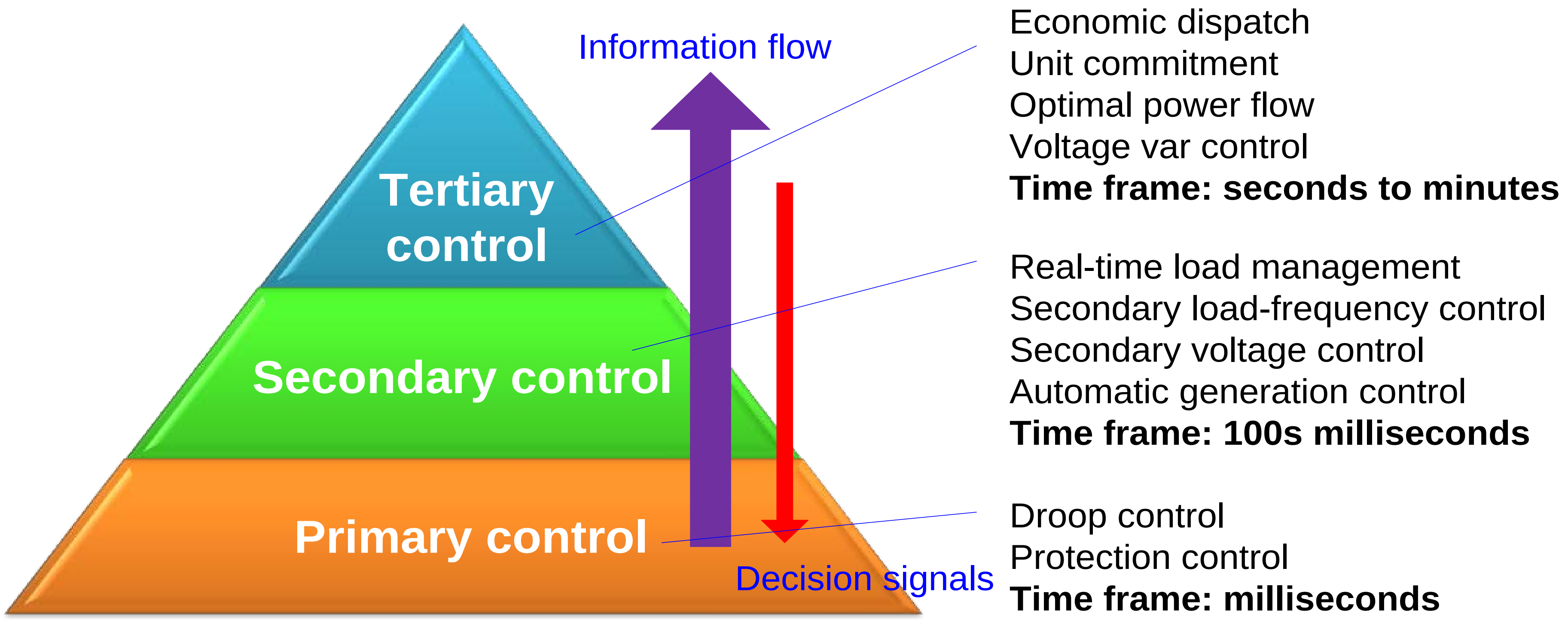


$$\frac{d\bar{f}}{dt} = -\frac{\Delta P_L f_{rated}}{2 \cdot \sum_{i=1}^{n} H_i}$$

Total inertia



Microgrid Control



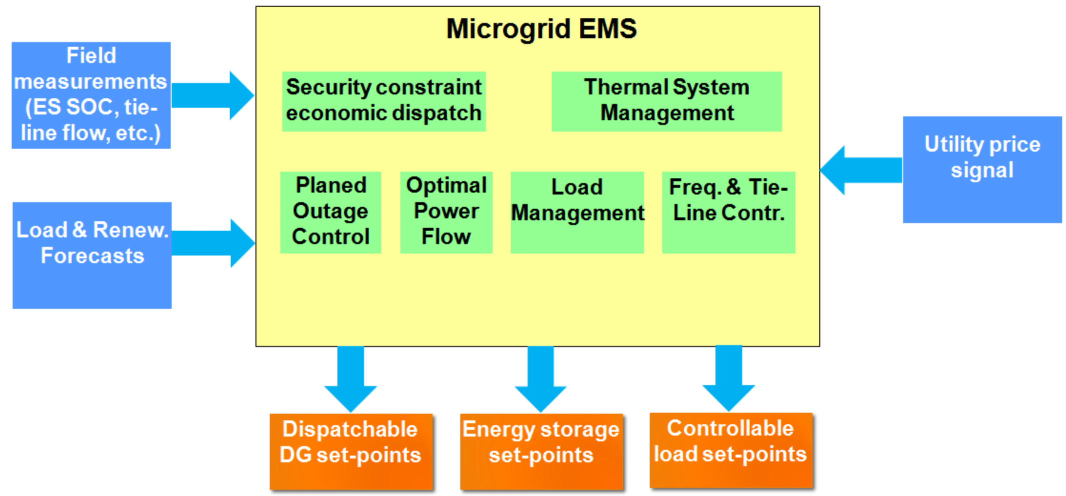
MPC-based Microgrid EMS

Objective and Approach

1. Objective
   - Enable economic and secure steady-state operation
   - Seamless integration with local controllers

2. Approach
   - Look-ahead operational planning: Optimize DER schedule for the next 12-24 hours
   - Online operation: Use ED/OPF to determine DER set-points
   - Planned outage control

3. HIL Test
   - Test the EMS performance
   - Test the EMS and fast control integration



$$\min \Sigma_{t=1}^{T}\{C_{gdt}P_{gdt}+\Sigma_{dg=1}^{ndg}[S_{dgt}C_{dgt}^{nl}+P_{dgt}C_{dgt}^{pg}+ \mathrm{SU}_{dgt}C_{dgt}^{su}+\mathrm{SD}_{dgt}C_{dgt}^{sd}]+\Sigma_{es=1}^{nes}[C_{est}^{SU_{CD}} (\mathrm{SU}_{est}^{D}+\mathrm{SU}_{est}^{C})+C_{est}^{SCD}(S_{est}^{D}+S_{est}^{C})]\}$$

where:

$$P_{gdt}+\Sigma_{dg=1}^{ndg}P_{dgt}+\Sigma_{es=1}^{nes}P_{est}+ \Sigma_{ndg=1}^{nndg}S_{ndgt}P_{ndgt}=K_2P_{TIdt} \quad t=1,\ldots,T$$

$$S_{dgt}P_{dg}^{min}\leq P_{dgt}\leq S_{dgt}P_{dg}^{max} \quad dg=1\ldots n_{dg} \; t=1,\ldots,T$$

$$S_{dgt}\leq S_{dg(t-1)}+\mathrm{SU}_{dgt} \quad dg=1\ldots n_{dg} \; t=1,\ldots,T$$

$$S_{dgt}\geq S_{dg(t-1)}-\mathrm{SD}_{dgt} \quad dg=1\ldots n_{dg} \; t=1,\ldots,T$$

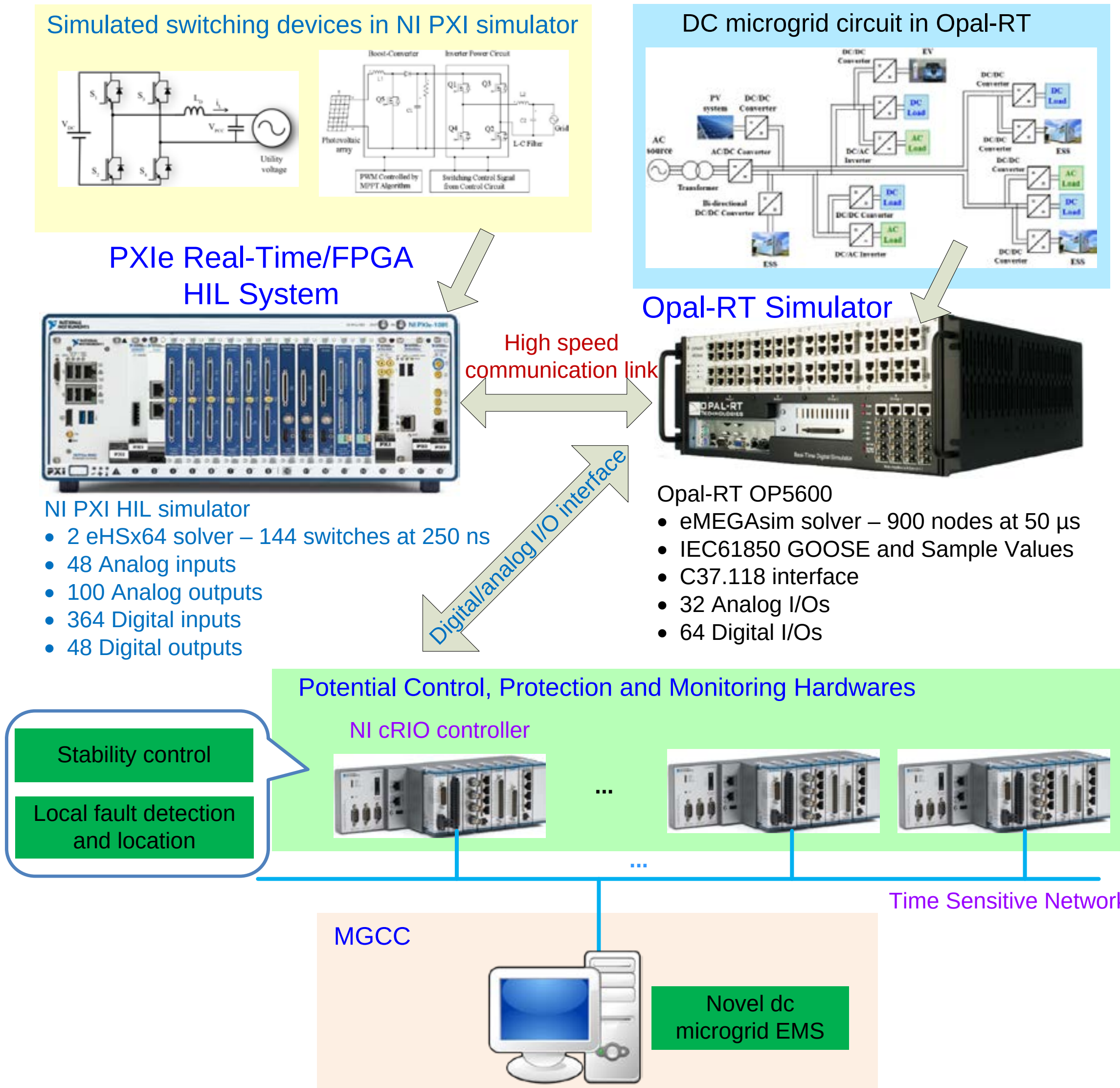
...

Mixed Integer Linear Programming (MILP) problem

MPC-based Microgrid EMS

HIL Test

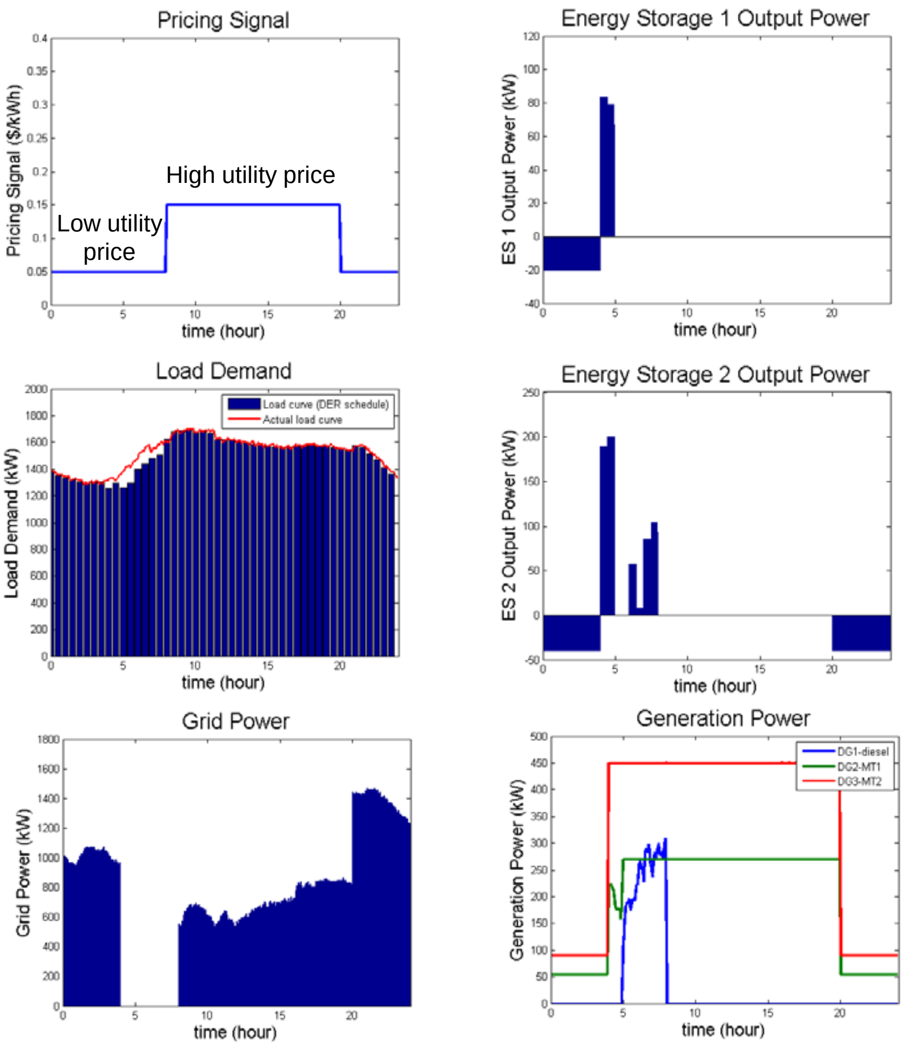
1. Opal-RT simulator
   - Simulated a 13.8 kV microgrid (step: 100 us)
   - Local controllers communicate with Opal-RT simulators
2. Microgrid EMS
   - Improve the economics and reliability
   - EMS is deployed on central controllers
   - Dispatch signals are transferred to local controllers through LAN



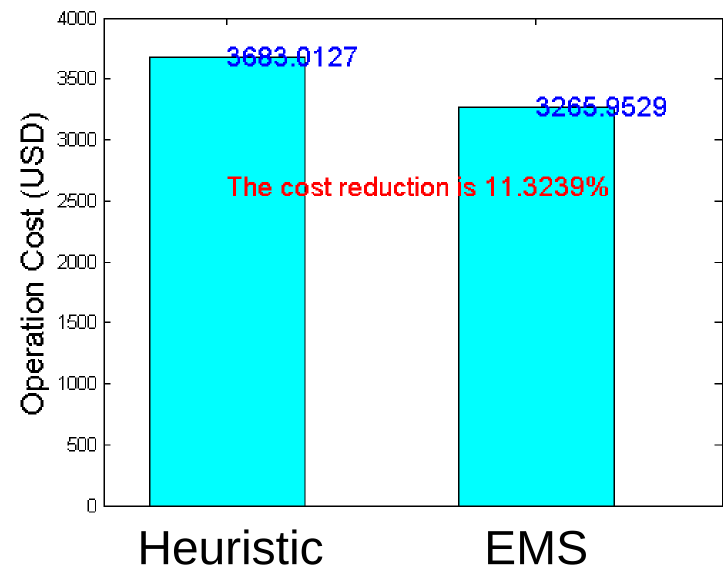
MPC-based Microgrid EMS

Preliminary Test Result

EMS optimization results for a day



Central EMS vs Heuristic Control



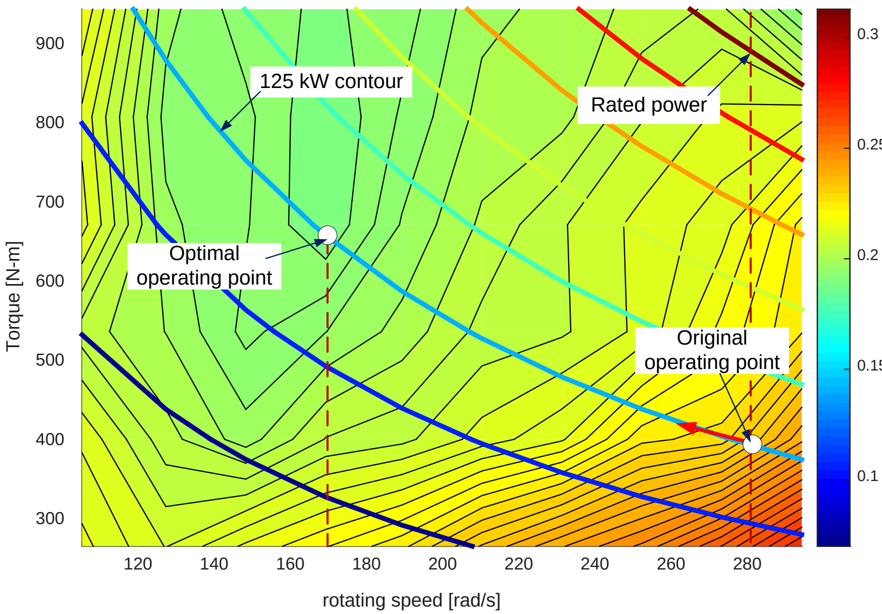
MPC-based Microgrid EMS

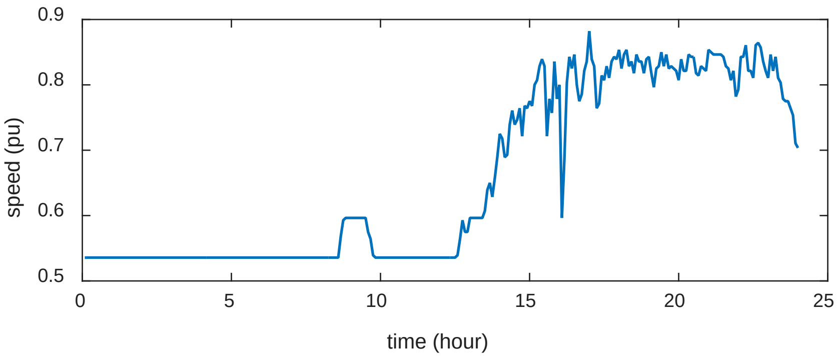
Improvements

1. DC microgrid
   - AC generator is interfaced with dc grid through converter
   - Re-dispatch ac generators for efficiency improvement

2. Hybrid approach
   - Use ESS to shift energy to operate generator at the maximum efficiency point
   - Develop comprehensive microgrid EMS to improve the overall system efficiency

Fuel efficiency map for a 250-kW fossil-fuel engine (unit in legend: kg/kWh)



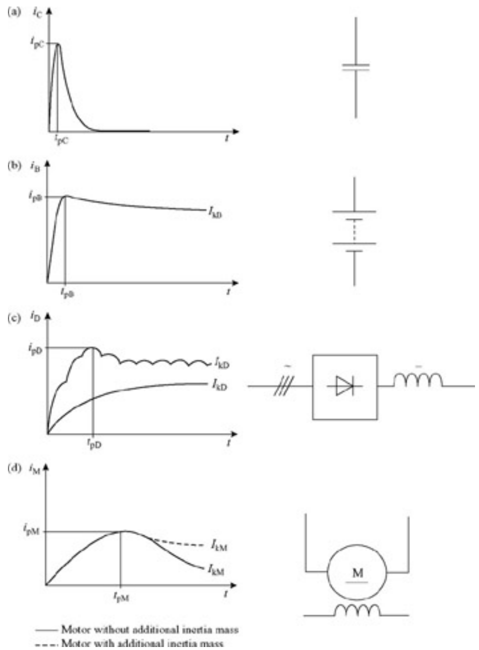


DC Microgrid Protection

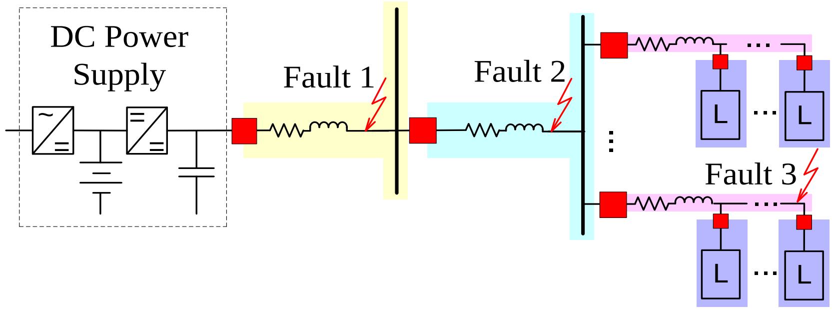
DC microgrid protection challenges

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

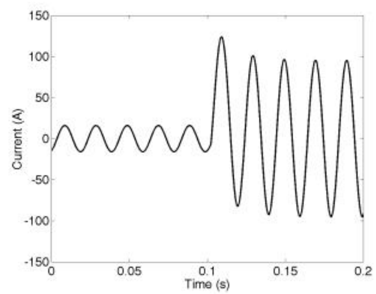
DC fault current



DC distribution system example



AC fault current



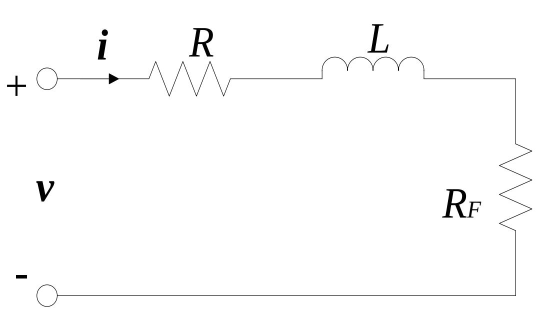
Fast DC Fault Localization Algorithm

Inductance-based dc fault location*

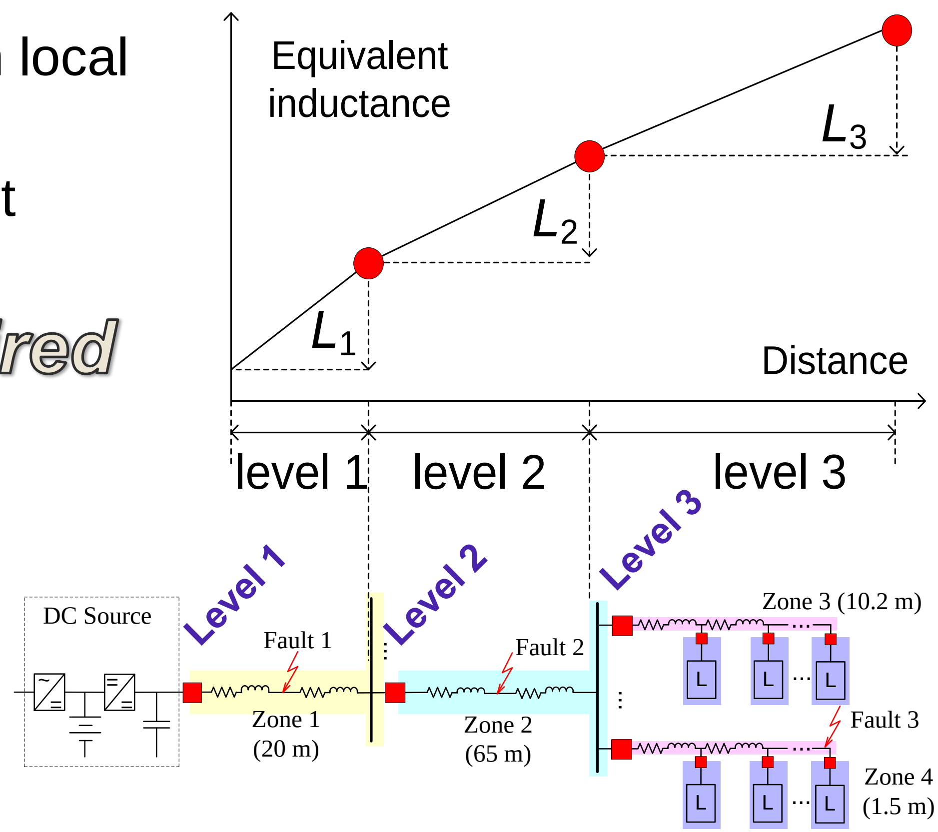
1. Estimate fault inductance with local measured *v*(*t*) and *i*(*t*)
2. Use estimated *L* to locate fault

No communication required

Equivalent fault circuit



Line inductance distribution

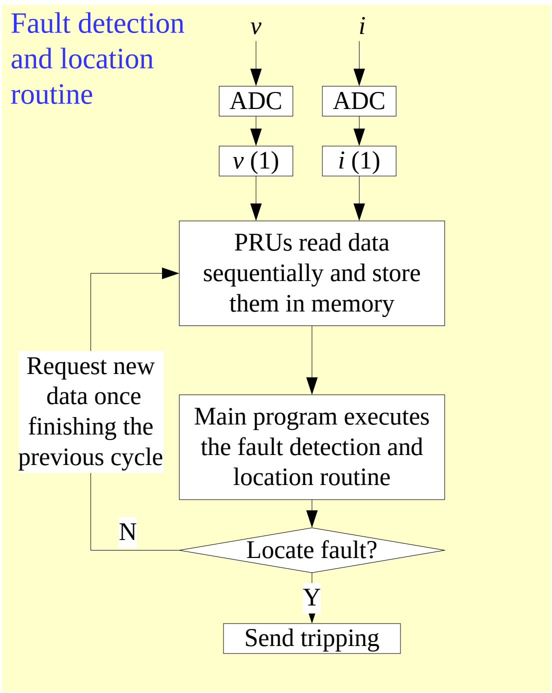


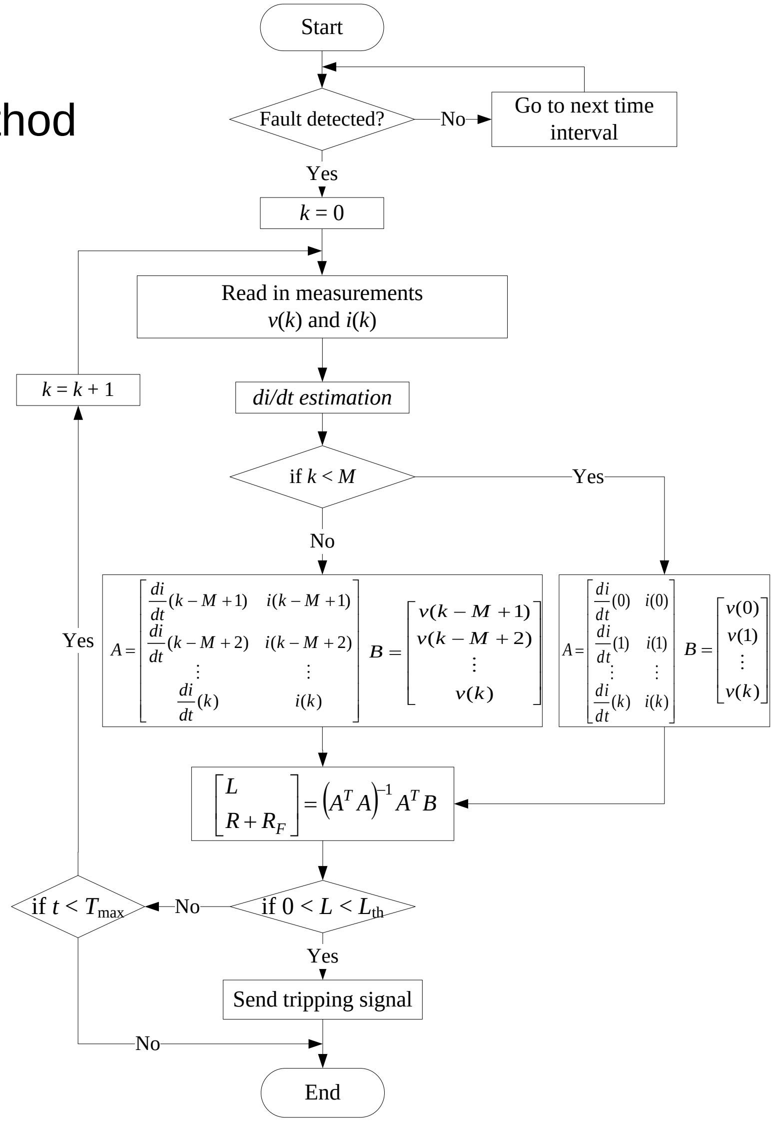
*X. Feng, et.al., "A novel fault location method for dc distribution protection," *IEEE Trans. Industrial Applications*, vol. 53, no. 3, May-June, 2017.

DC Protection Control Prototype

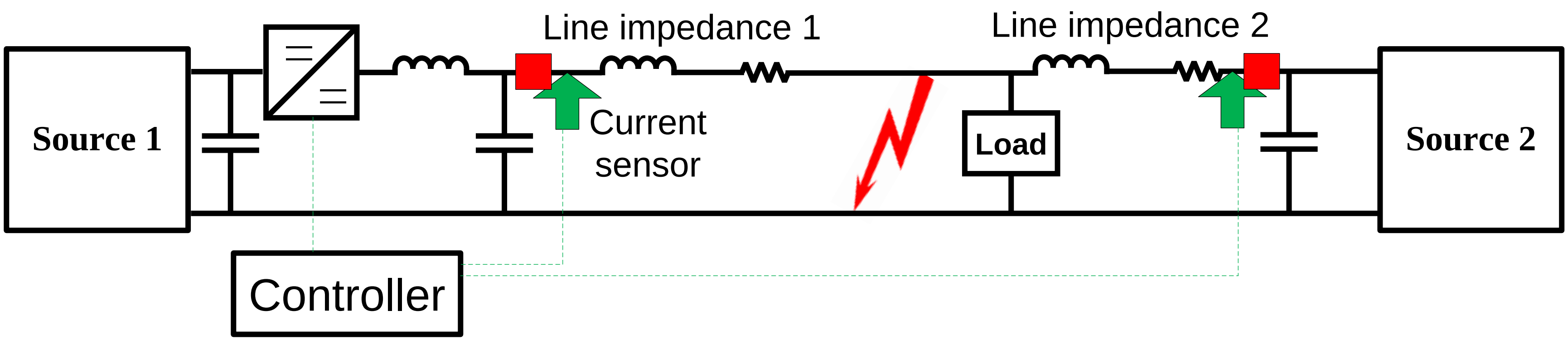
Protection strategy design

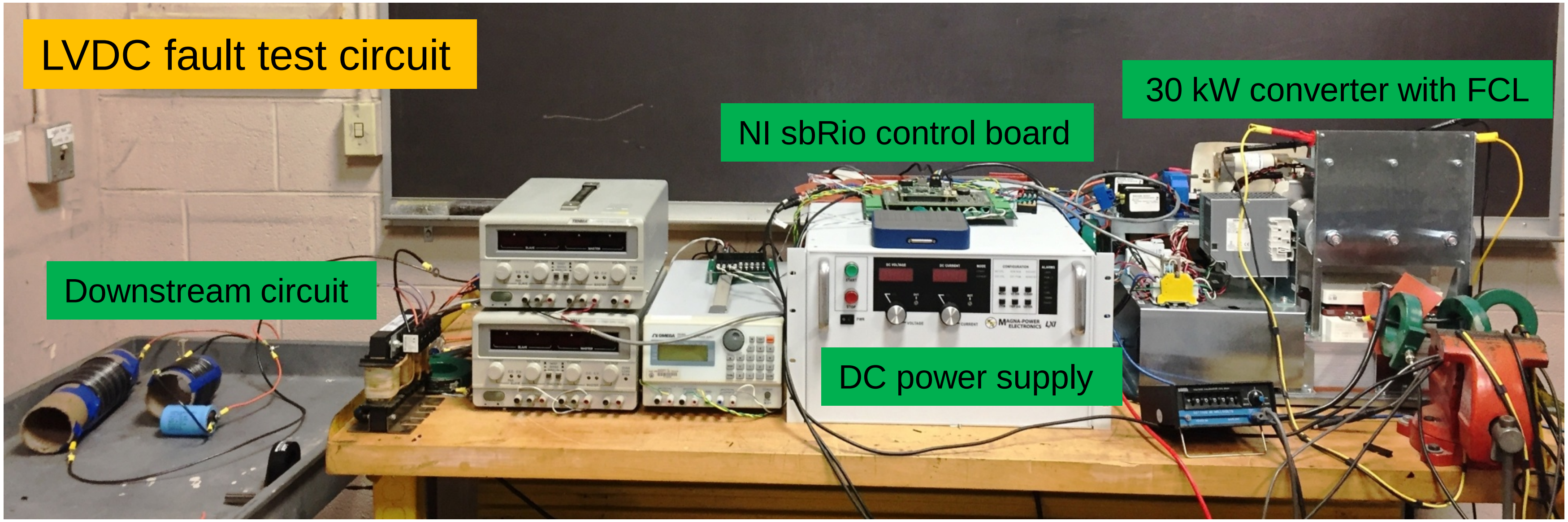
1. Online moving-window least square method
2. Digital di/dt approximation
3. Algorithm on embedded controller





DC Microgrid Protection Test





DC Protection Test Results

Test Circuit:

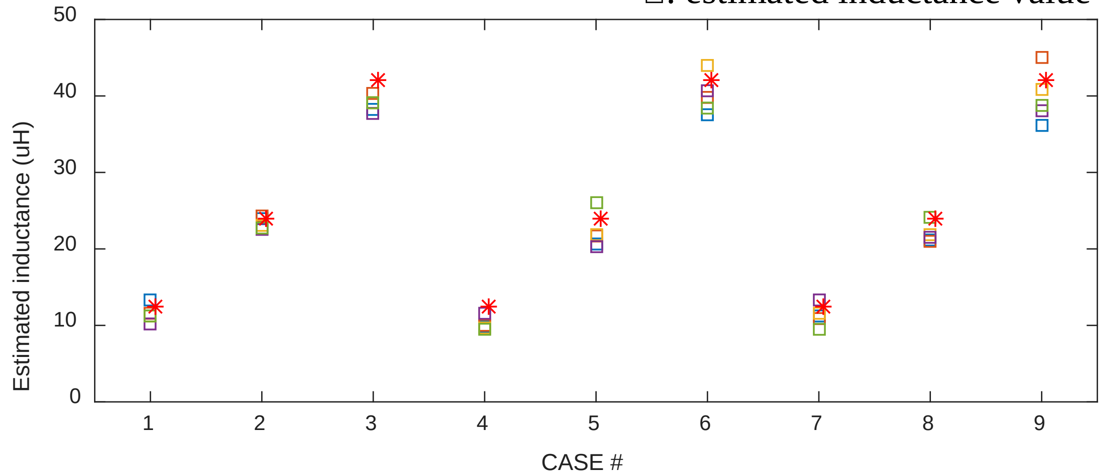
- Single dc source
- One line impedance connecting source and load
- Fault is on load side

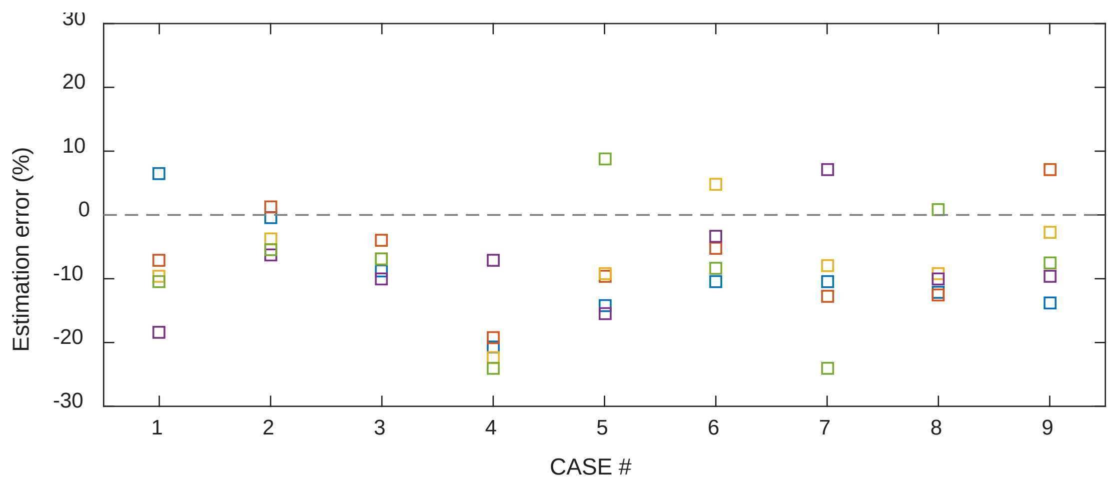
Test Scenarios

Case #	R_F (mΩ)	L (μH)
1	33	12.5
2	33	24
3	33	42
4	50	12.5
5	50	24
6	50	42
7	100	12.5
8	100	24
9	100	42

*5 tests in each case

*: measured inductance value
□: estimated inductance value





Summary

1. The look-ahead EMS approach fully utilizes the most recent load and renewable forecast to improve the predictive control accuracy
2. The decoupled DER schedule and real-time ED approach significantly reduces the computational complexity
3. DC prot. is enabling tech. for large-scale deployment of dc systems
4. Extra-fast fault location and restoration are keys for grid resilience

Thanks for your attention

Question?

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