



# SEL Microgrid Lessons Learned

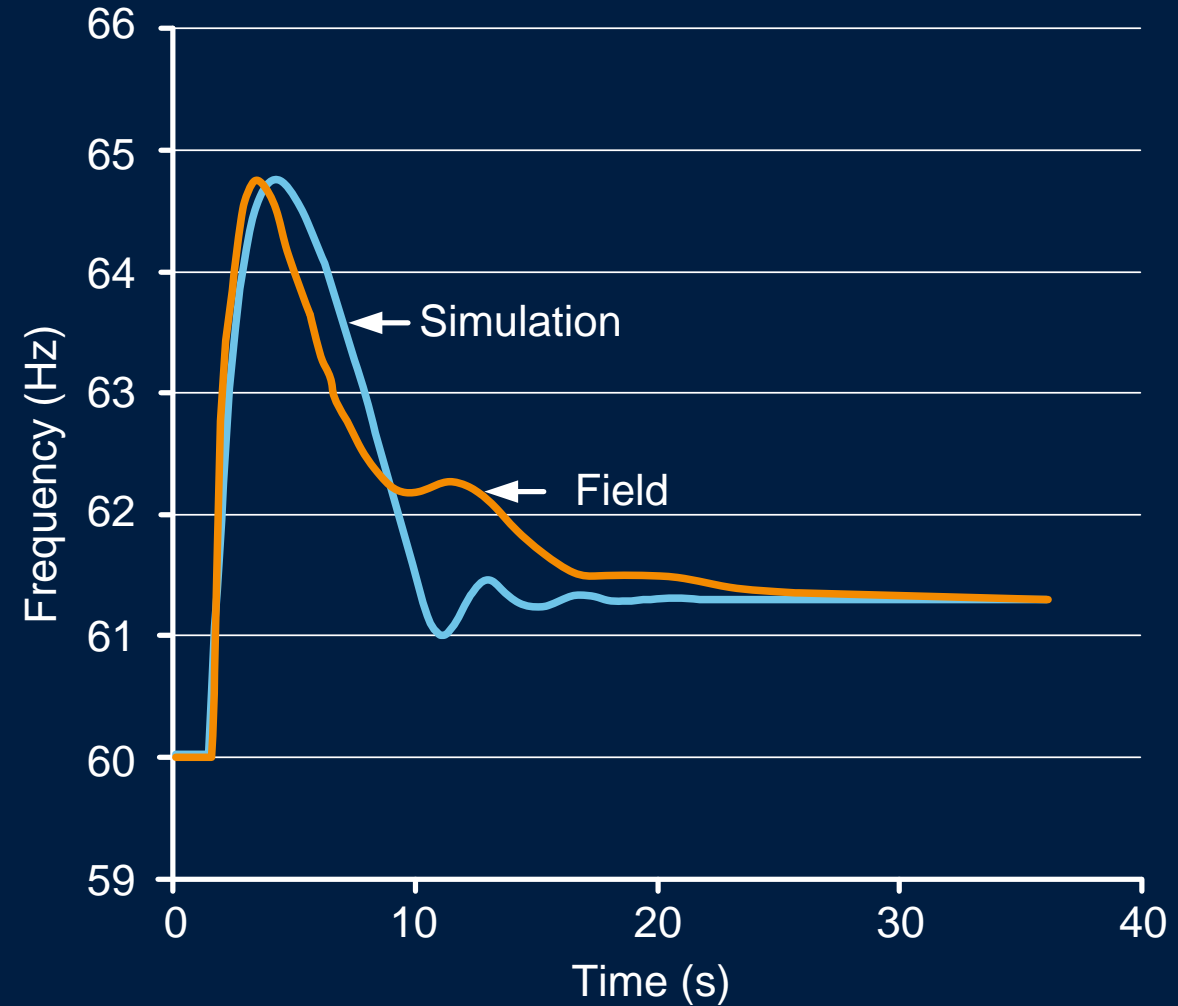
*Will Edwards  
(SEL Engineering Services Division)*



# Essential Keys to Successful Microgrid Projects?

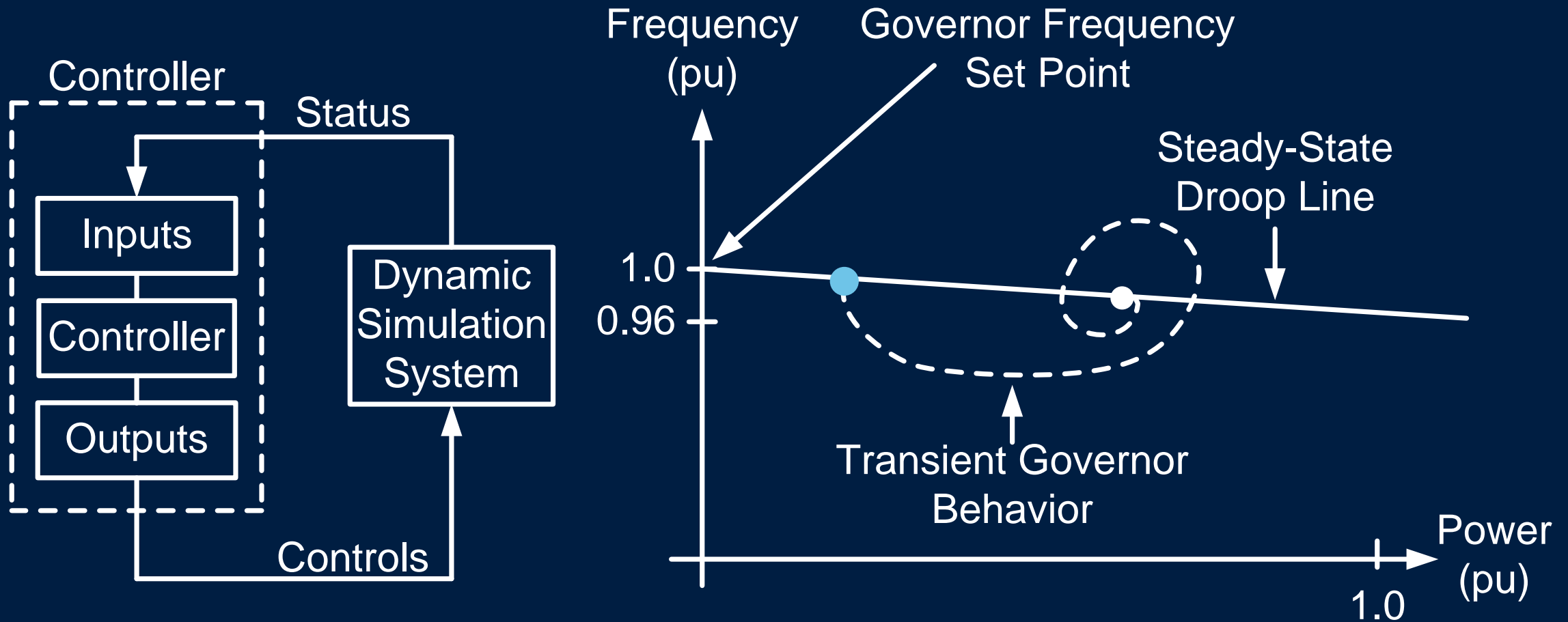
- Comprehensive HIL testing
- Subcycle fast controls
- Adaptive protection
- Practical security
- Fit for function
- Minimal complexity

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



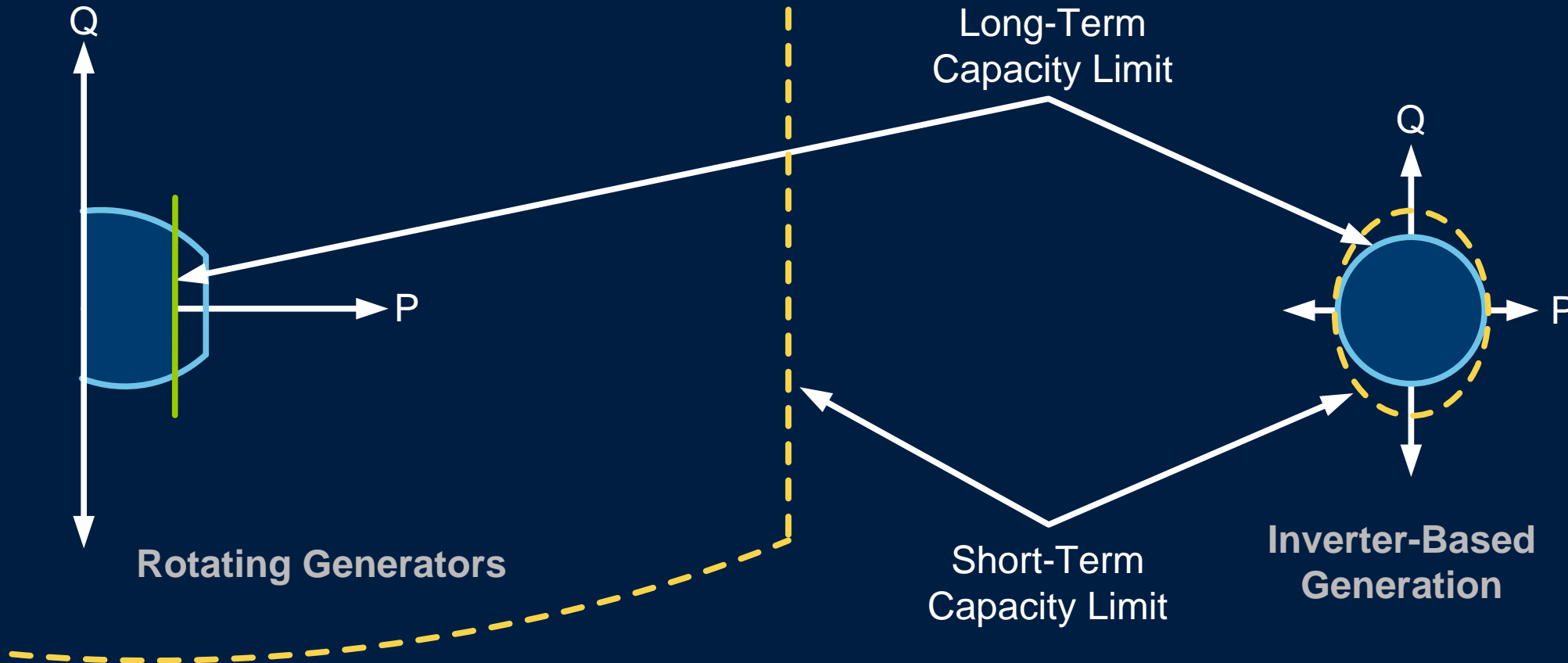
# Control Cost, Quality, and Features

## Hardware-in-the-Loop Testing

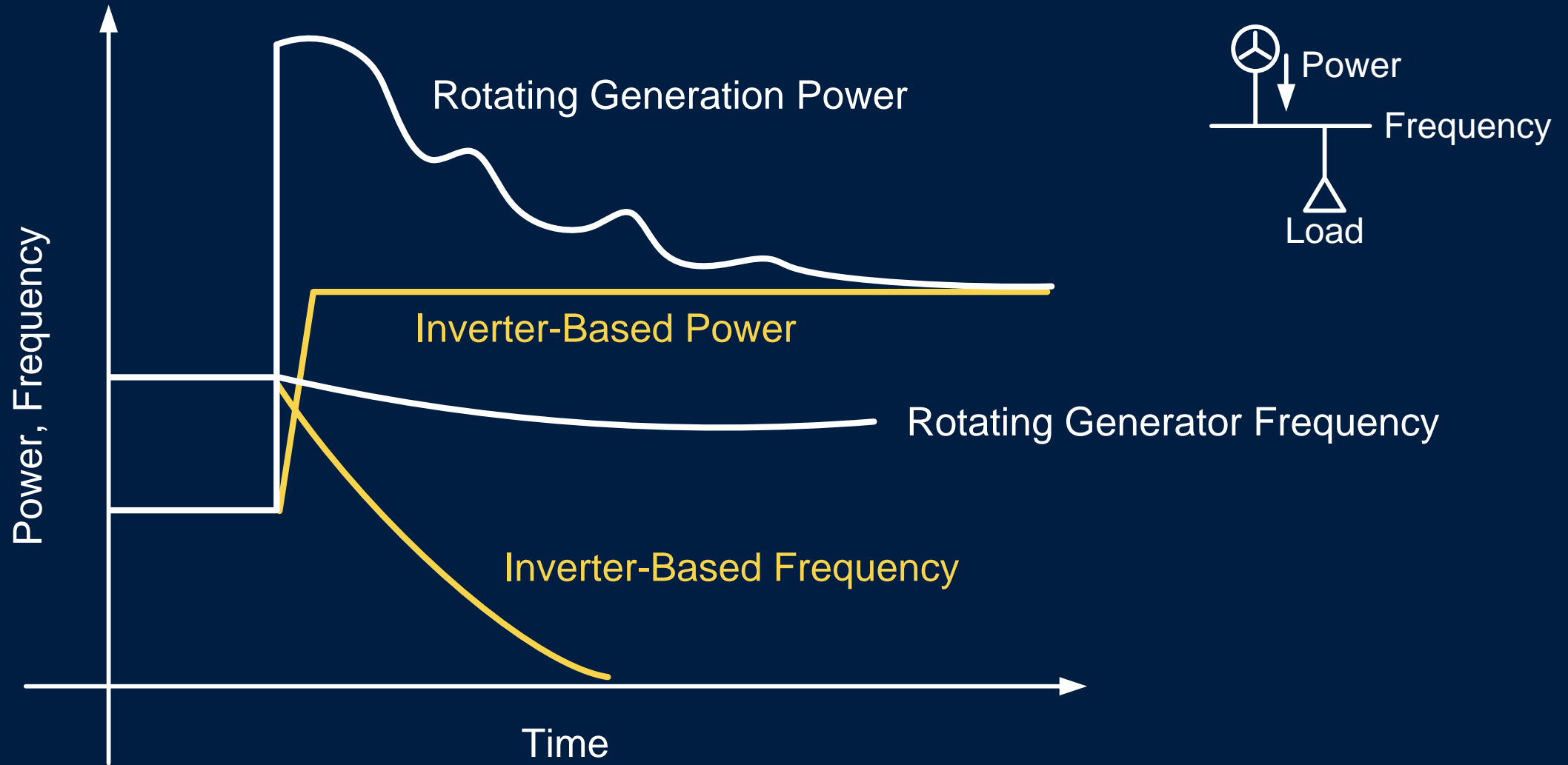


Both Mechanical and Electrical Systems Must Be Modeled Accurately

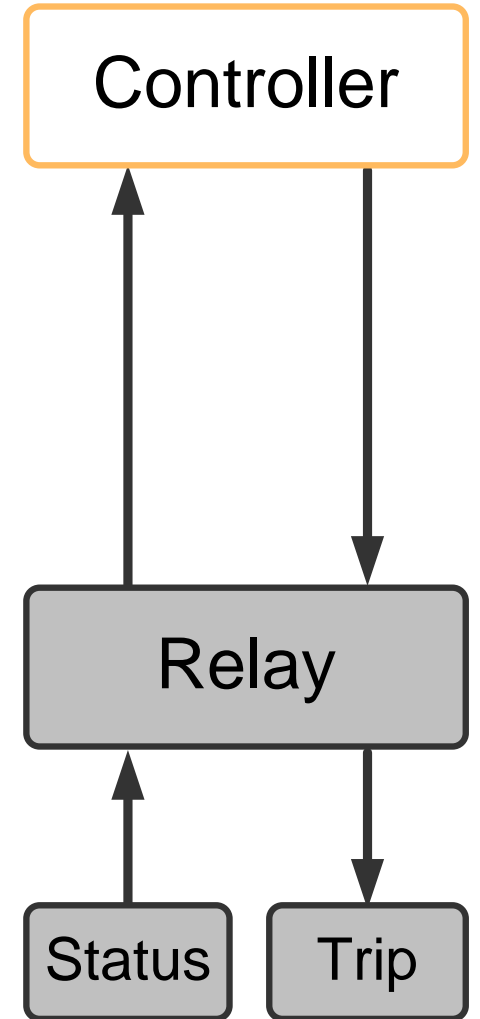
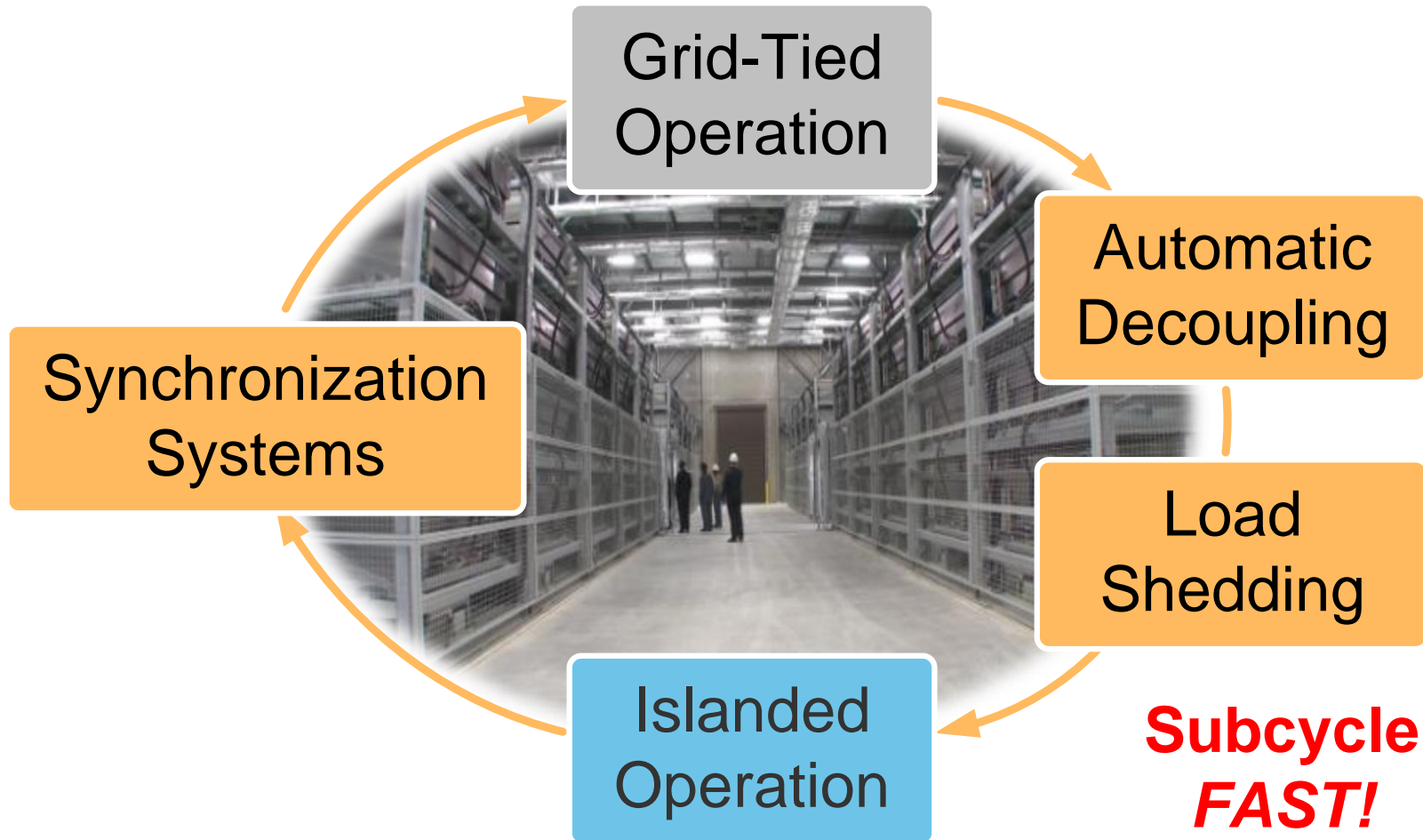
# Inverter-Based Generation Has Limited Overload Capacity



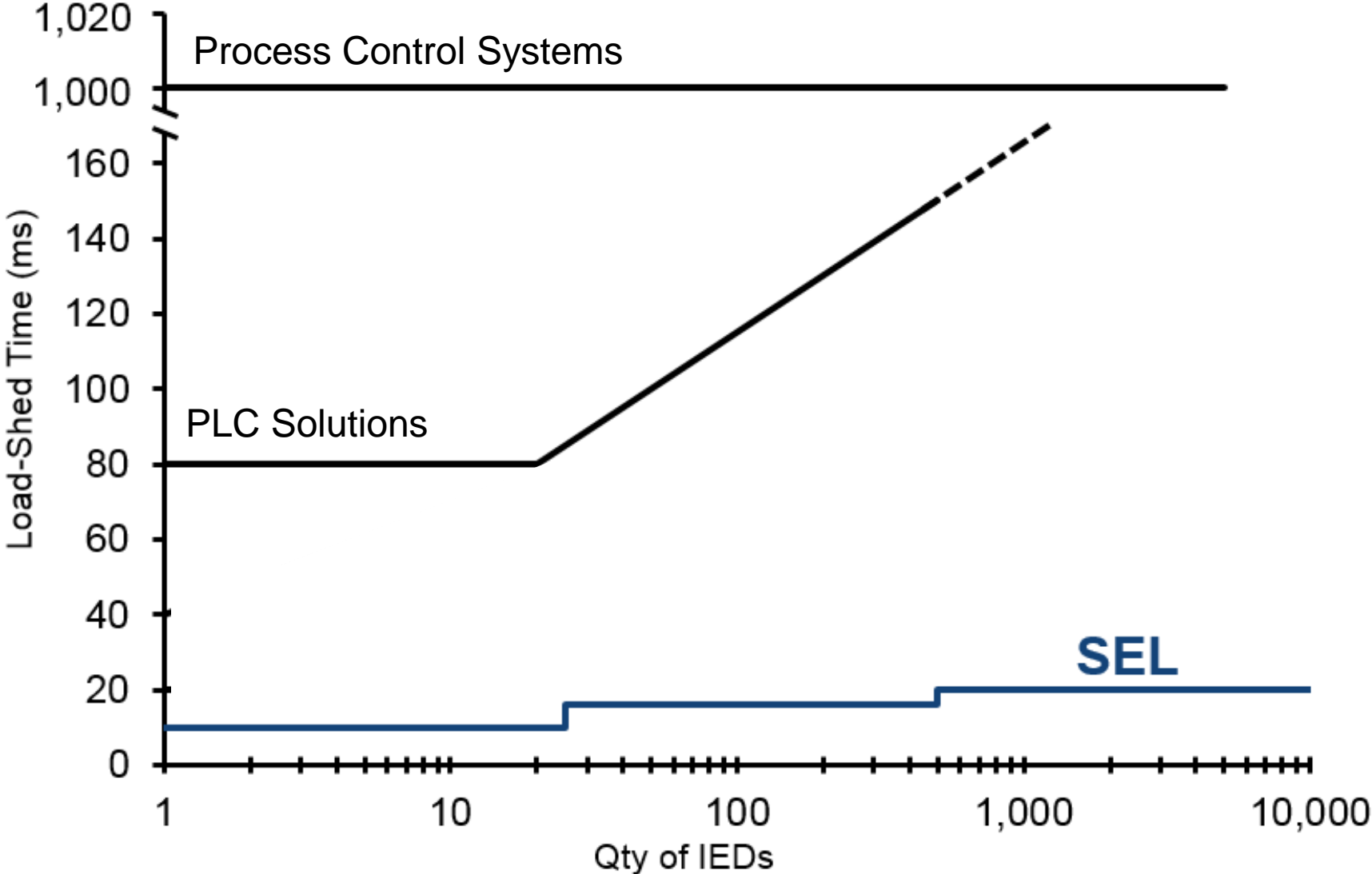
# Load Balancing Must Happen *FASTER* With Inverter-Based Generation



# FAST Load Shedding Prevents Blackouts

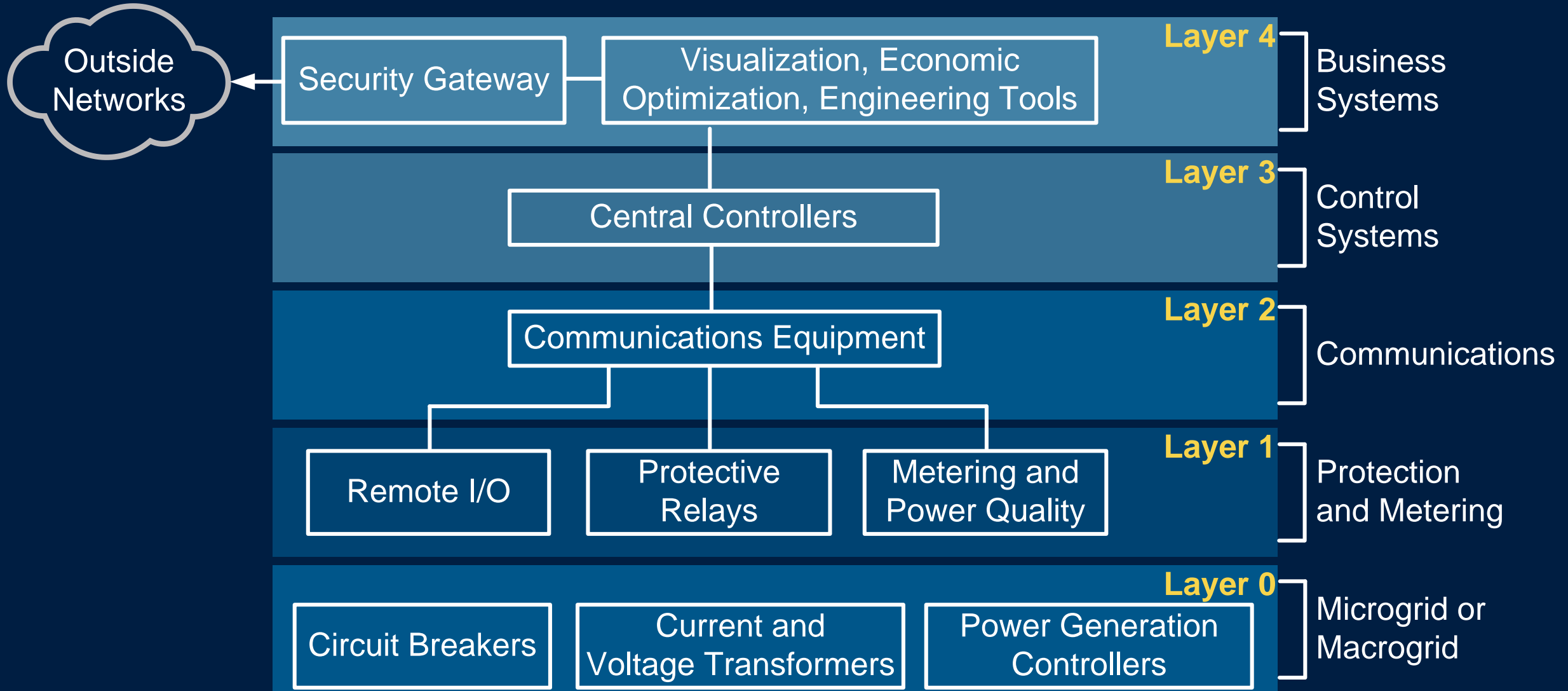


# SEL Controllers Take Action *FASTER*





# Protection, Automation, Controls, and Security

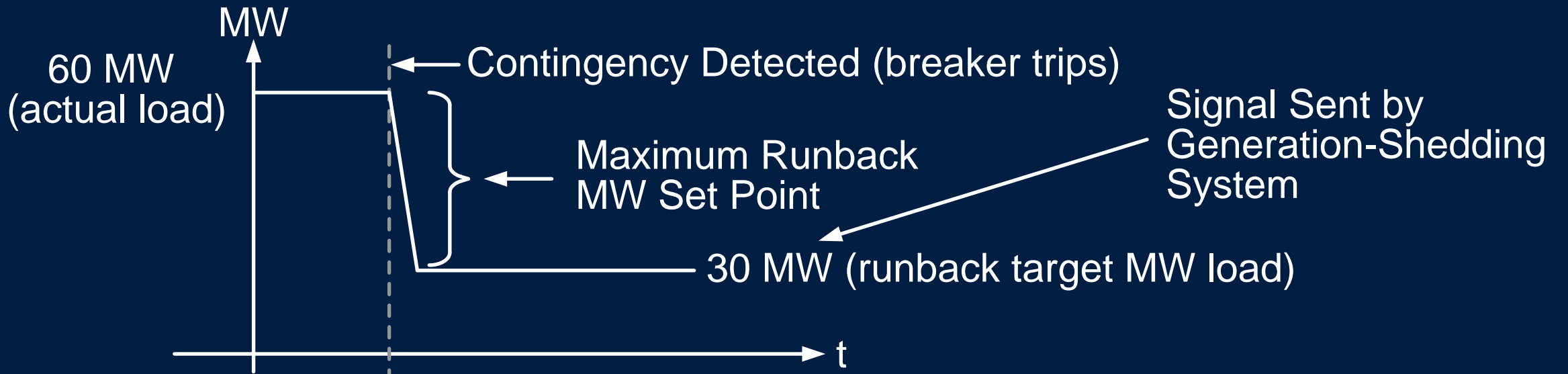
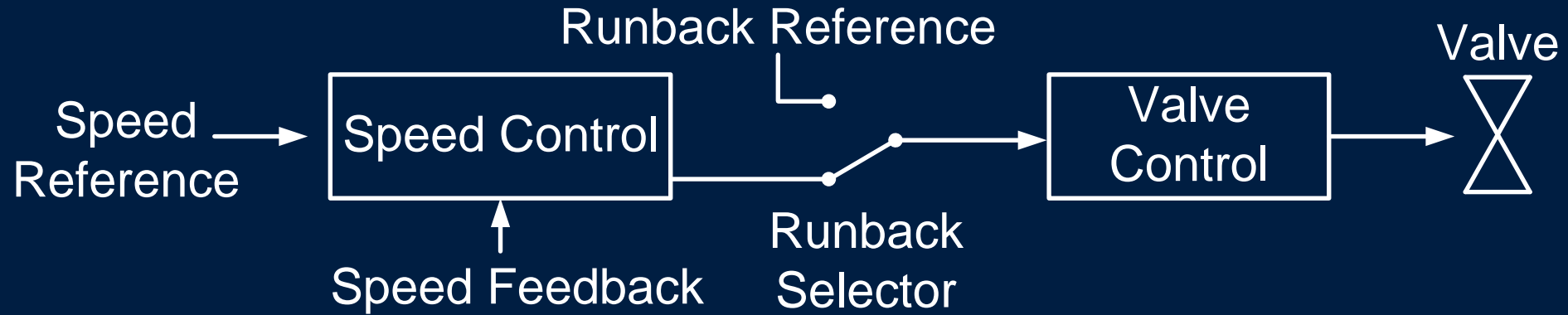


# Security for Critical Infrastructure

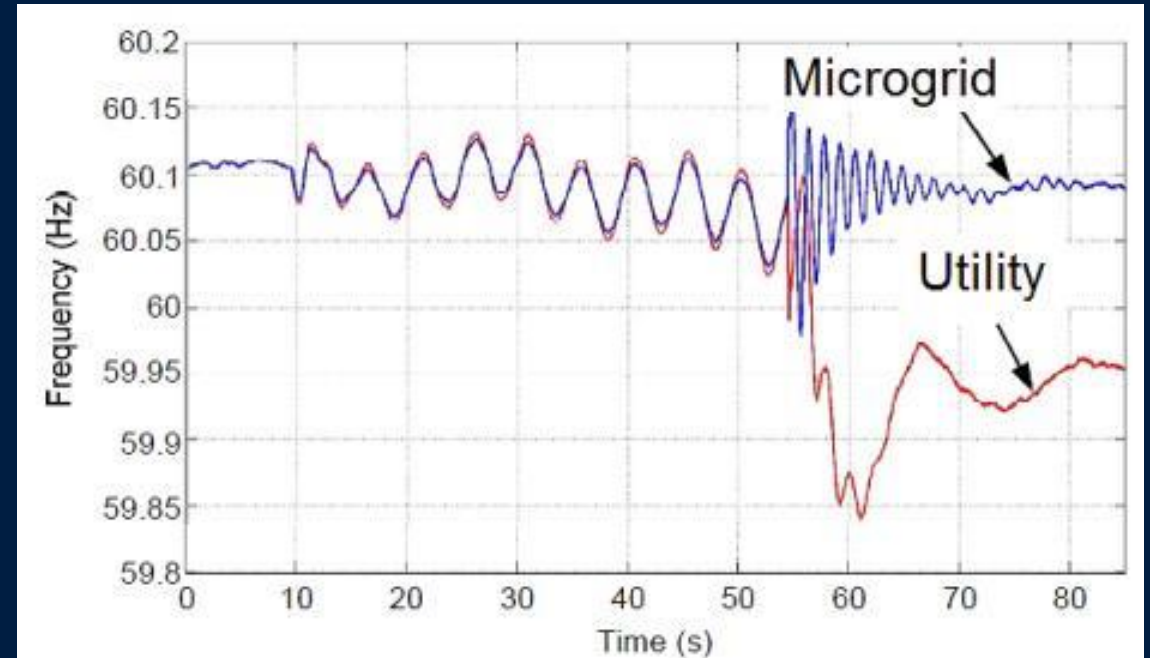
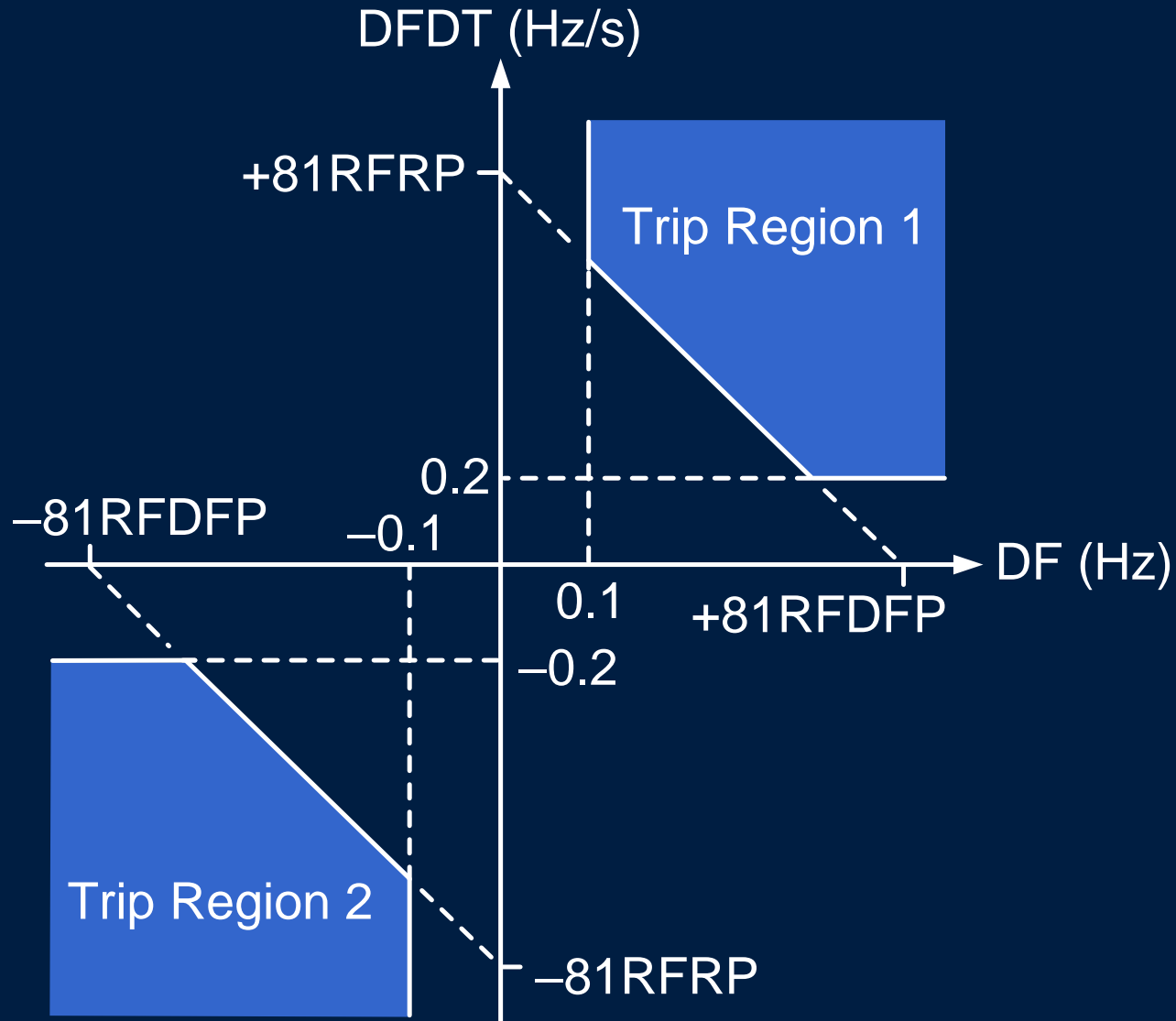
- Avoid OS and software
- Made in the USA
- Mature processes
- Vertical integration
- Cybersecurity



# Generation Runback Philosophy



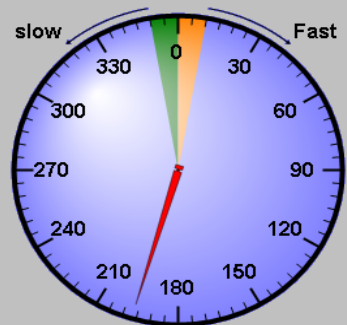
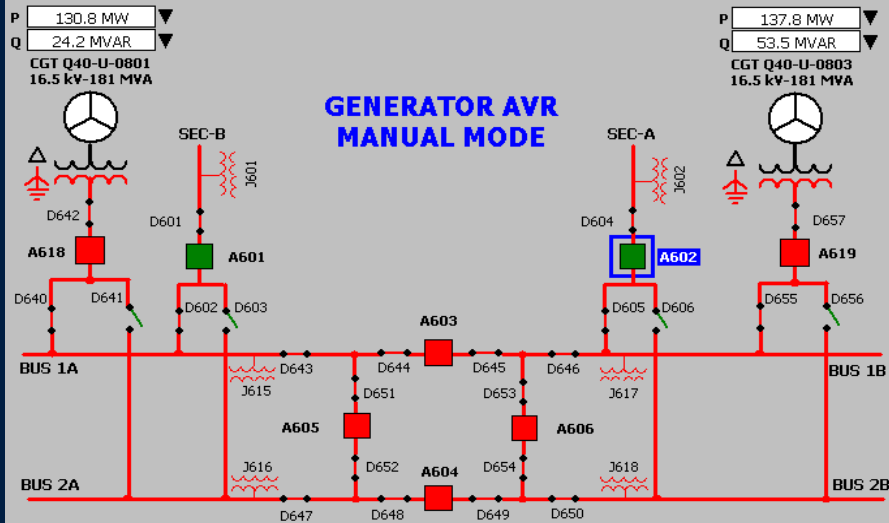
# Seamless Islanding and Decoupling Systems



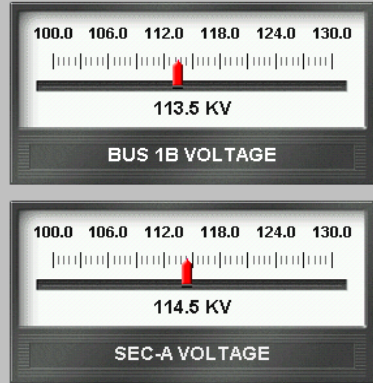
# System Synchronization

## Safely Reconnecting Islanded Grids

### BACK SYNCHRONIZATION



SYNCHROSCOPE



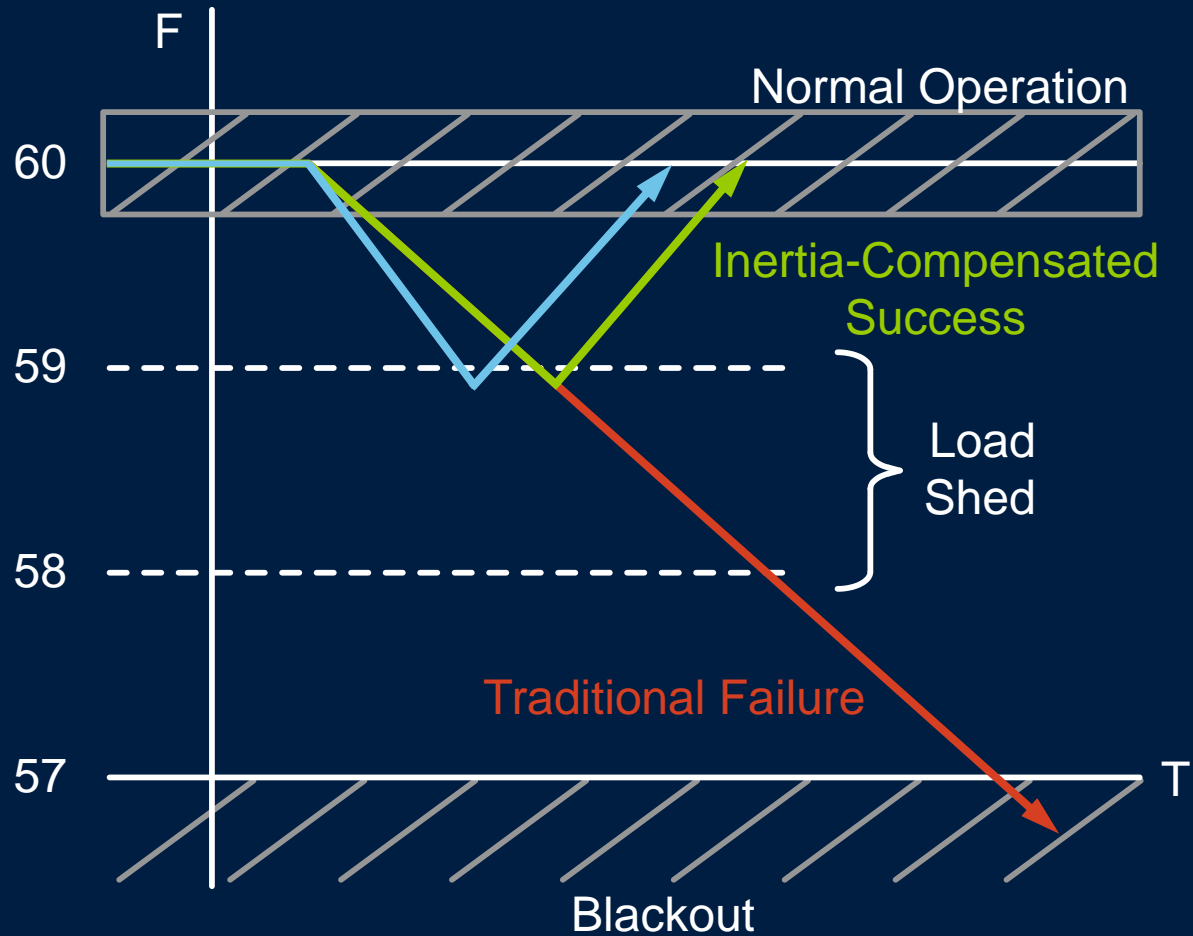
BUS 1B FREQUENCY	60 HZ
SEC-A FREQUENCY	60 HZ
SLIP FREQUENCY	0
ANGLE DIFFERENCE	197
BUS 1B VOLTAGE	113.5 KV
SEC-A VOLTAGE	114.5 KV

<input checked="" type="checkbox"/> ENABLED	<input type="checkbox"/> TRIP	<input type="checkbox"/> SYNCH SUCCESSFUL	<input type="checkbox"/> CLOSE FAILED	<input type="checkbox"/> SELECT CB601	<input type="checkbox"/> ABORT SYNCH PROCESS
<input checked="" type="checkbox"/> FREQ. OK TO INITIATE	<input checked="" type="checkbox"/> SLIP OK	<input type="checkbox"/> dV/dT OK	<input type="checkbox"/> ANGLE OK	<input checked="" type="checkbox"/> SELECT CB602	<input checked="" type="checkbox"/> INITIATE SYNCH PROCESS
<input checked="" type="checkbox"/> MASTER REQUEST UNAVAILABLE	<input type="checkbox"/> GEN. FREQ. HI	<input type="checkbox"/> GEN. FREQ. LO	<input type="checkbox"/> RAISE GEN. FREQUENCY	<input type="checkbox"/> SELECT CB603	<input type="checkbox"/> CLOSE SELECTED CB
<input type="checkbox"/> dV/dT OK	<input type="checkbox"/> ANGLE OK	<input type="checkbox"/> RAISE GEN. FREQUENCY	<input type="checkbox"/> LOWER GEN. FREQUENCY	<input type="checkbox"/> SELECT CB604	<input type="checkbox"/> AUTO LOCAL
<input type="checkbox"/> VOLT. OK TO INITIATE	<input type="checkbox"/> VOLT. DIFF. OK	<input type="checkbox"/> BREAKER STATUS ALARM	<input type="checkbox"/> SYNCH COMM. ALARM	<input type="checkbox"/> SELECT CB605	<input type="checkbox"/> AUTO REMOTE
<input type="checkbox"/> VOLT. OK TO INITIATE	<input type="checkbox"/> VOLT. DIFF. OK	<input type="checkbox"/> SYNCH COMM. ALARM	<input type="checkbox"/> VOLT. HI	<input type="checkbox"/> SELECT CB606	<input checked="" type="checkbox"/> LOCAL MANUAL
<input type="checkbox"/> SELECTED CB OPEN	<input type="checkbox"/> BREAKER STATUS ALARM	<input type="checkbox"/> VOLT. LO	<input type="checkbox"/> RAISE VOLT.		
<input type="checkbox"/> CLOSE LOCKOUT	<input type="checkbox"/> LOWER VOLT.				



# Inertia-Compensated Load Shedding

## Do It Right!

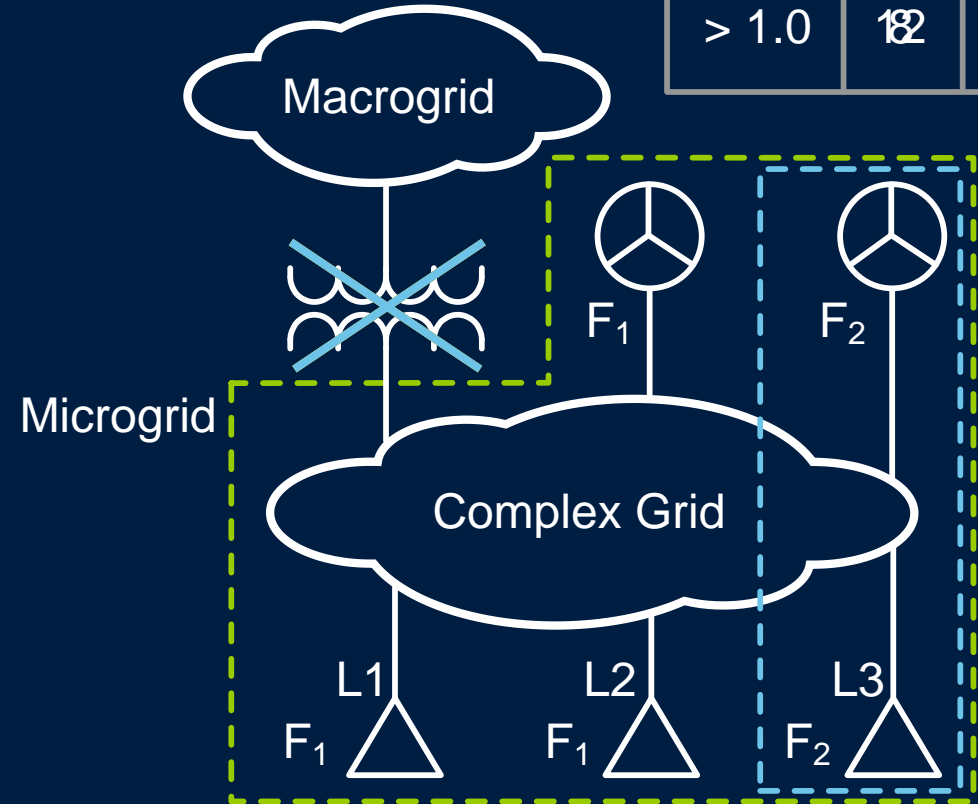


Load Shed  $\sim H \cdot \text{DFDT} = 8 \cdot 1 = 8 \text{ MW}$

Load Shed  $\sim H \cdot \text{DFDT} = 4 \cdot 2 = 8 \text{ MW}$

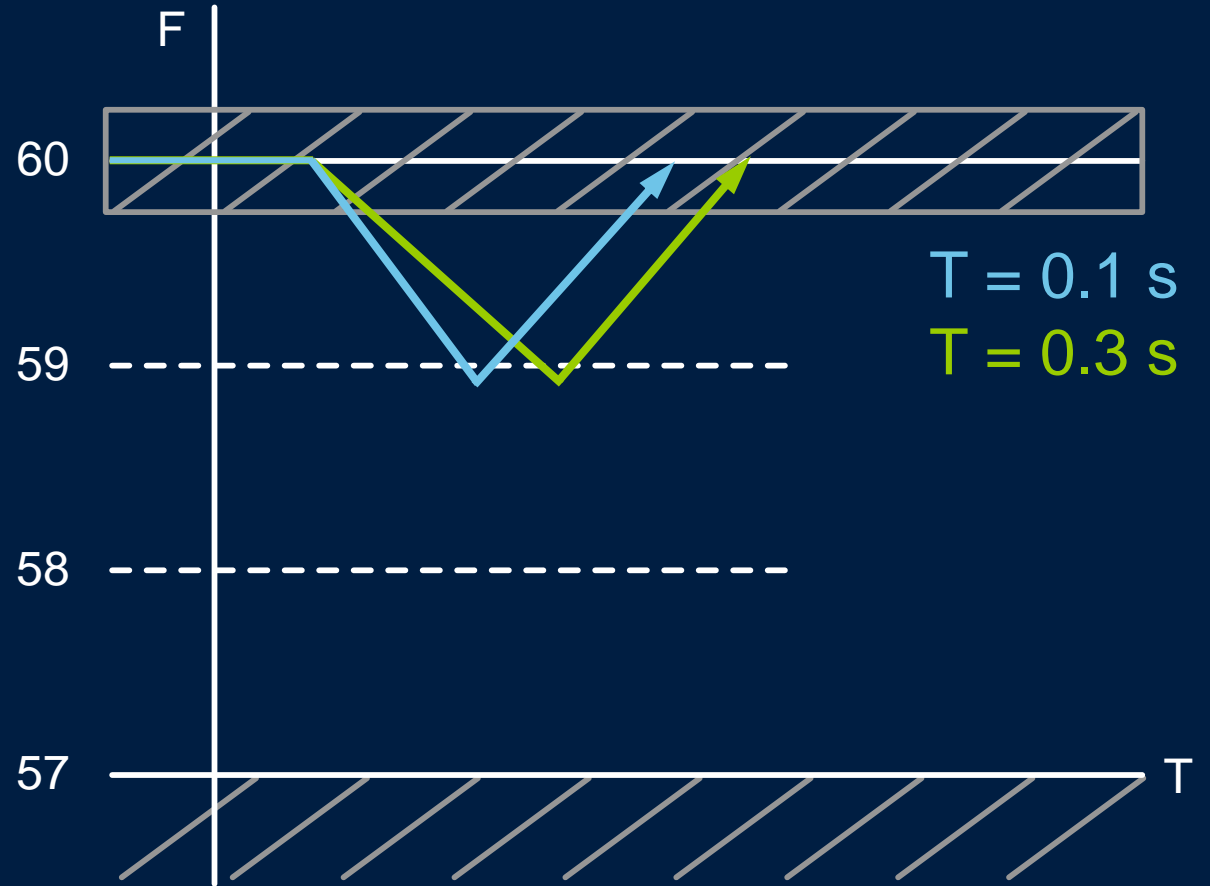
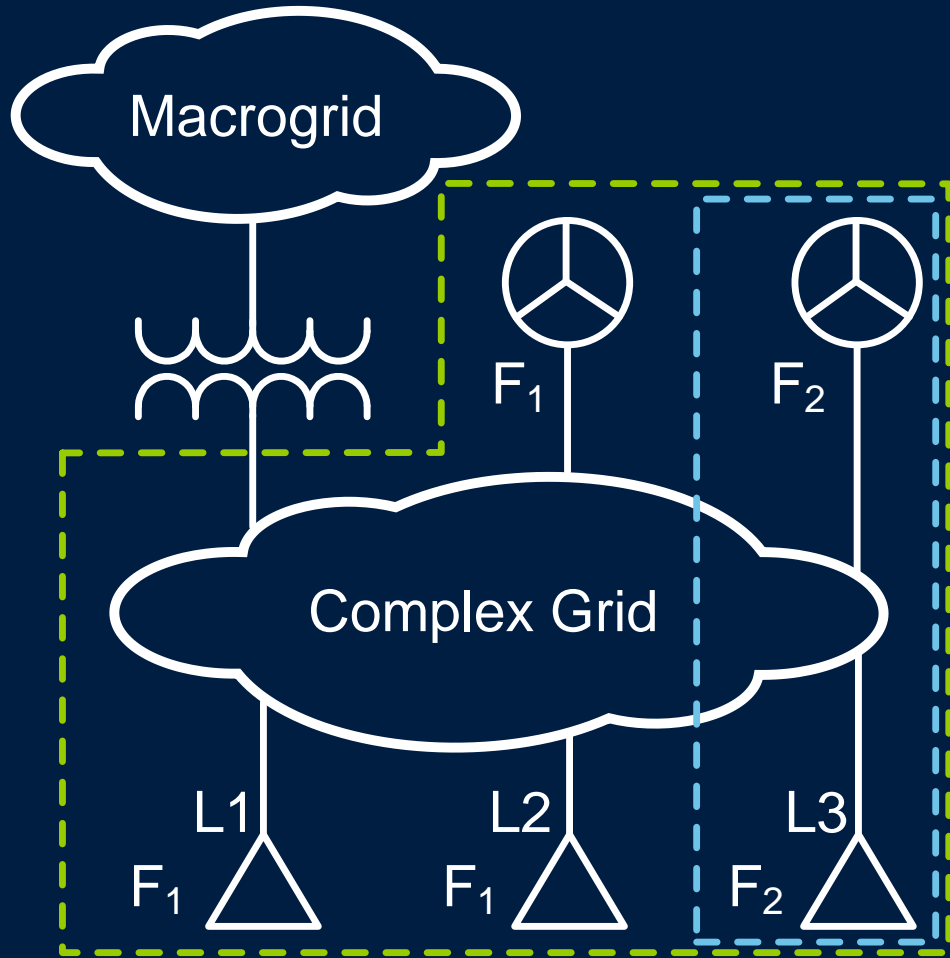
MW Load to Shed

DFDT \ F	59	58
< 0.5	2	8
0.5 to 1.0	8	12
> 1.0	12	16



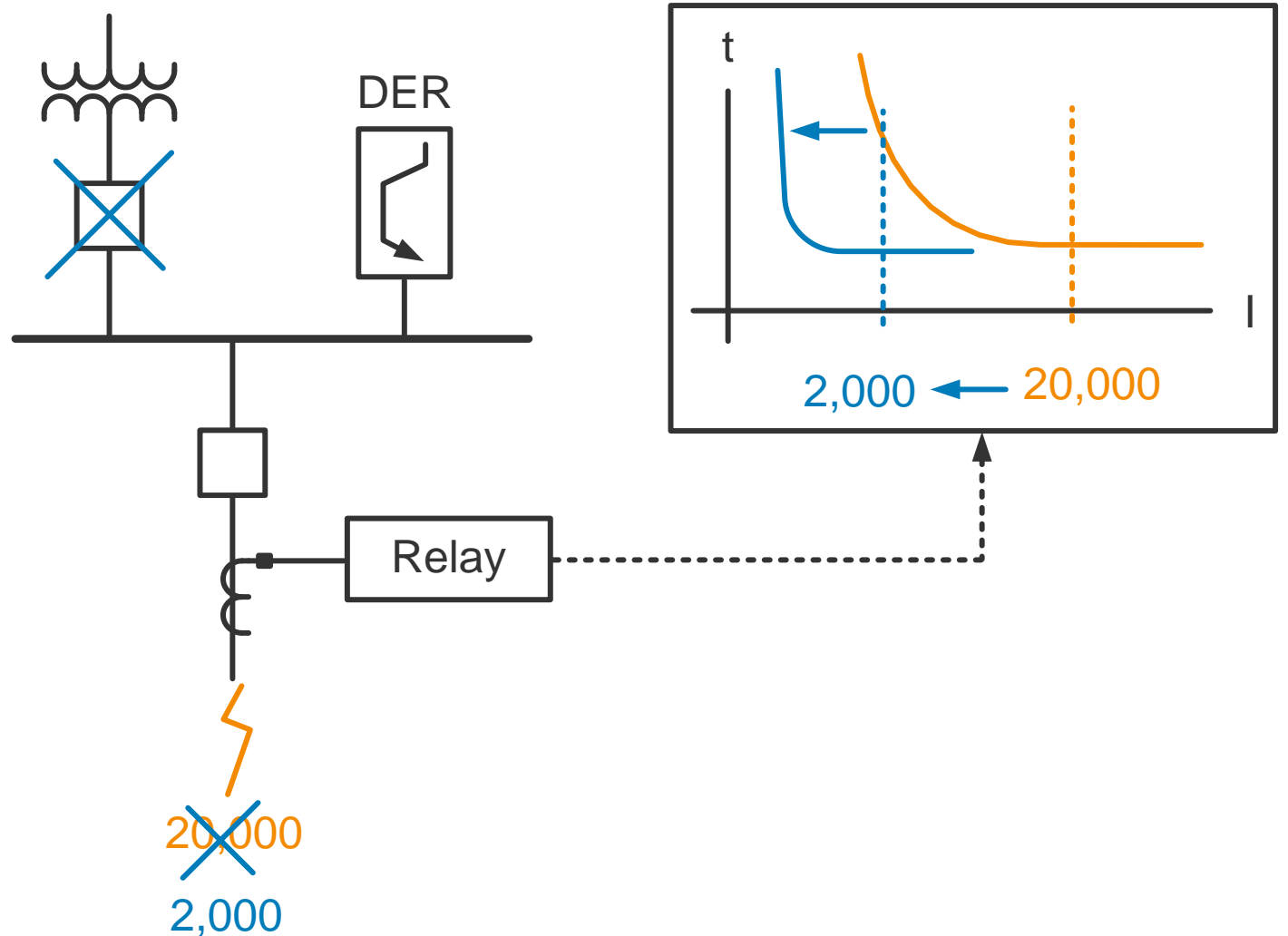
# Load Tracking – Add Your H's

## Discriminate Islands With Time



# Protection Must *ADAPT* To Changing Fault Conditions

- Fault levels
- Grounding
- Directions
- Impedances





# Physics Are the Same – Big or Small

Import: 471 GWh  
Export: 931 GWh

Large  
Hydro  
Generation

Enguri



Load Center

Thermal  
Generation

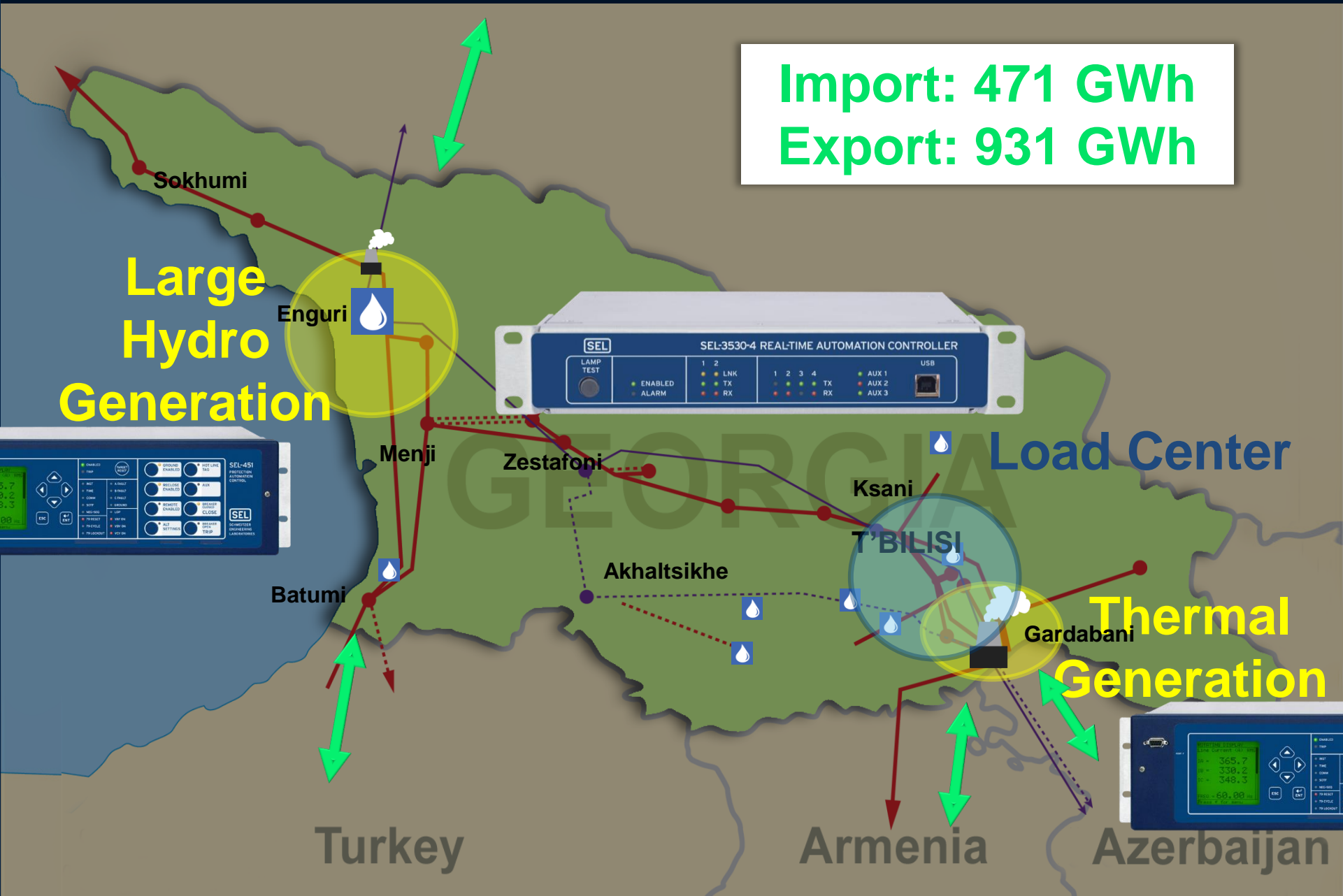
Gardabani



Turkey

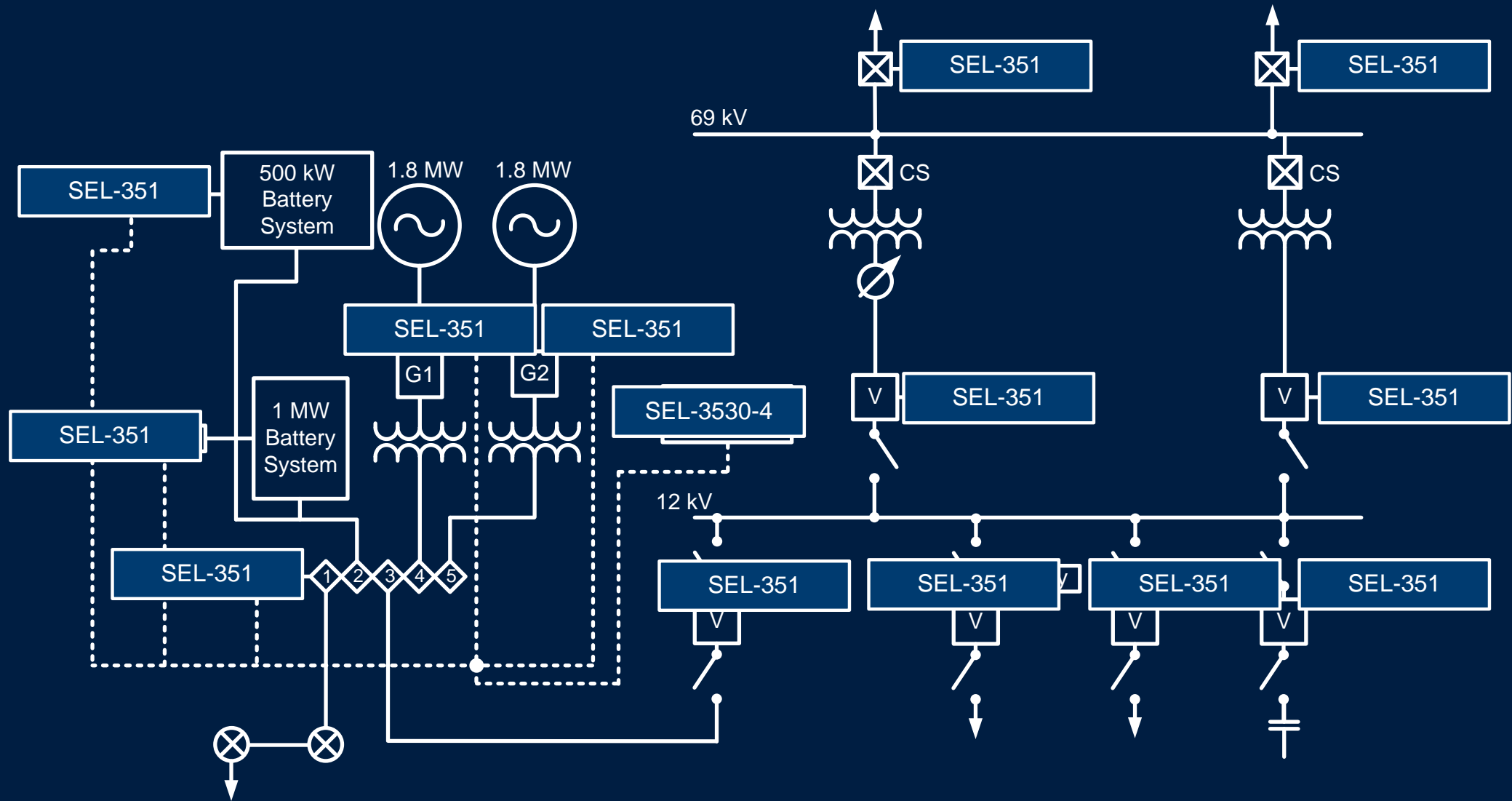
Armenia

Azerbaijan



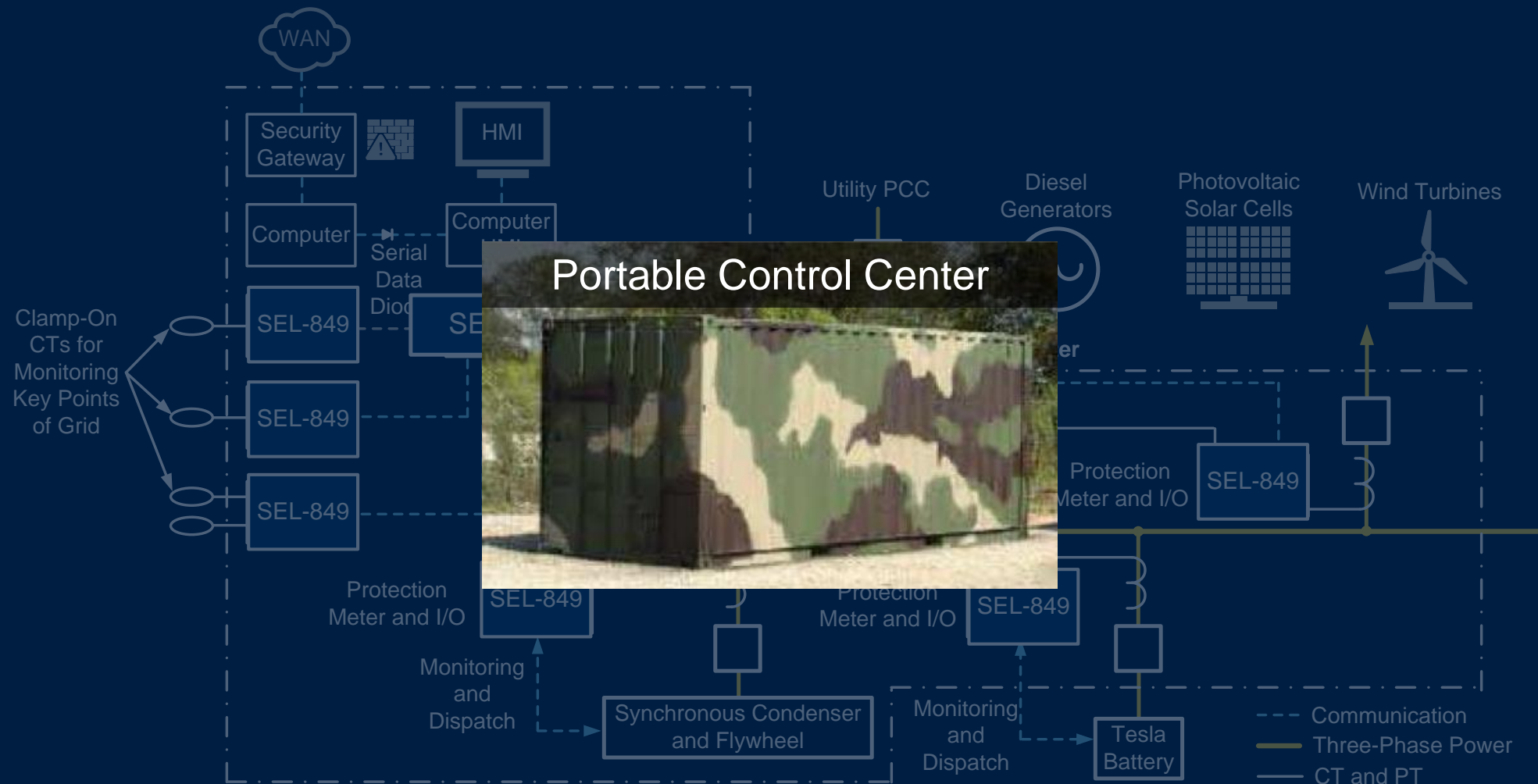
# Physics Are the Same – Simple or Complex

## 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

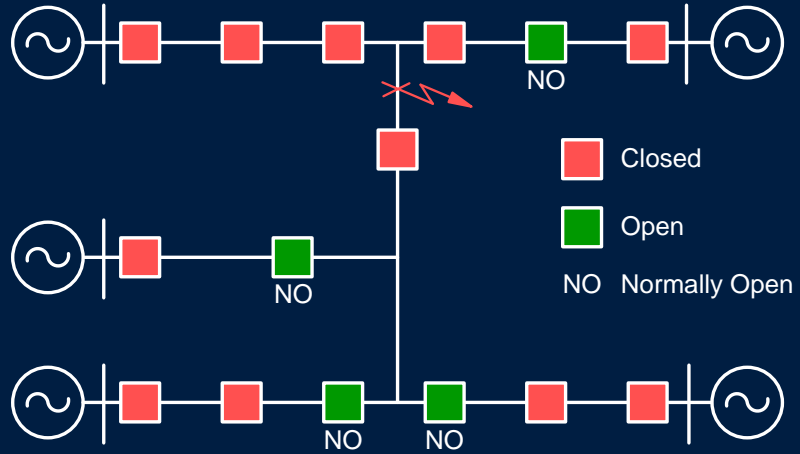
Industrial and utility technology, procedures, modeling, testing, and commissioning methods were a perfect fit!



# Engineering Services in U.S. and Canada



# Distribution Automation



Chattanooga Electric Power Board



Mississippi  
DAC System



AEP Ohio



# Questions?

