SEL Microgrid Lessons Learned

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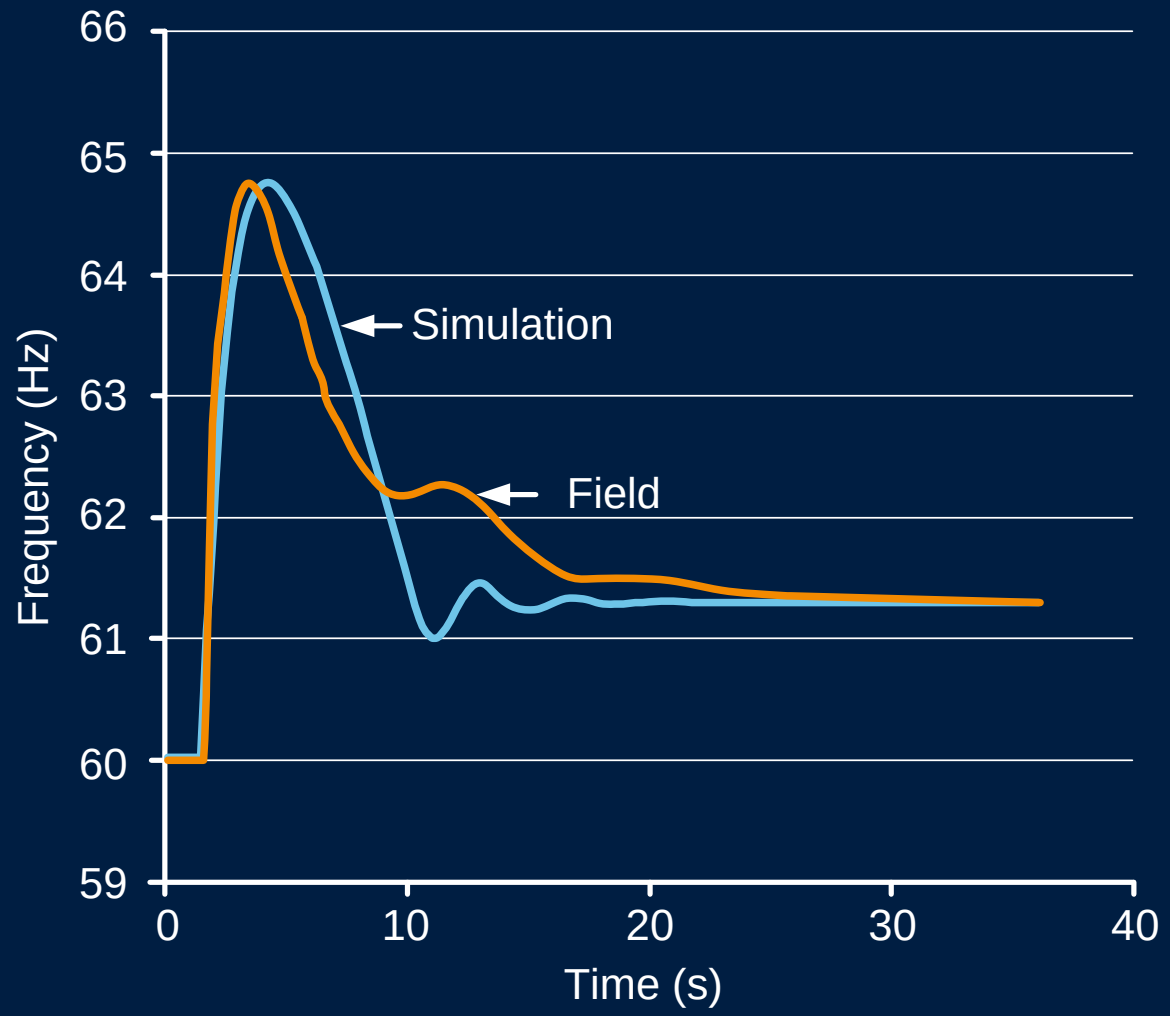
Essential Keys to Successful Microgrid Projects?

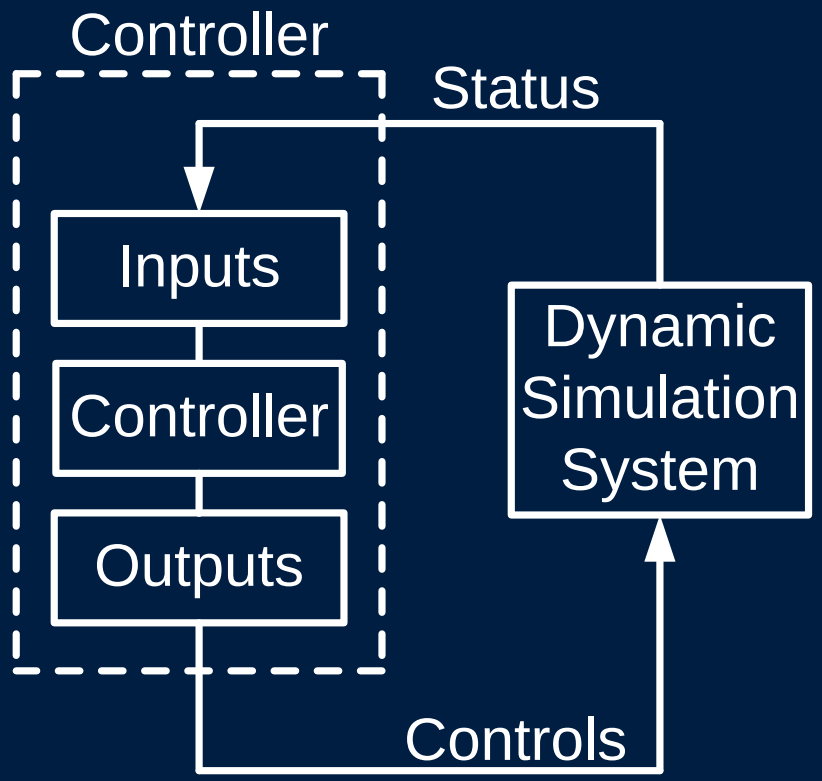
- Comprehensive HIL testing
- Subcycle fast controls
- Adaptive protection
- Practical security
- Fit for function
- Minimal complexity

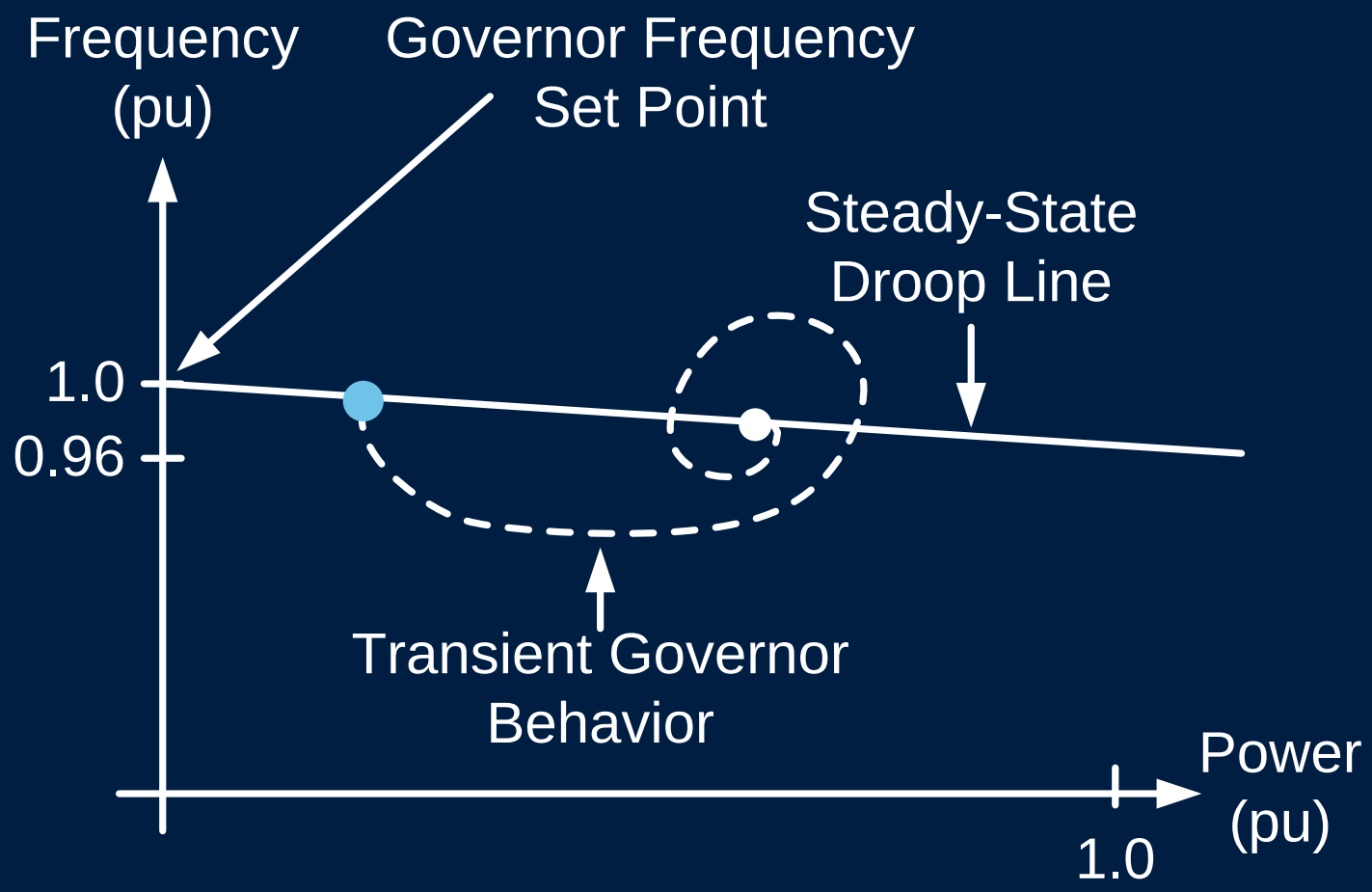
Hardware-in-the-Loop Testing Improves Factory Acceptance Tests



Control Cost, Quality, and Features

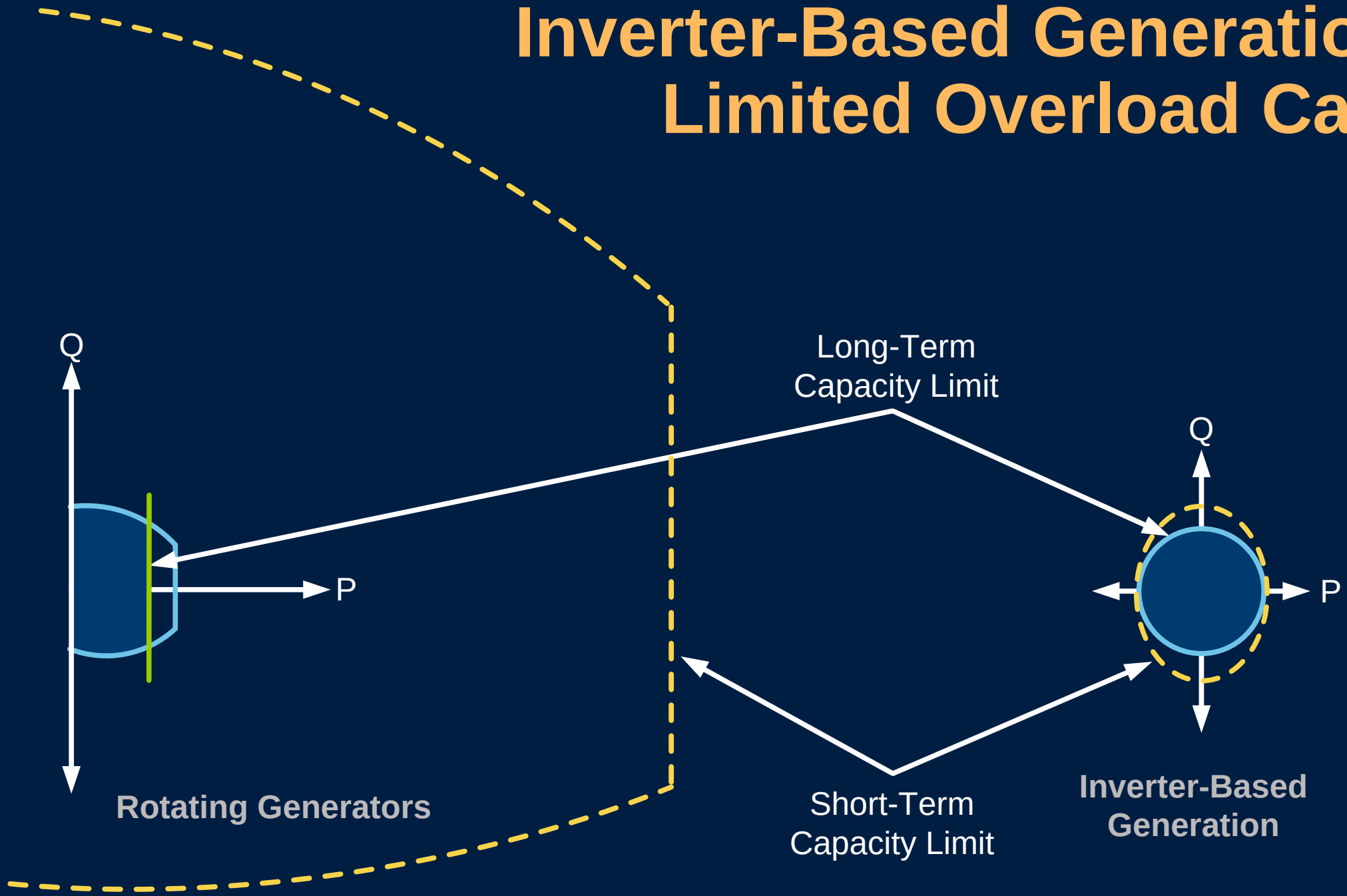
Hardware-in-the-Loop Testing



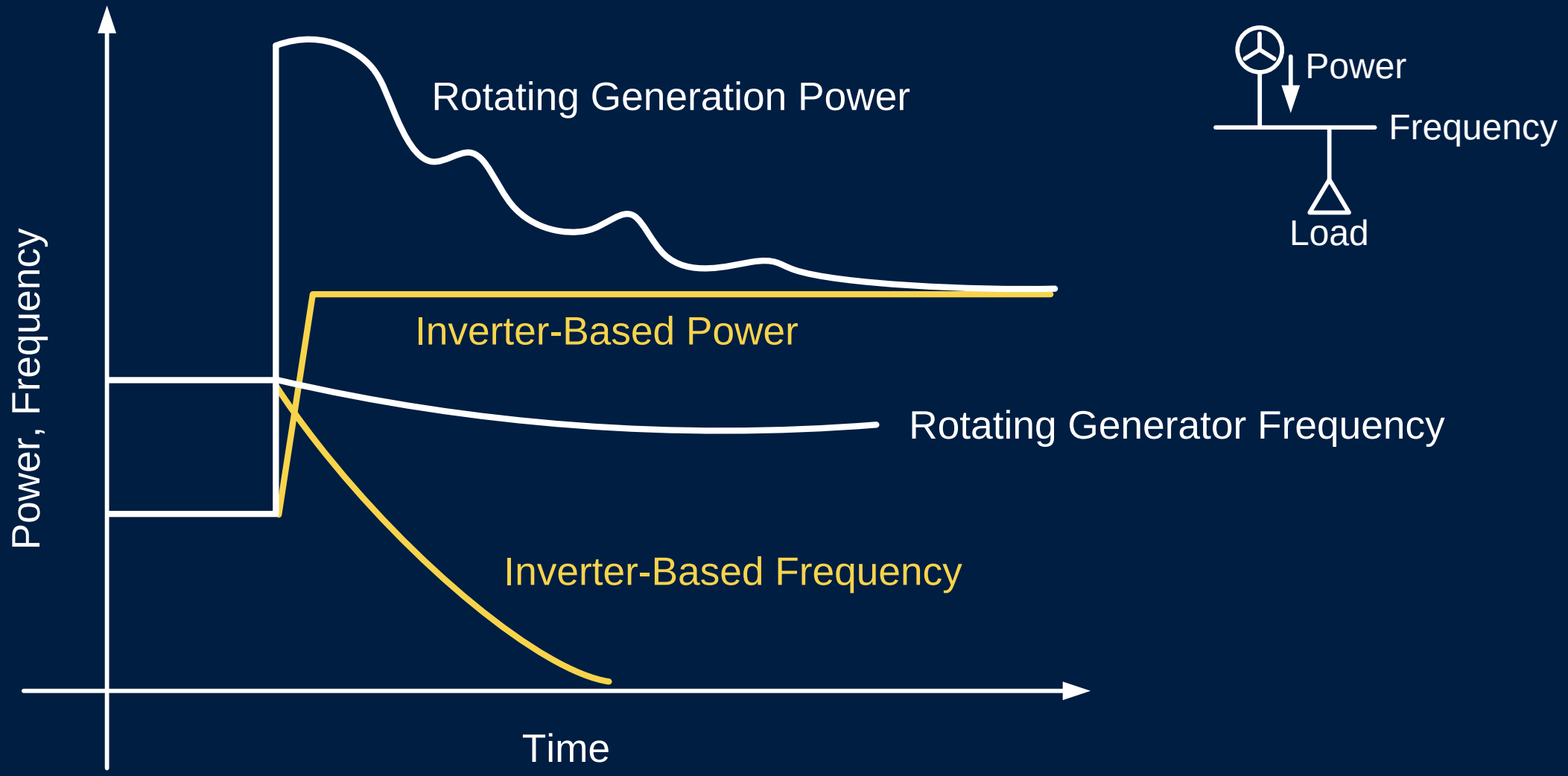


Both Mechanical and Electrical Systems Must Be Modeled Accurately

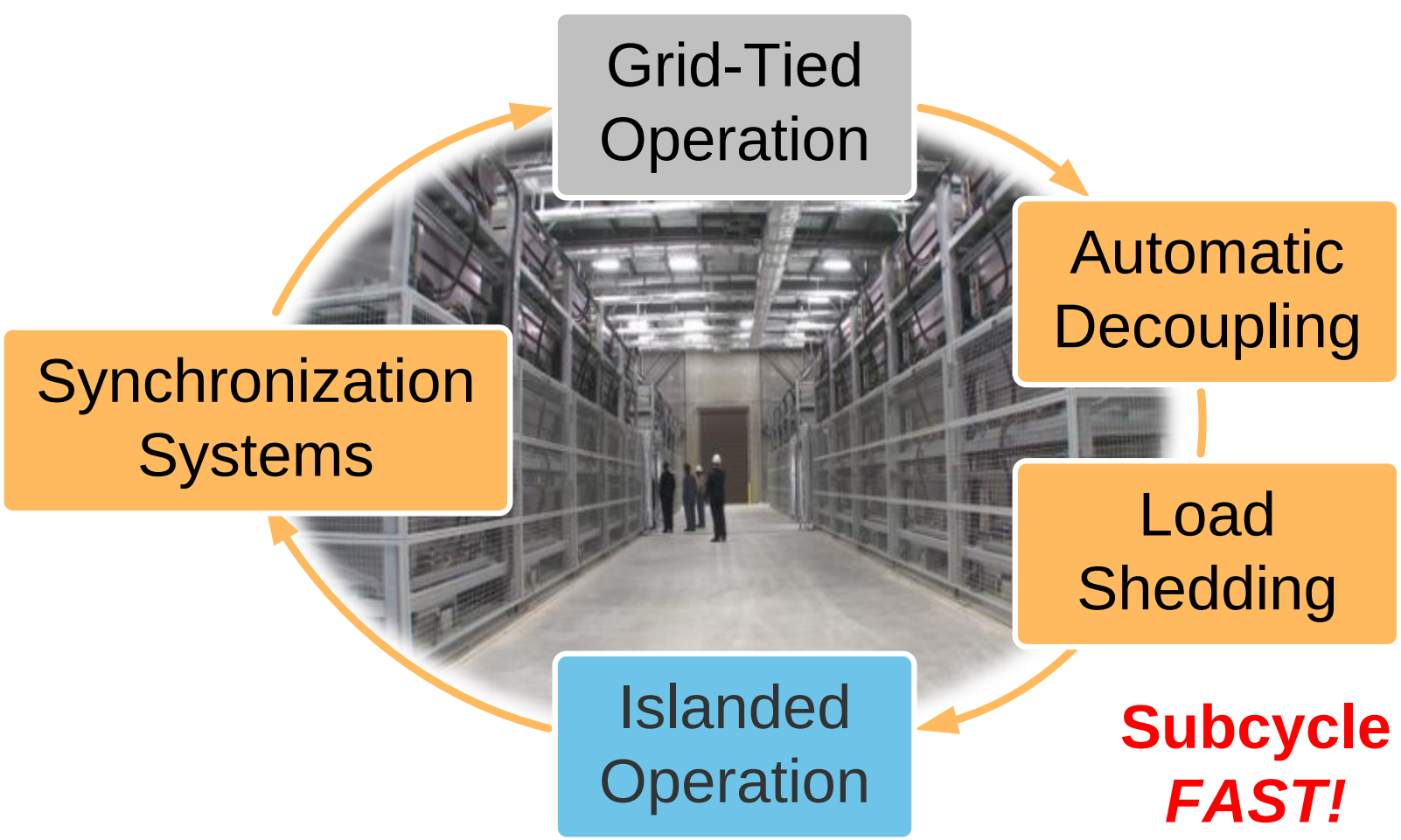
Inverter-Based Generation Has Limited Overload Capacity



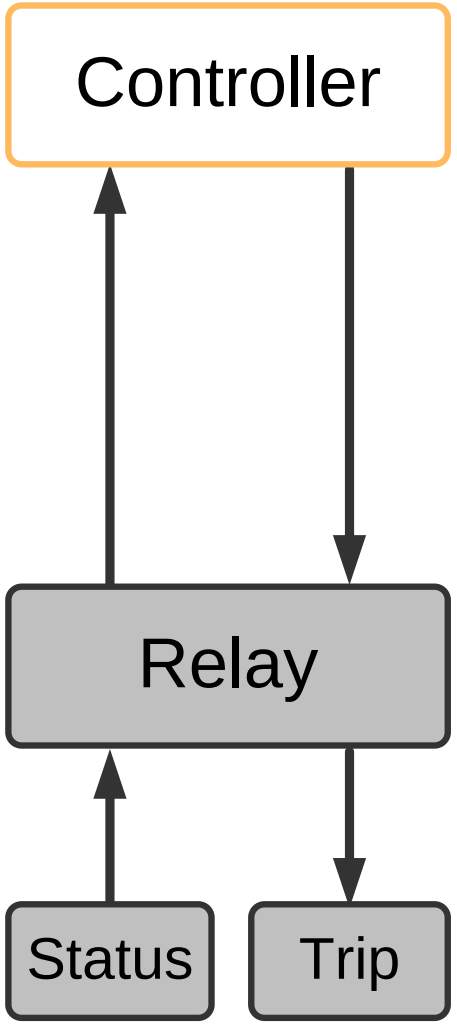
Load Balancing Must Happen *FASTER* With Inverter-Based Generation



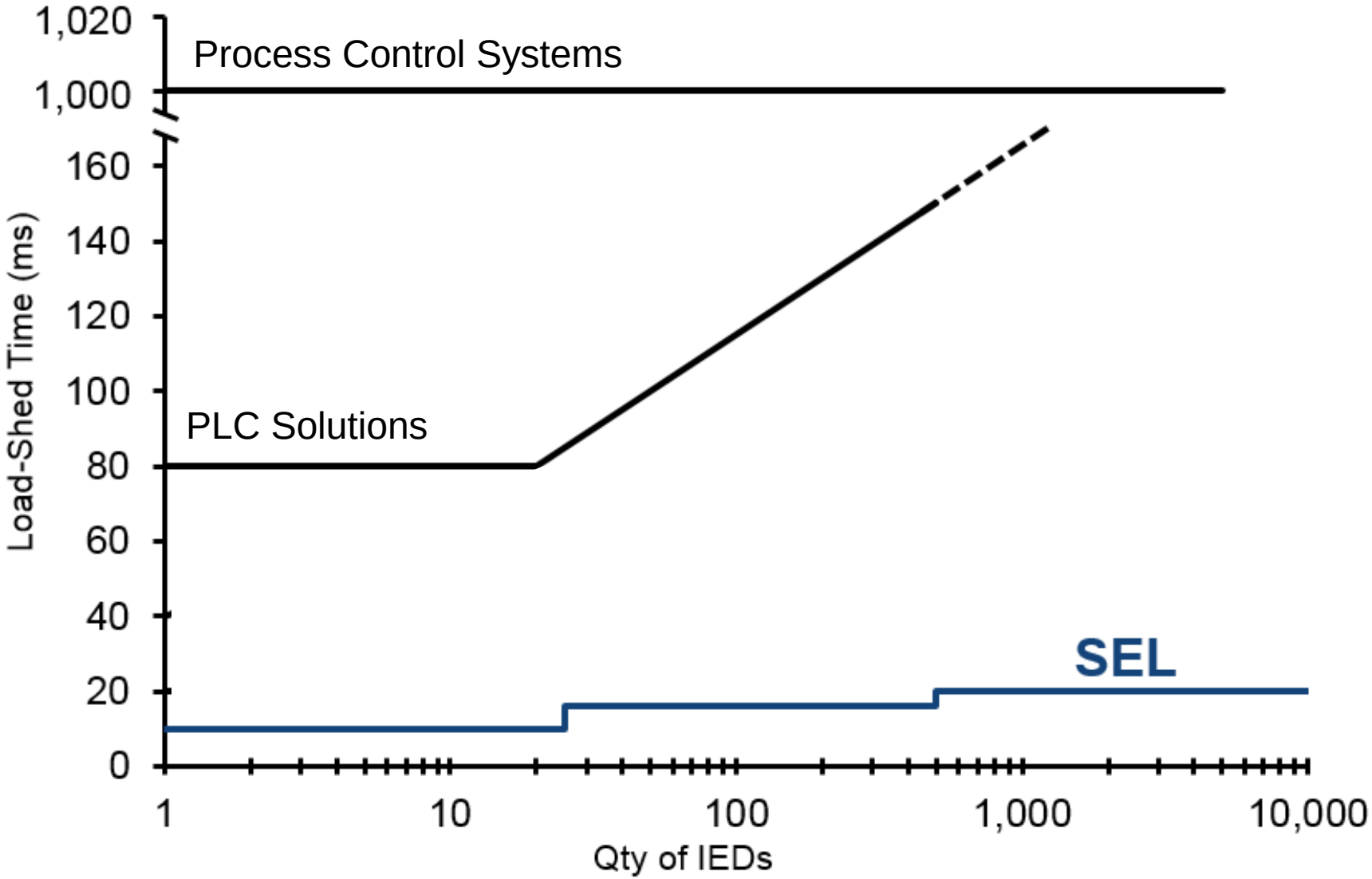
FAST Load Shedding Prevents Blackouts



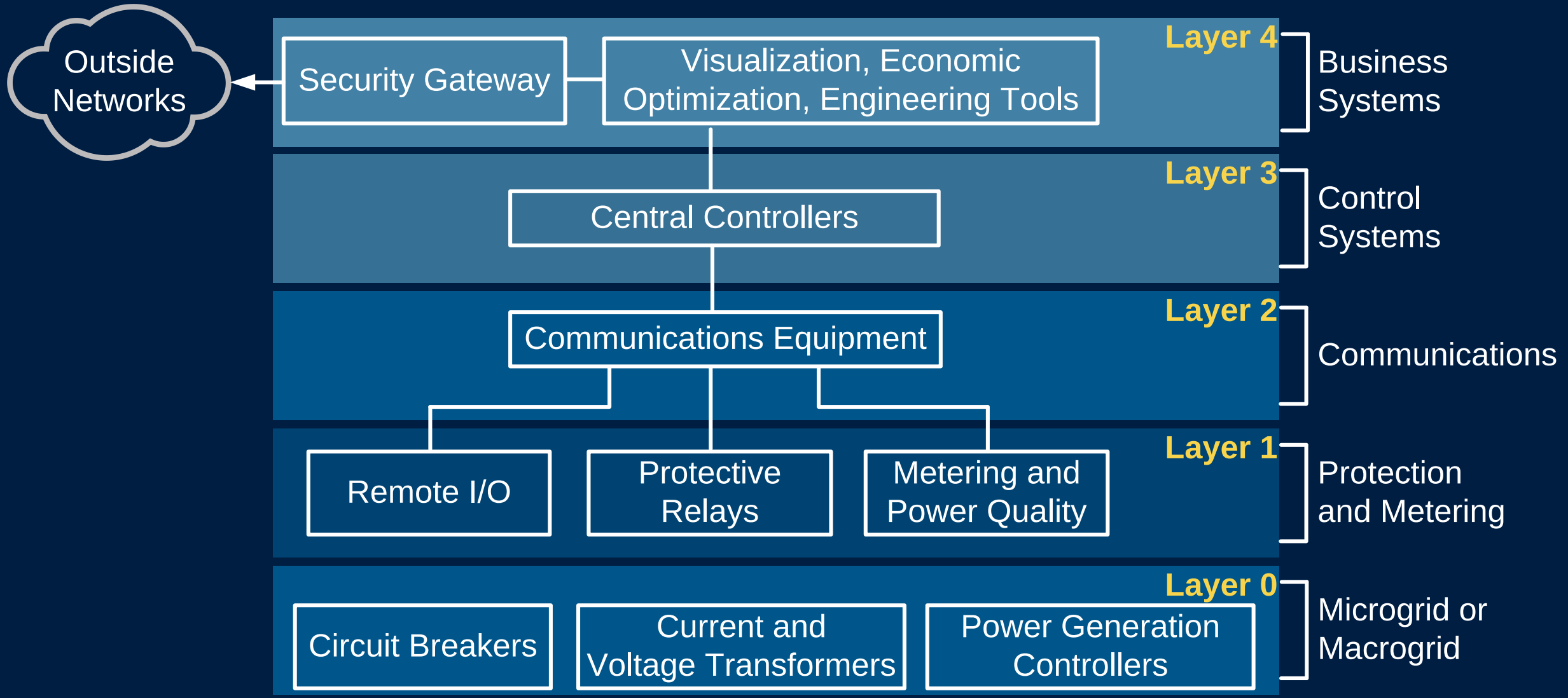
Subcycle *FAST!*



SEL Controllers Take Action *FASTER*



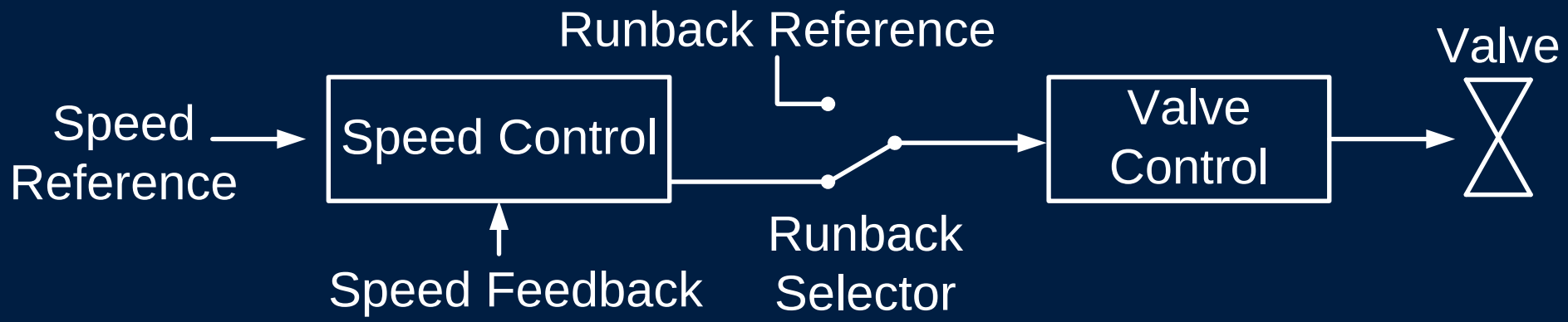
Protection, Automation, Controls, and Security

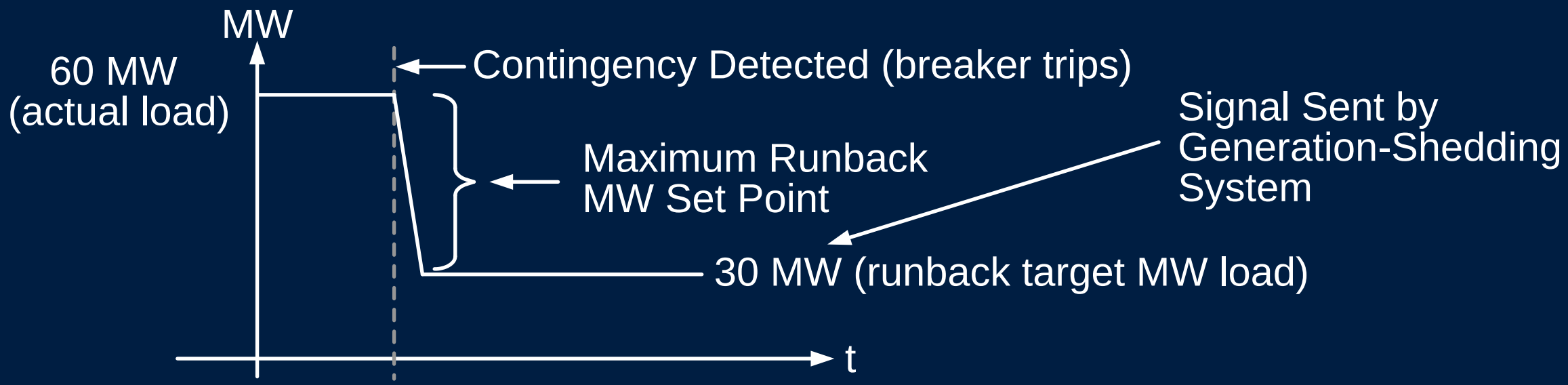


Security for Critical Infrastructure

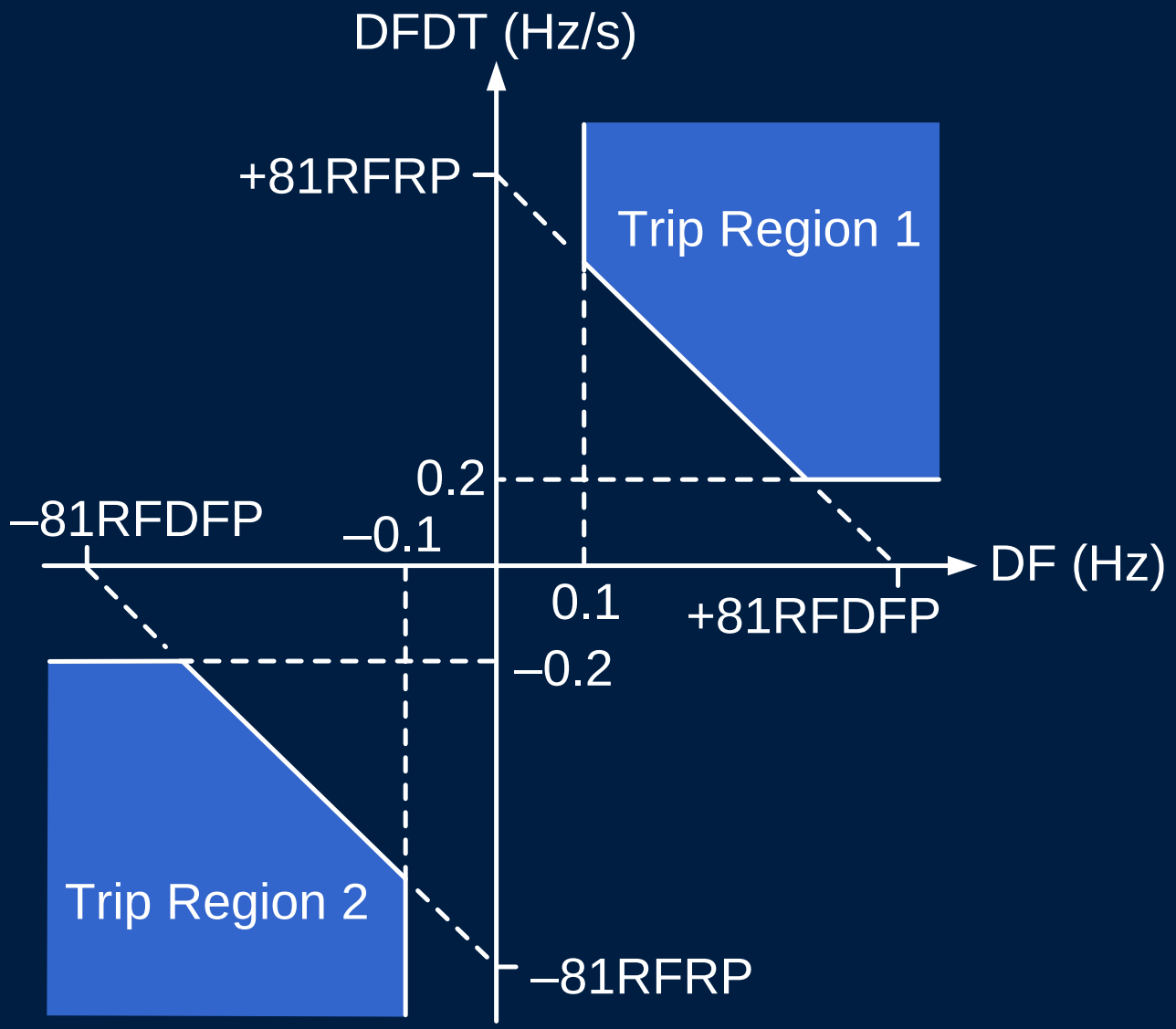
- Avoid OS and software
- Made in the USA
- Mature processes
- Vertical integration
- Cybersecurity

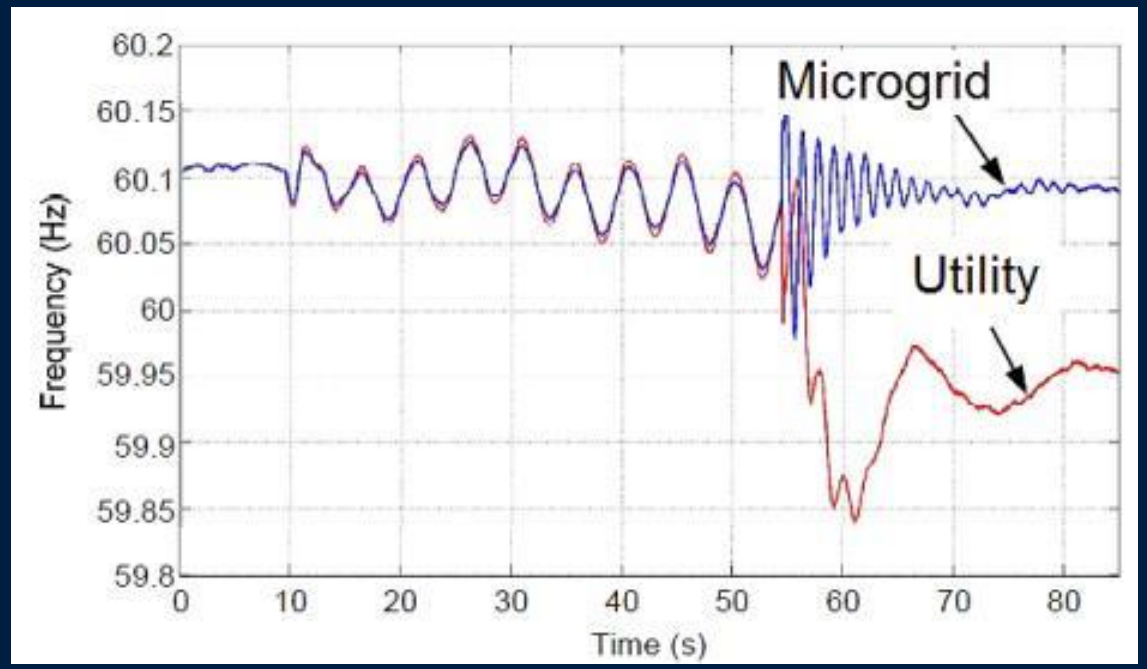
Generation Runback Philosophy



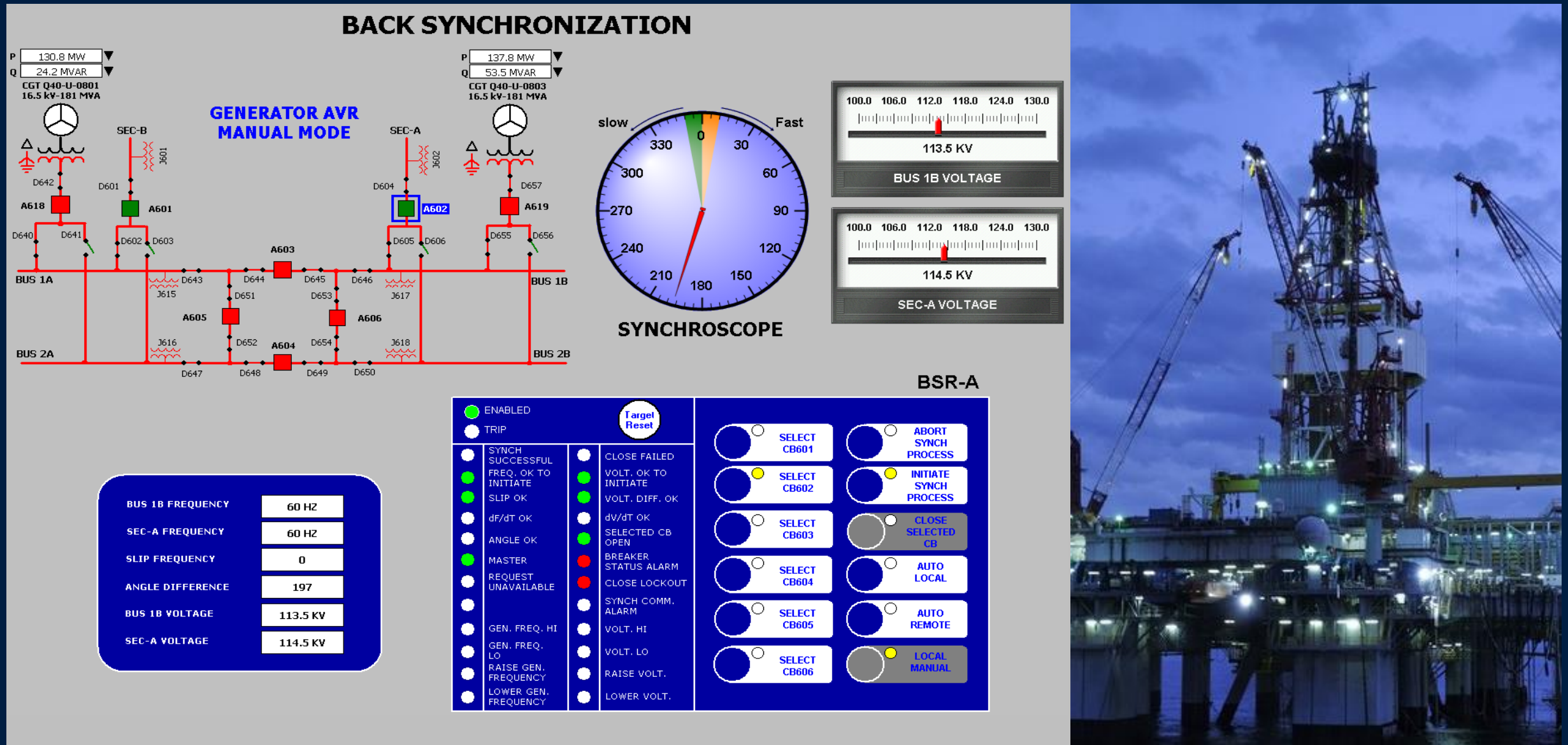


Seamless Islanding and Decoupling Systems



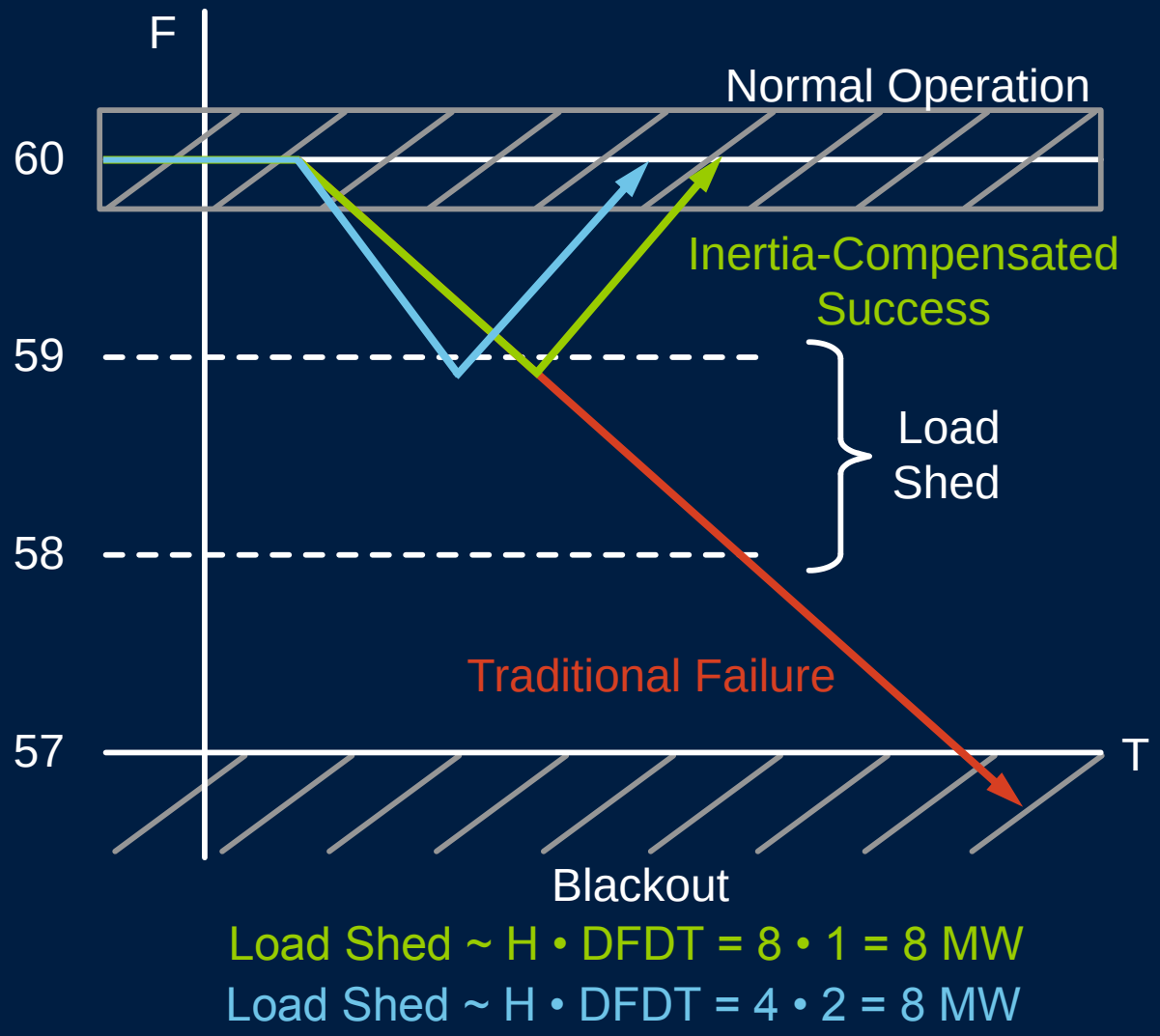


System Synchronization
Safely Reconnecting Islanded Grids



Inertia-Compensated Load Shedding

Do It Right!

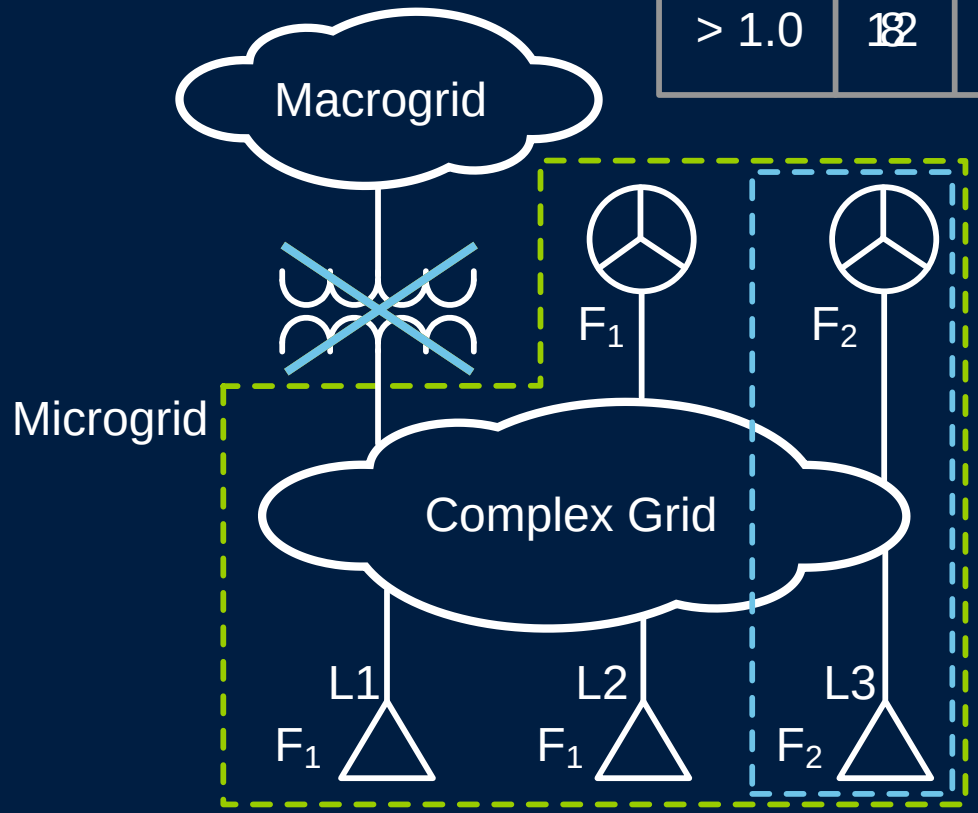


Load Shed ~ H • DFDT = 8 • 1 = 8 MW

Load Shed ~ H • DFDT = 4 • 2 = 8 MW

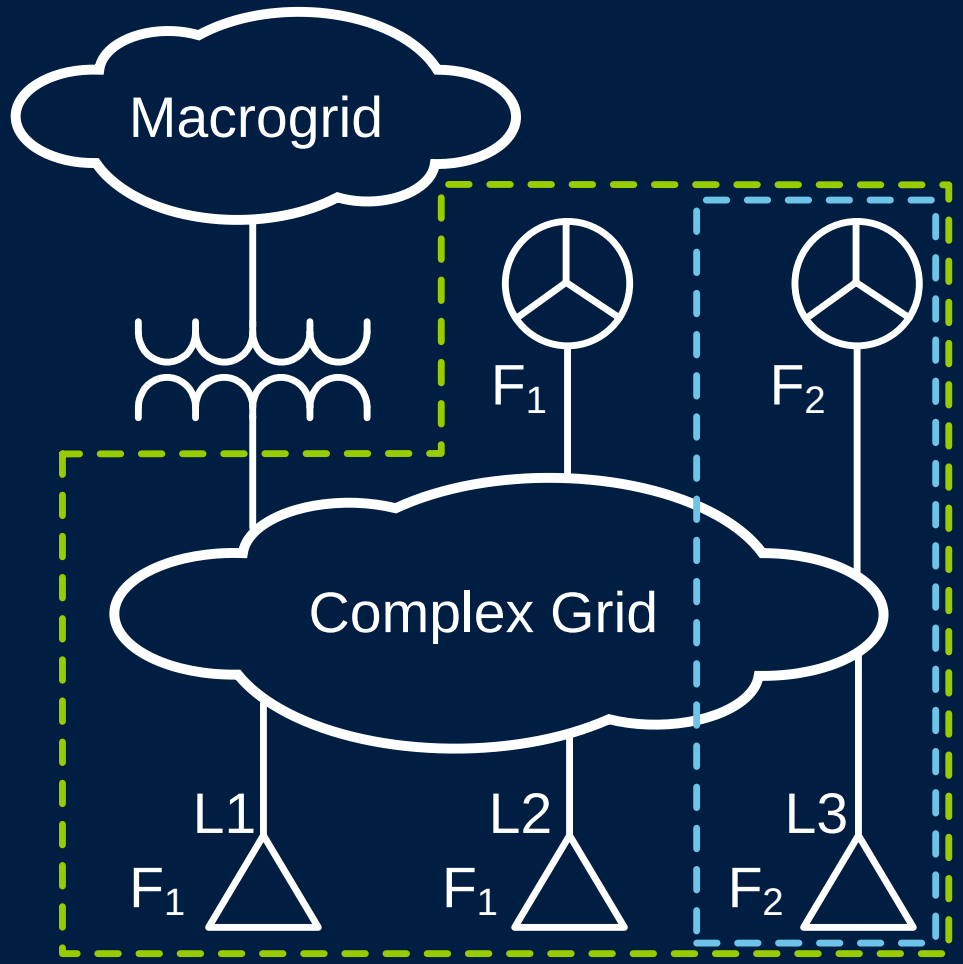
MW Load to Shed

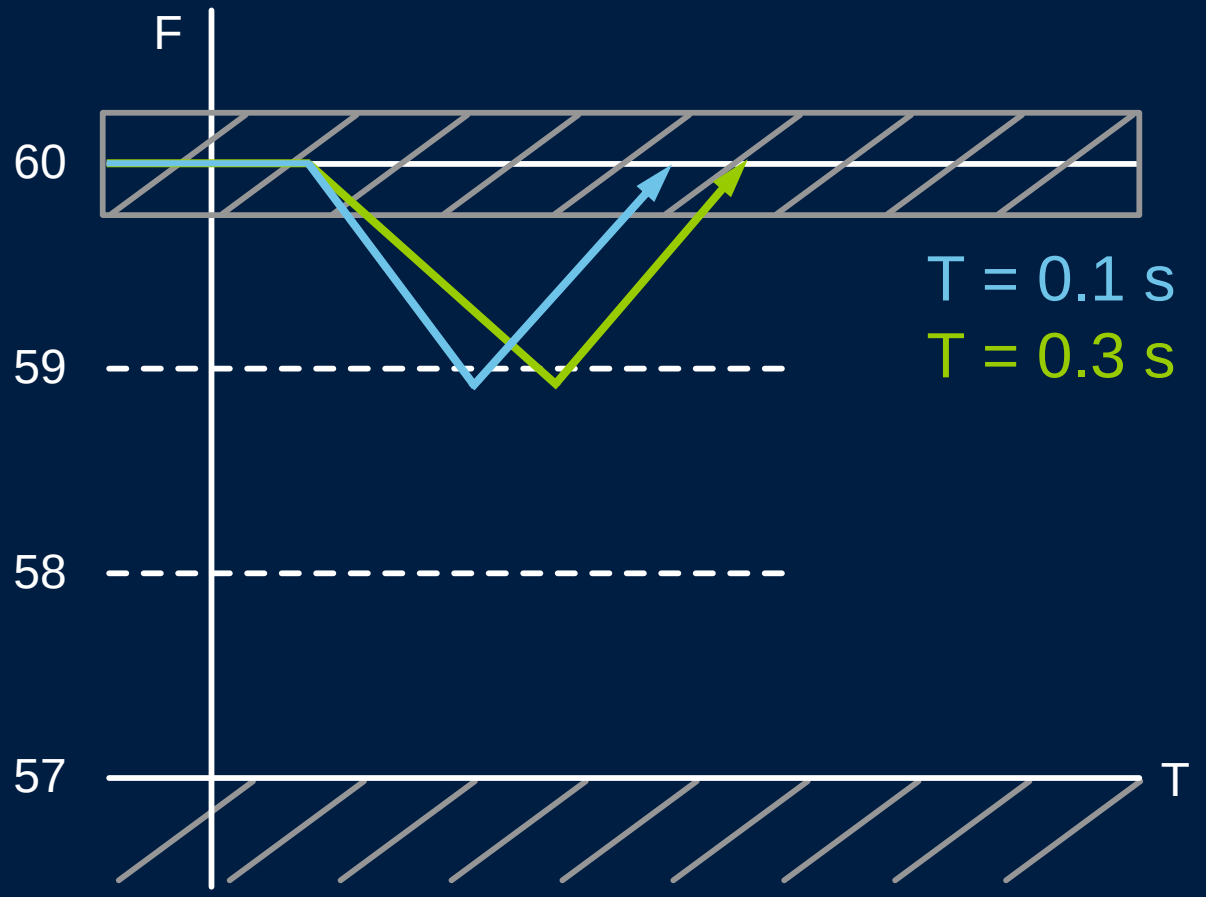
DFDT \ F	59	58
< 0.5	2	4
0.5 to 1.0	4	8
> 1.0	8	16



Load Tracking – Add Your H's

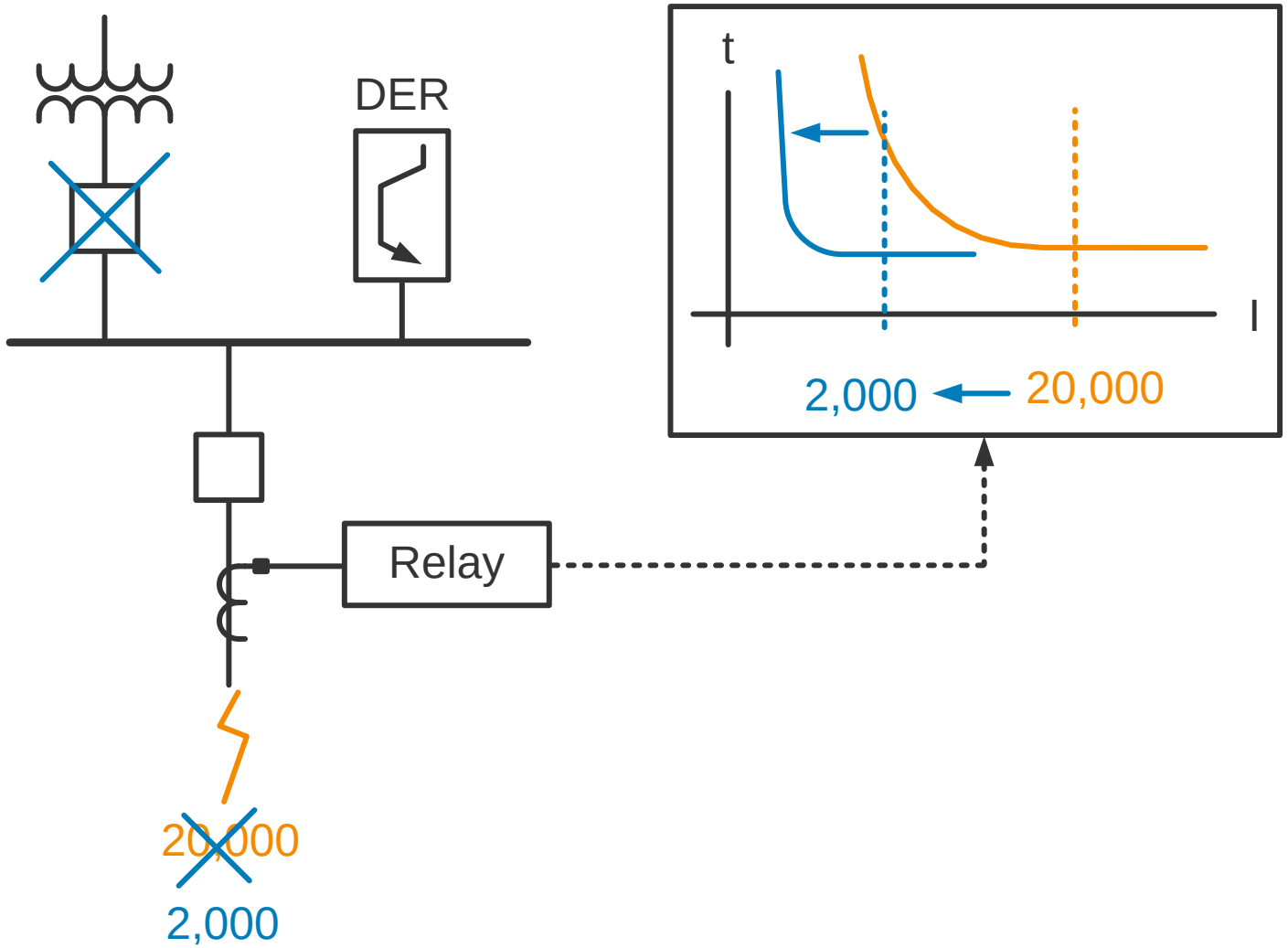
Discriminate Islands With Time



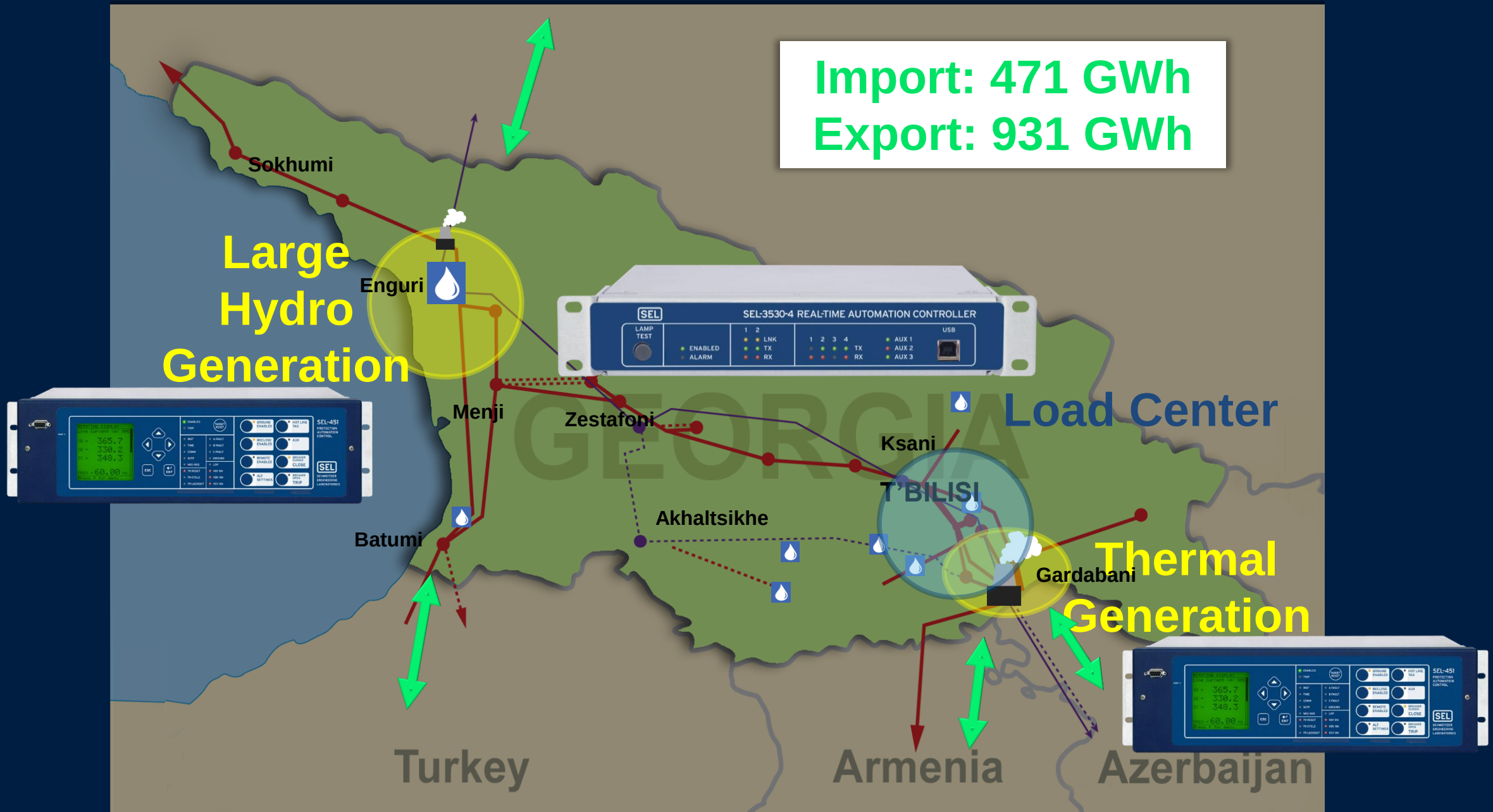


Protection Must *ADAPT* To Changing Fault Conditions

- Fault levels
- Grounding
- Directions
- Impedances

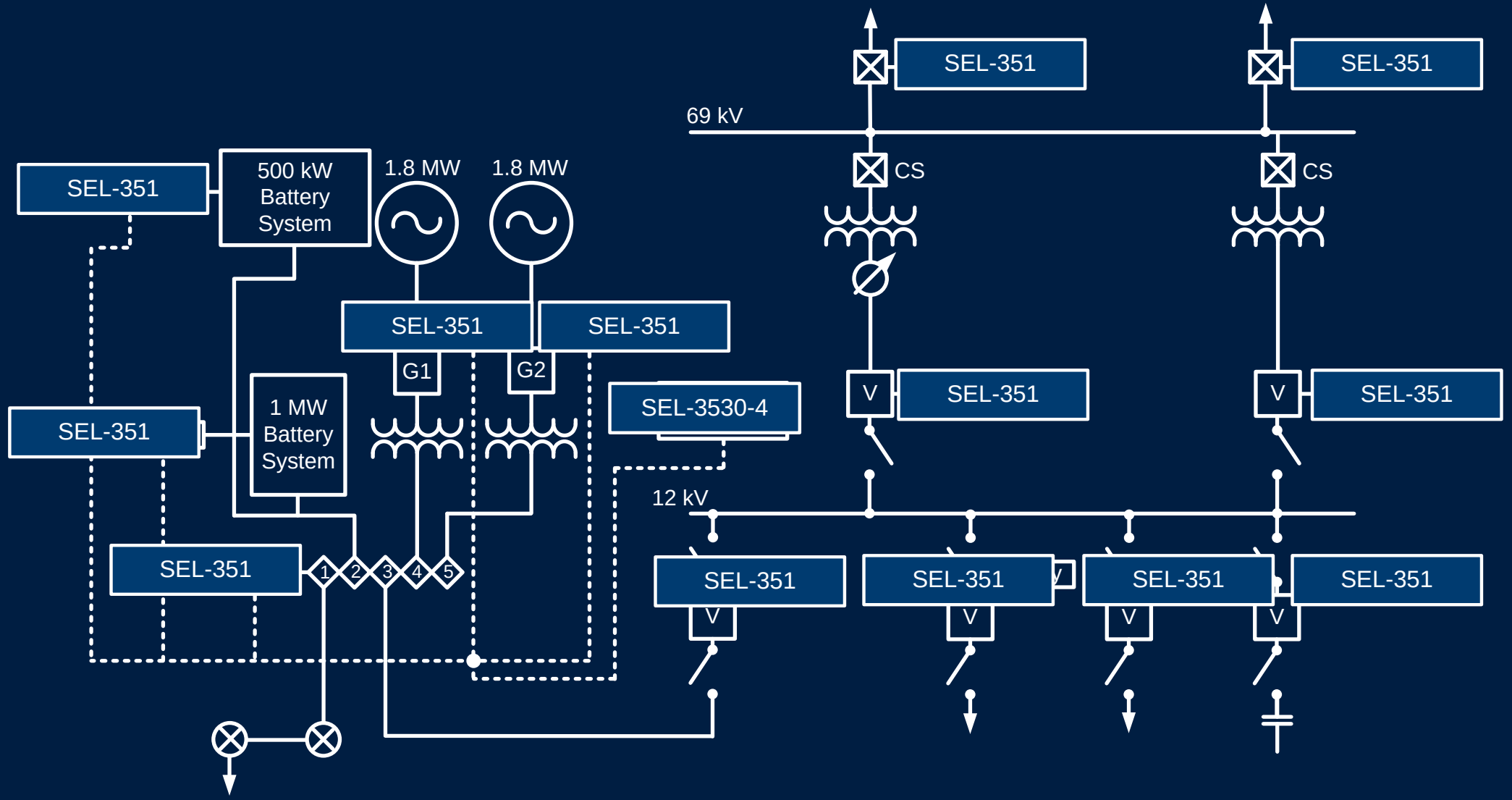


Physics Are the Same – Big or Small



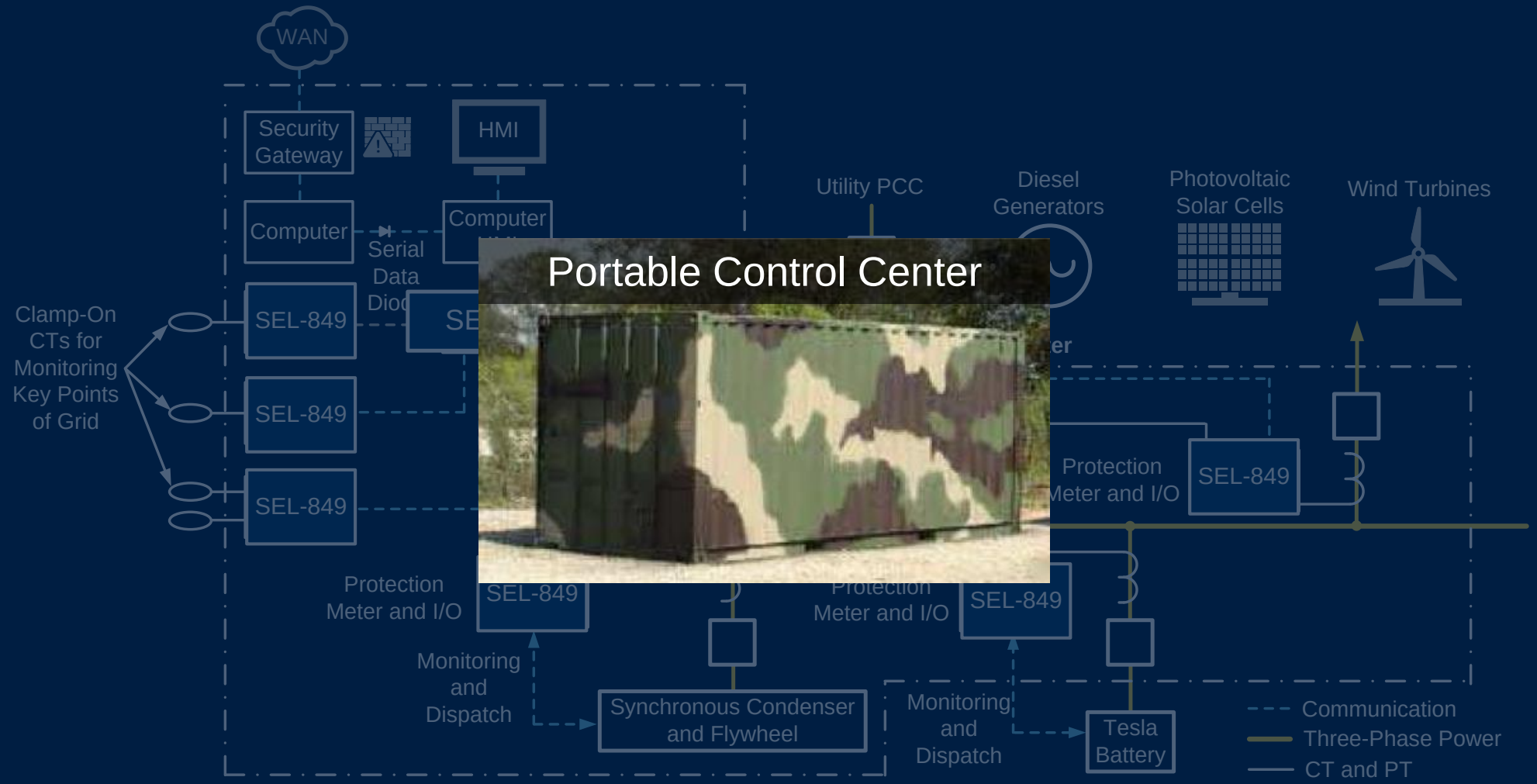
Physics Are the Same – Simple or Complex

Borrego Microgrid



Navy Seabees, U.S. Navy

Portable Microgrid Controls, Protection, and Security



Rugged and Economical for Restricted Budgets

DGs, wind turbines, synchronous condenser, flywheel, and loads

- Load shedding
- Voltage / VAR optimization
- Frequency / power dispatch
- Autosynchronization
- Decoupling
- Comprehensive HIL testing

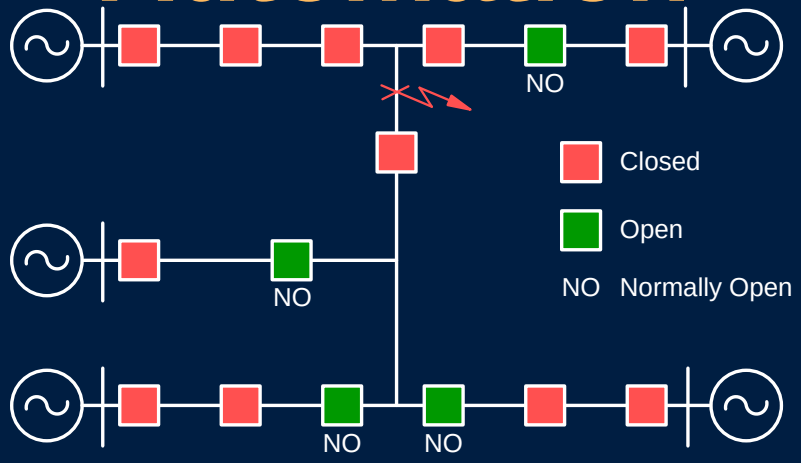
UCSD San Diego, California

- Load shedding
- Underfrequency load shedding
- Synchrophasor-based monitoring, recording, and grid decoupling system
- Comprehensive HIL testing
- Radio-based high-speed contingency detection
- Complete SCADA, panel, and SOE logging
- Natural gas generators, steam generators, emergency DGs, and fuel cells

Industrial and utility technology, procedures, modeling, testing, and commissioning methods were a perfect fit!

Engineering Services in U.S. and Canada

Distribution Automation



Questions?