



Microgrid Solutions

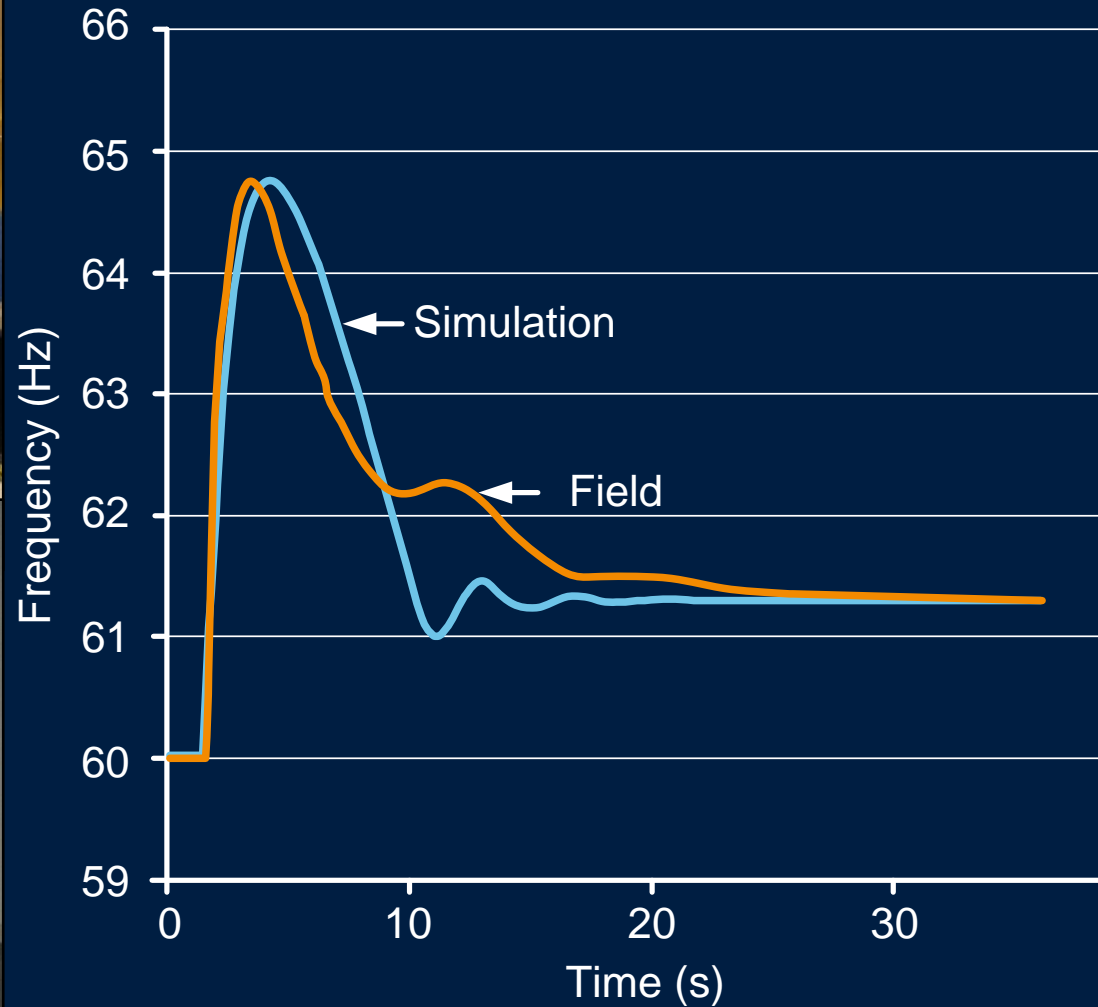
*Sai Krishna Raghupathula
(SEL Engineering Services Division)*



Essential Keys to Successful Microgrid Projects

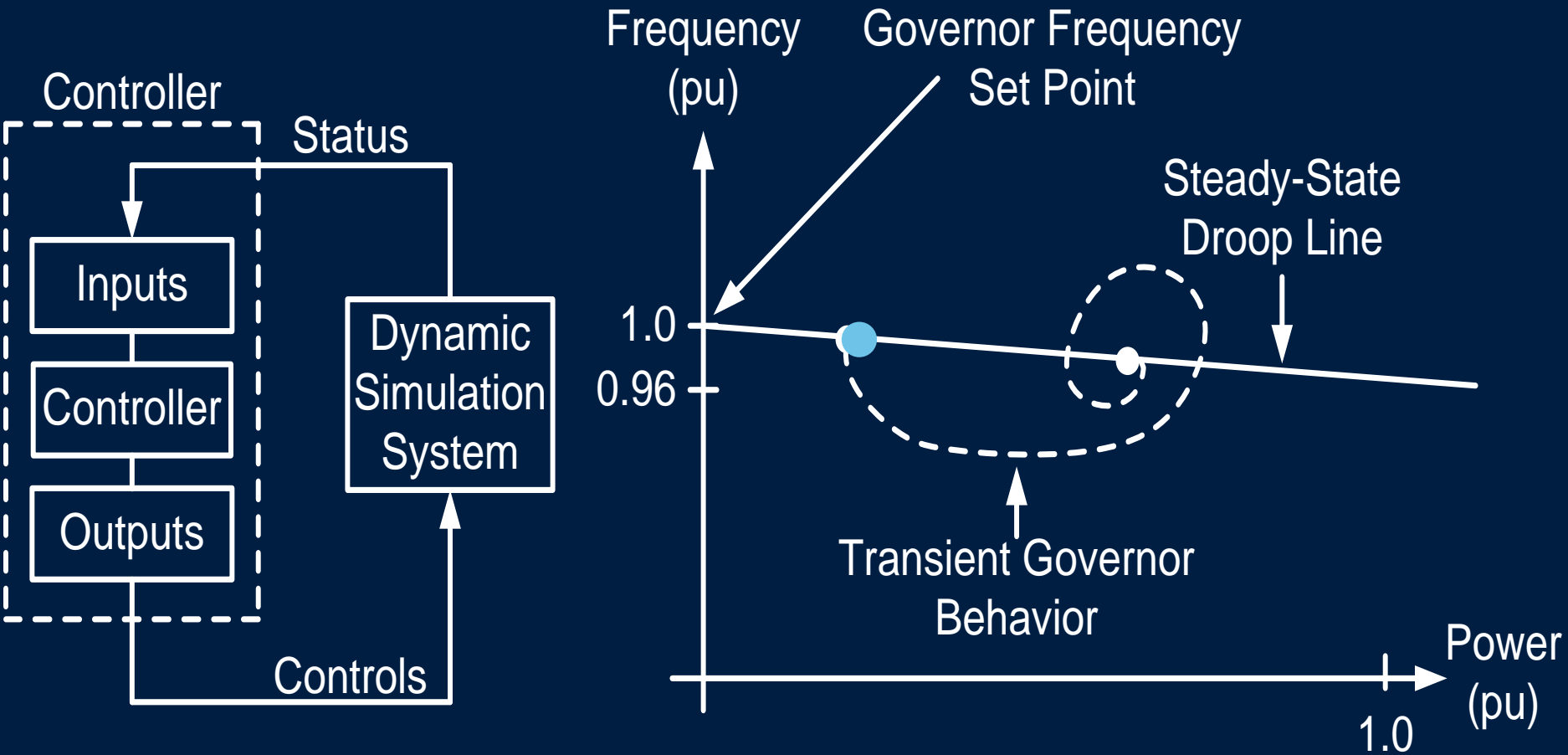
- Comprehensive HIL testing
- Subcycle fast controls
- Adaptive protection
- Practical security
- Fit for function
- Minimal complexity

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



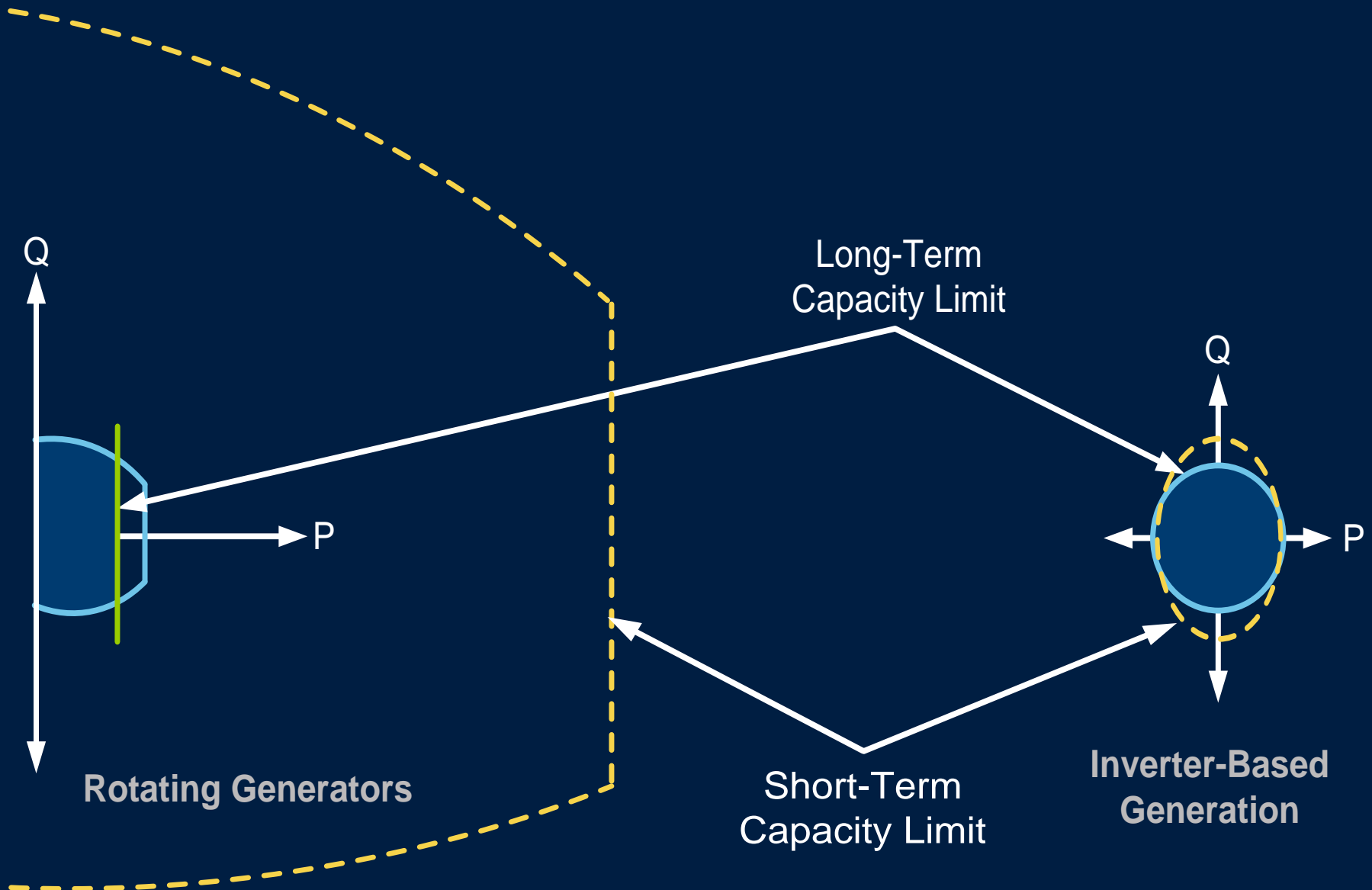
Control Cost, Quality, and Features

Hardware-in-the-Loop Testing

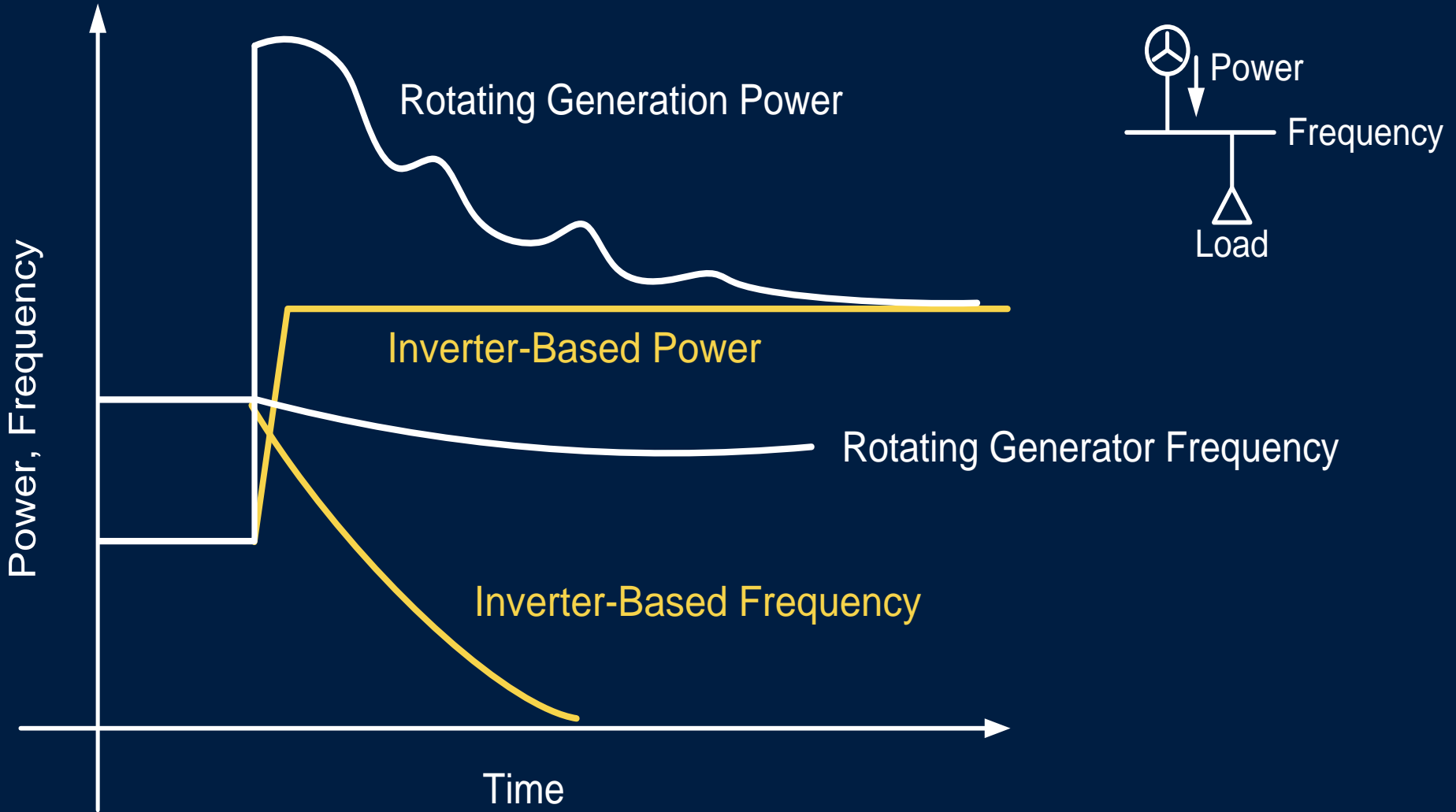


Both Mechanical and Electrical Systems Must Be Modeled Accurately

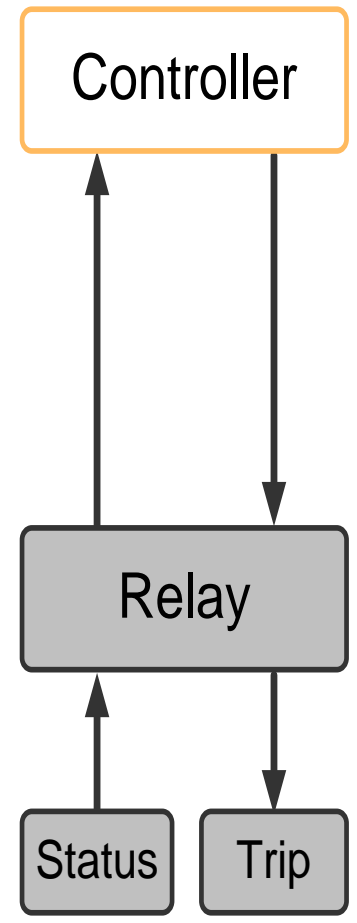
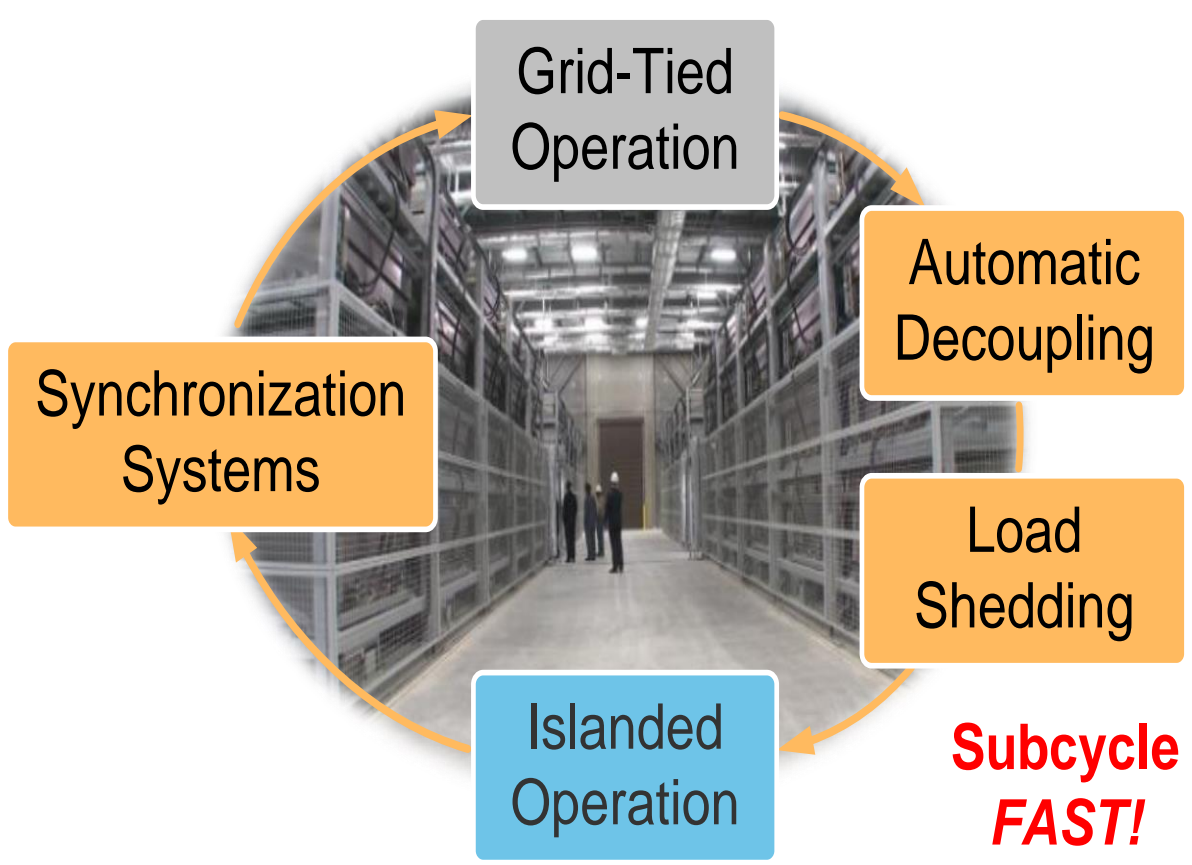
Inverter-Based Generation Has Limited Overload Capacity



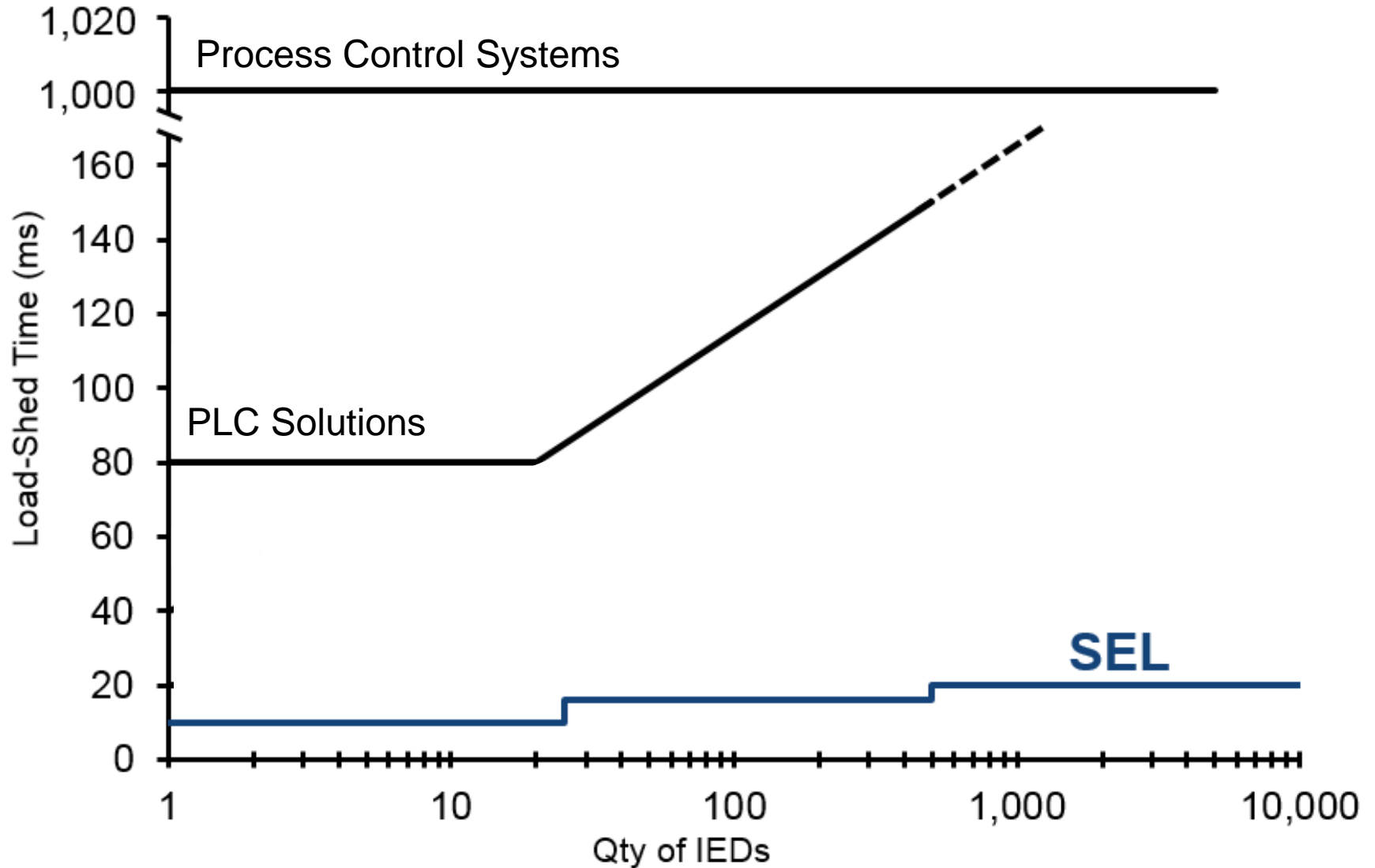
Load Balancing Must Happen *FASTER* With Inverter-Based Generation



FAST Load Shedding Prevents Blackouts



Controllers Must Take Action *FASTER*



Solutions Must Be Scaled!

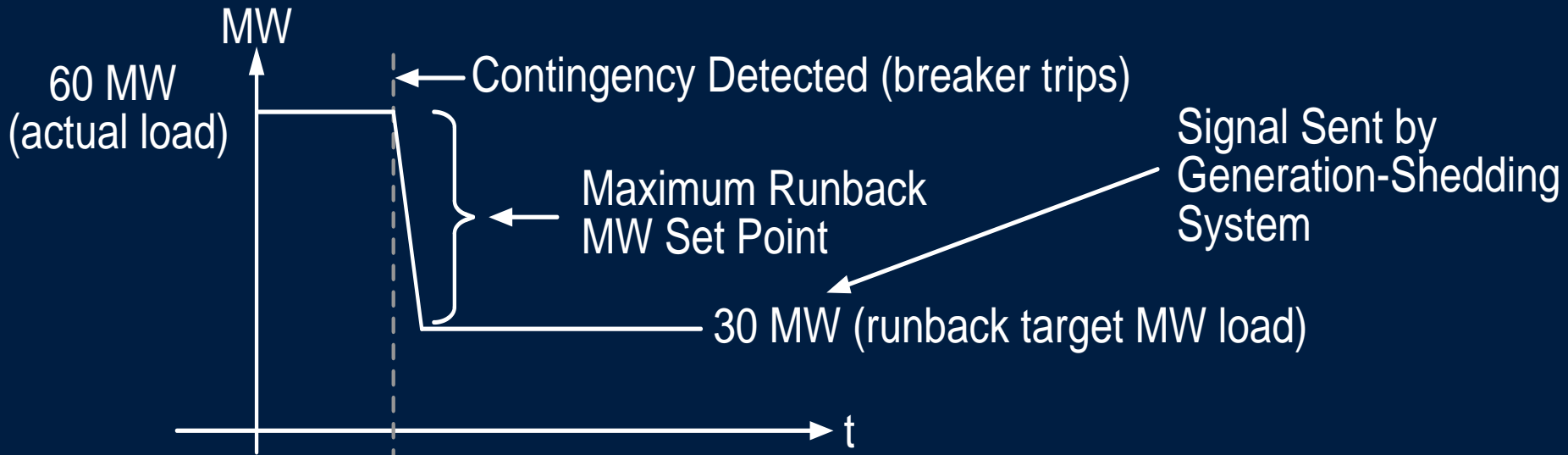
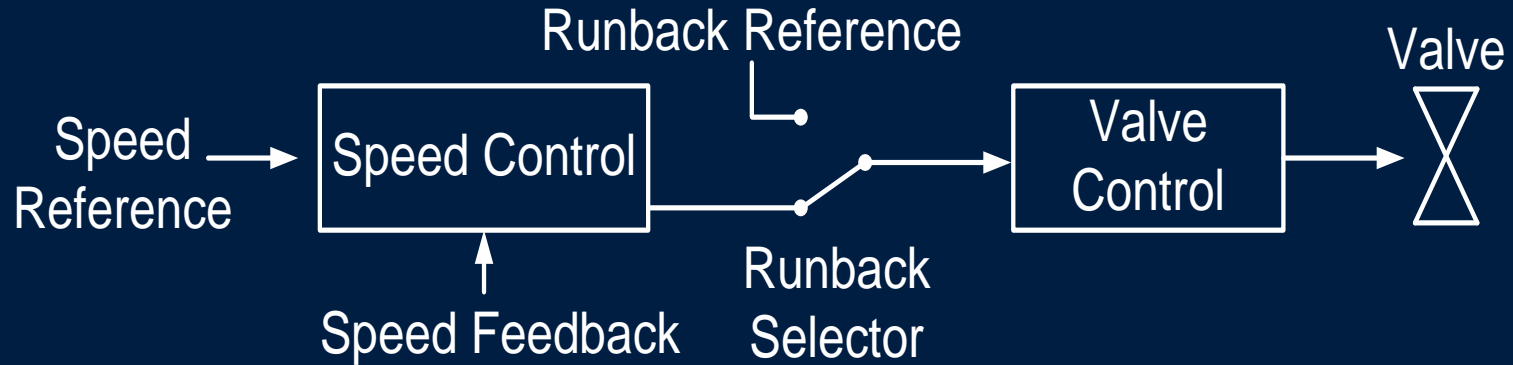
Feature	Relays Only	Relays + RTAC	POWERMAX Utilities & Industries
Relays	✓	✓	✓
SEL controllers	–	SEL-3530-4	SEL-3555
SEL POWERMAX libraries	–	Partial	Complete
Generators	Limited size	Distributed	Centralized
Security	Comprehensive		

Security for Critical Infrastructure

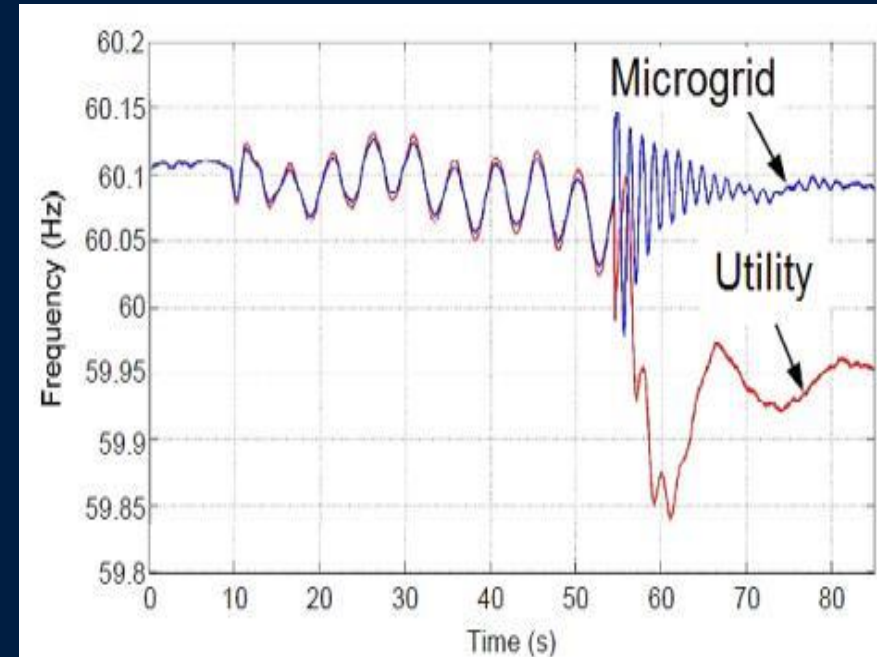
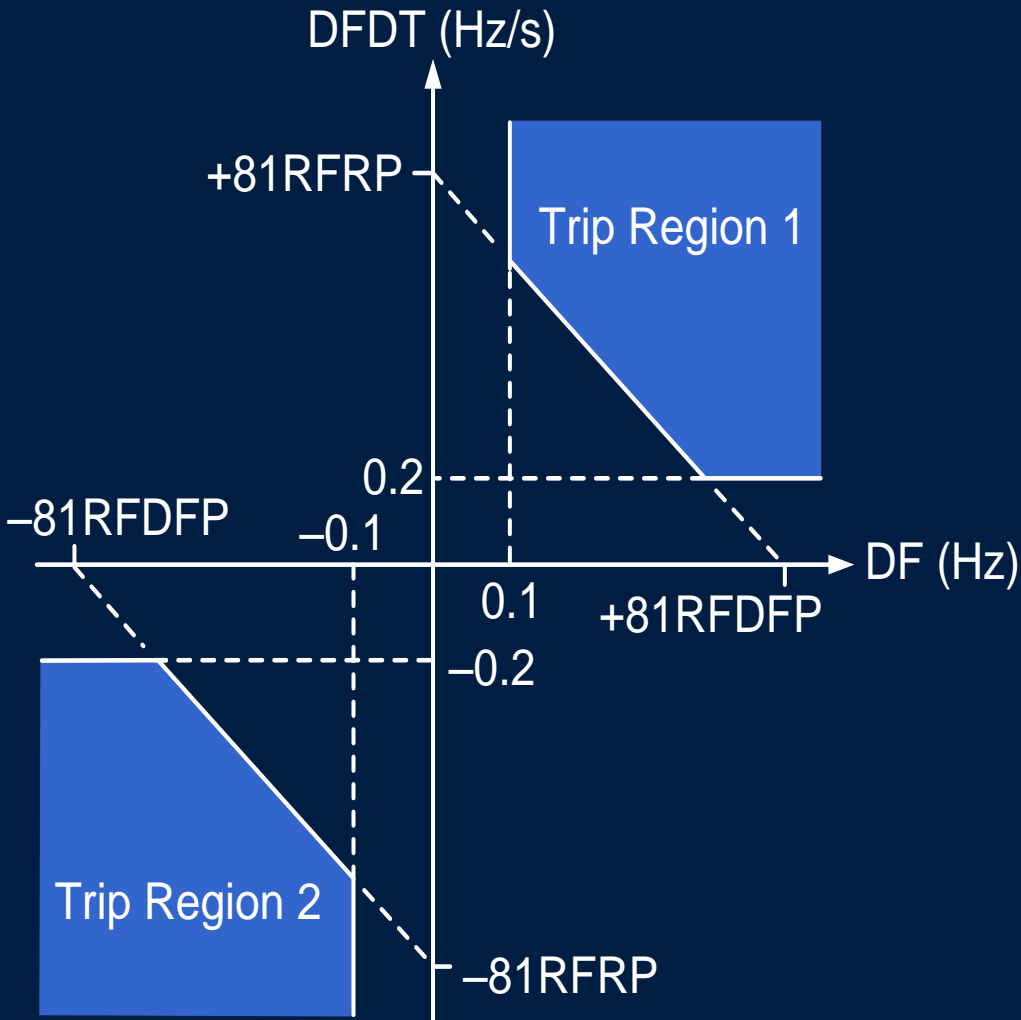
- Avoid OS and software
- Made in the USA
- Mature processes
- Vertical integration
- Cybersecurity



Generation Runback Philosophy



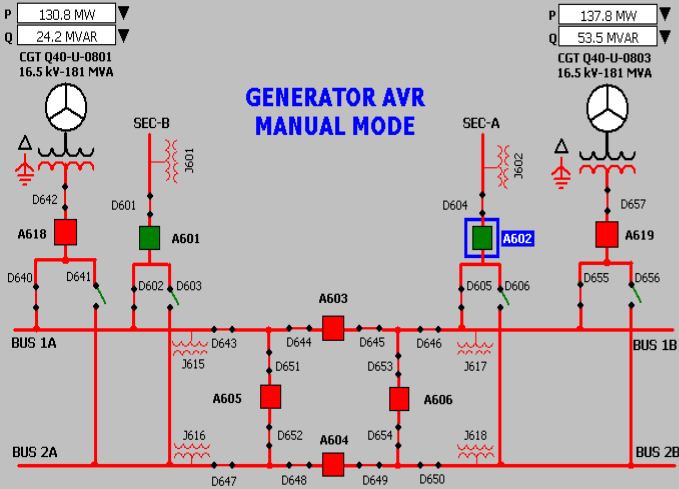
Seamless Islanding and Decoupling Systems



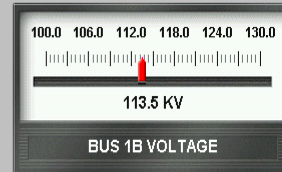
System Synchronization

Safely Reconnecting Islanded Grids

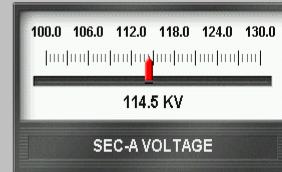
BACK SYNCHRONIZATION



SYNCHROSCOPE



BUS 1B VOLTAGE



SEC-A VOLTAGE

BSR-A

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

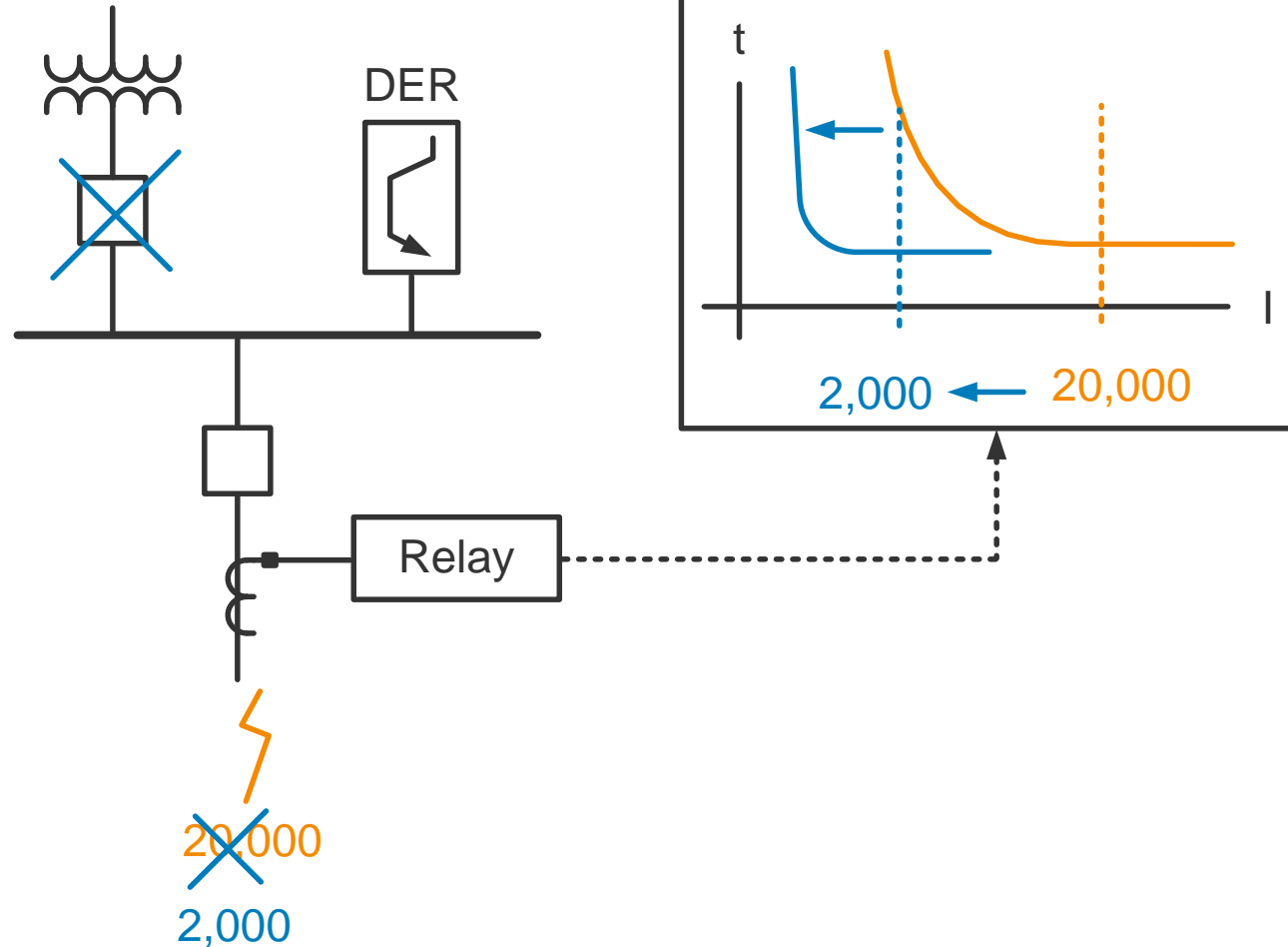
<input checked="" type="checkbox"/> ENABLED	<input type="checkbox"/> TRIP	<input type="checkbox"/> SYNCH SUCCESSFUL	<input type="checkbox"/> FREQ. OK TO INITIATE	<input type="checkbox"/> SLIP OK	<input type="checkbox"/> dF/dT OK	<input type="checkbox"/> ANGLE OK	<input type="checkbox"/> MASTER REQUEST UNAVAILABLE	<input type="checkbox"/> GEN. FREQ. HI	<input type="checkbox"/> GEN. FREQ. LO	<input type="checkbox"/> RAISE GEN. FREQUENCY	<input type="checkbox"/> LOWER GEN. FREQUENCY
<input type="checkbox"/> CLOSE FAILED	<input type="checkbox"/> VOLT. OK TO INITIATE	<input type="checkbox"/> VOLT. DIFF. OK	<input type="checkbox"/> dV/dT OK	<input type="checkbox"/> SELECTED CB OPEN	<input type="checkbox"/> BREAKER STATUS ALARM	<input type="checkbox"/> CLOSE LOCKOUT	<input type="checkbox"/> SYNCH COMM. ALARM	<input type="checkbox"/> VOLT. HI	<input type="checkbox"/> VOLT. LO	<input type="checkbox"/> RAISE VOLT.	<input type="checkbox"/> LOWER VOLT.

<input type="checkbox"/> SELECT CB601	<input type="checkbox"/> ABORT SYNCH PROCESS
<input checked="" type="checkbox"/> SELECT CB602	<input checked="" type="checkbox"/> INITIATE SYNCH PROCESS
<input type="checkbox"/> SELECT CB603	<input type="checkbox"/> CLOSE SELECTED CB
<input type="checkbox"/> SELECT CB604	<input type="checkbox"/> AUTO LOCAL
<input type="checkbox"/> SELECT CB605	<input type="checkbox"/> AUTO REMOTE
<input type="checkbox"/> SELECT CB606	<input checked="" type="checkbox"/> LOCAL MANUAL



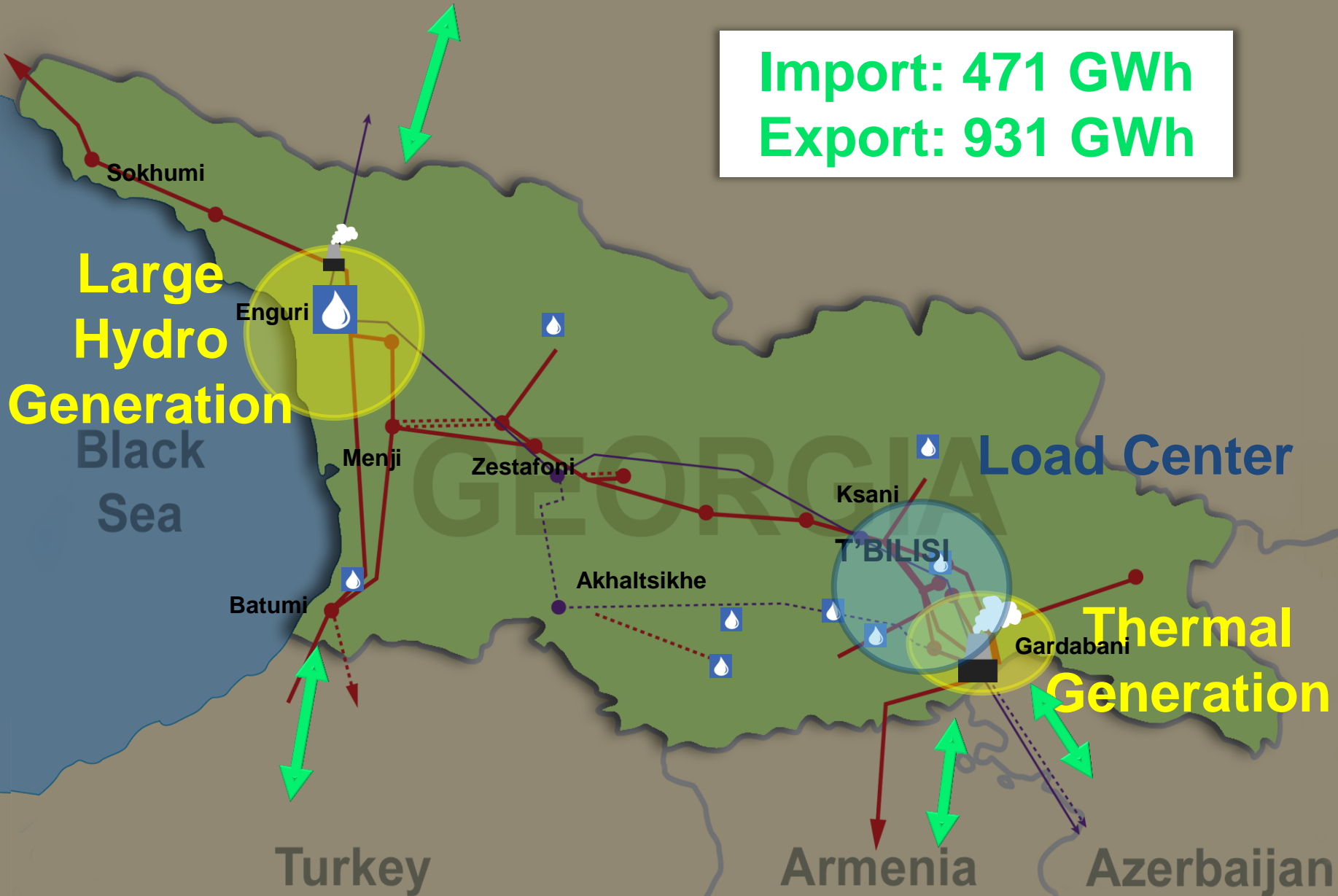
Protection Must *ADAPT* To Changing Fault Conditions

- Fault levels
- Grounding
- Directions
- Impedances



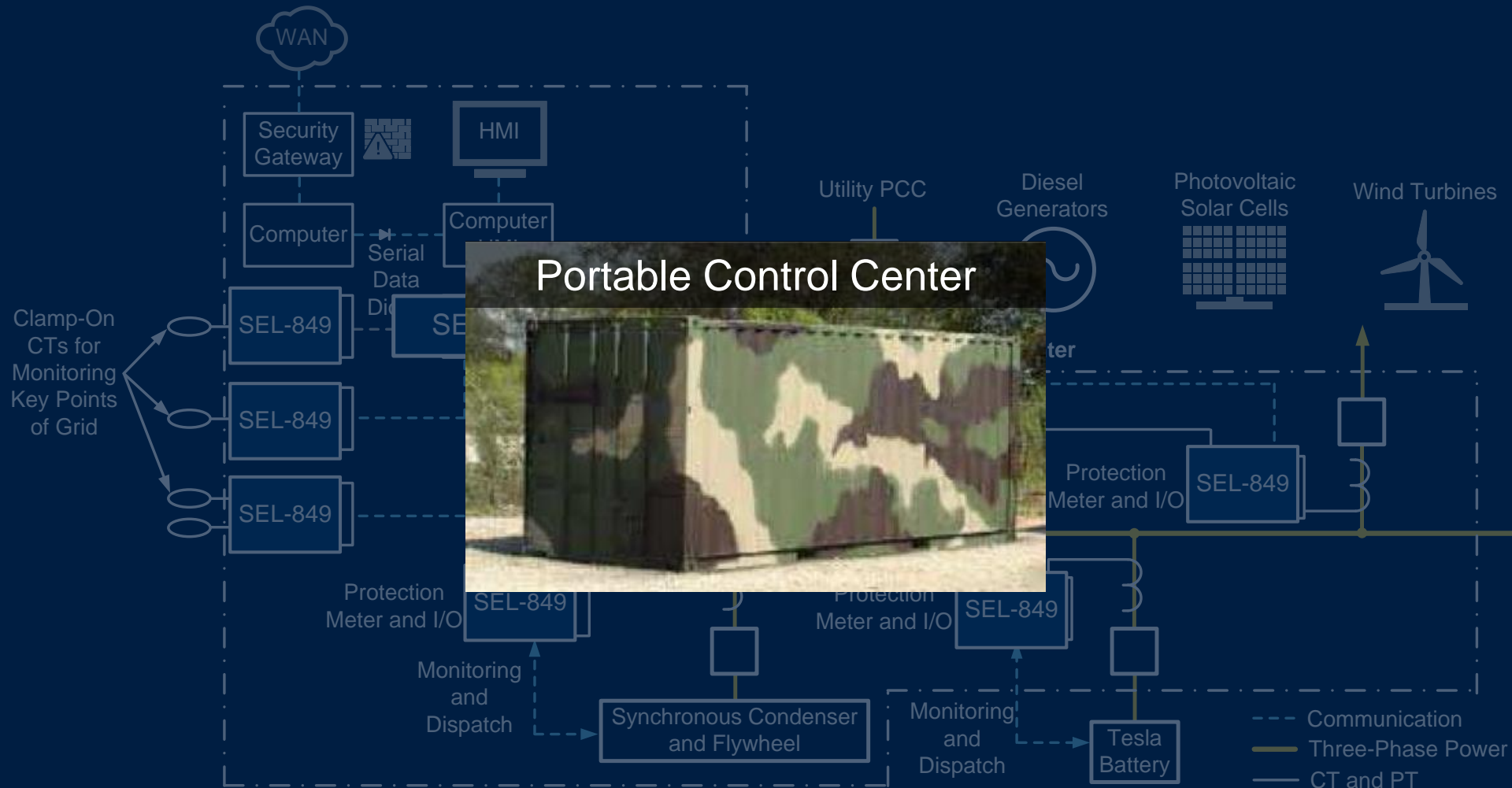
Physics Are the Same – Big or Small

Import: 471 GWh
Export: 931 GWh



Navy Seabees, U.S. Navy

Portable Microgrid Controls, Protection, and Security



Rugged and Economical for Restricted Budgets

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



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

Conclusions on Lessons Learned

- **Testing** reduces installation and maintenance costs
- **Fast control systems** prevent outages
- **Reliable load balancing** maintains stability
- **Adaptive protection** saves lives
- **Security in depth** is mandatory

Questions?

