Operational Security in 100% Inverter-Based Power Systems: Demonstration for Hawai`i Big Island System

Nan Xue, Siemens Technology

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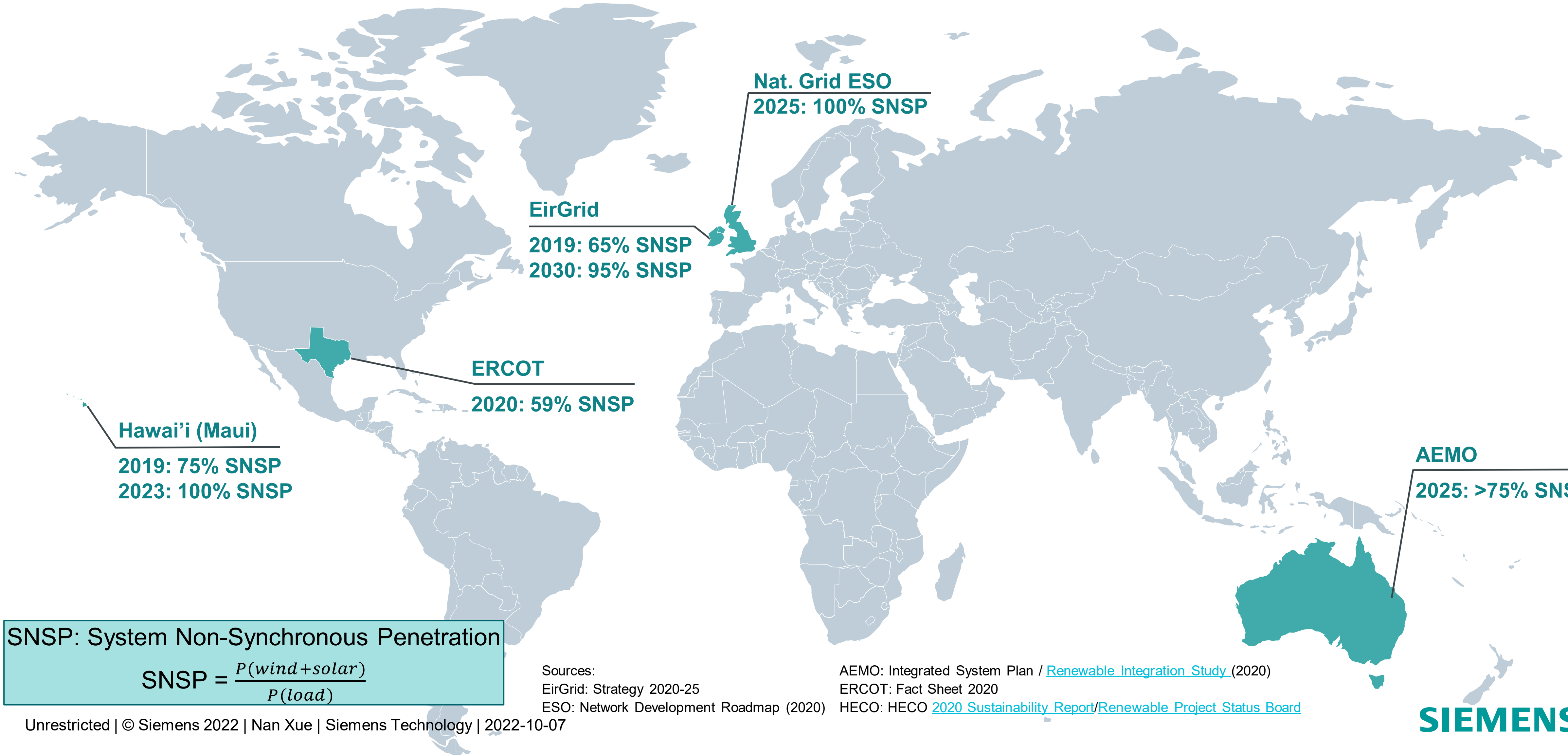
High renewable integration poses the same challenges around the globe



SNSP: System Non-Synchronous Penetration

$$SNSP = \frac{P(wind+solar)}{P(load)}$$

Sources:
EirGrid: Strategy 2020-25
ESO: Network Development Roadmap (2020)
AEMO: Integrated System Plan / Renewable Integration Study (2020)
ERCOT: Fact Sheet 2020
HECO: HECO 2020 Sustainability Report/Renewable Project Status Board

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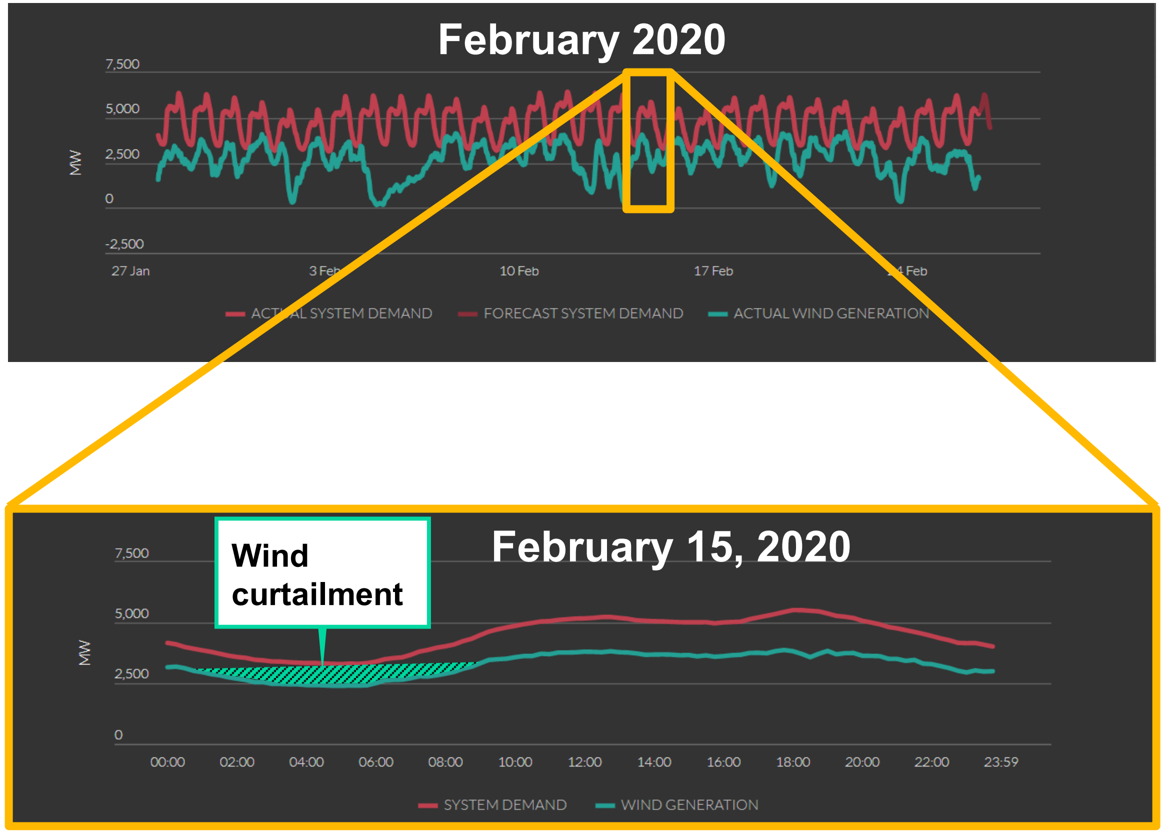
Lack of N-1 security limits renewable integration and leads to higher cost & emissions

Ireland and Hawaii replace renewable by conventional generation to guarantee N-1 security

Ireland

Renewables replaced by conventional generation on 20 of 28 nights

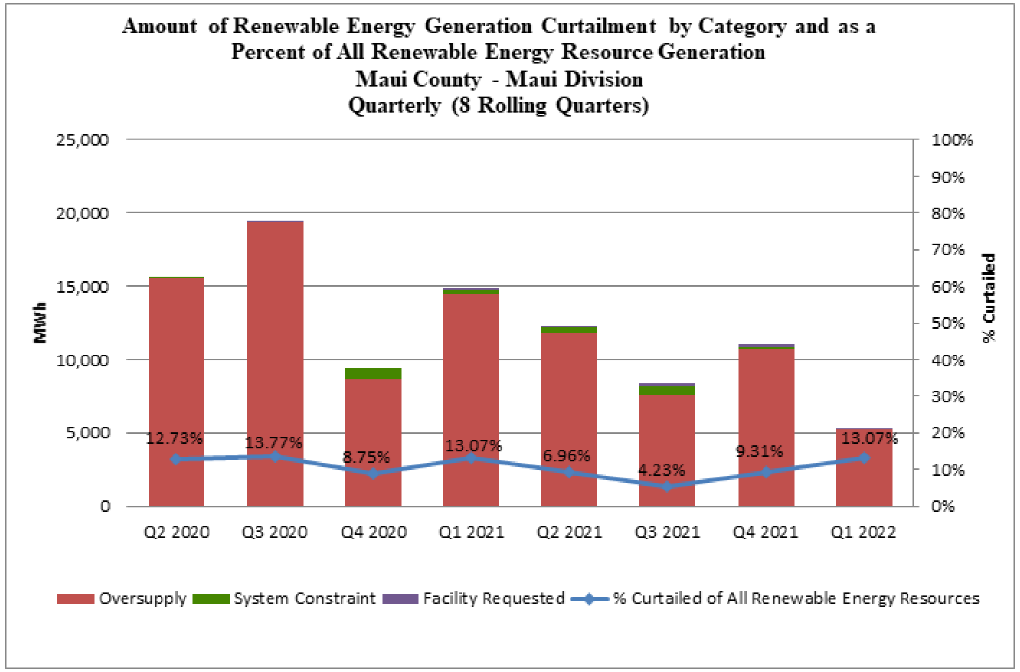


http://smartgriddashboard.eirgrid.com/

Maui

10% of renewable generation replaced by conventional generation

Maui County – Maui Division



https://www.hawaiianelectric.com/about-us/performance-scorecards-and-metrics/renewable-energy

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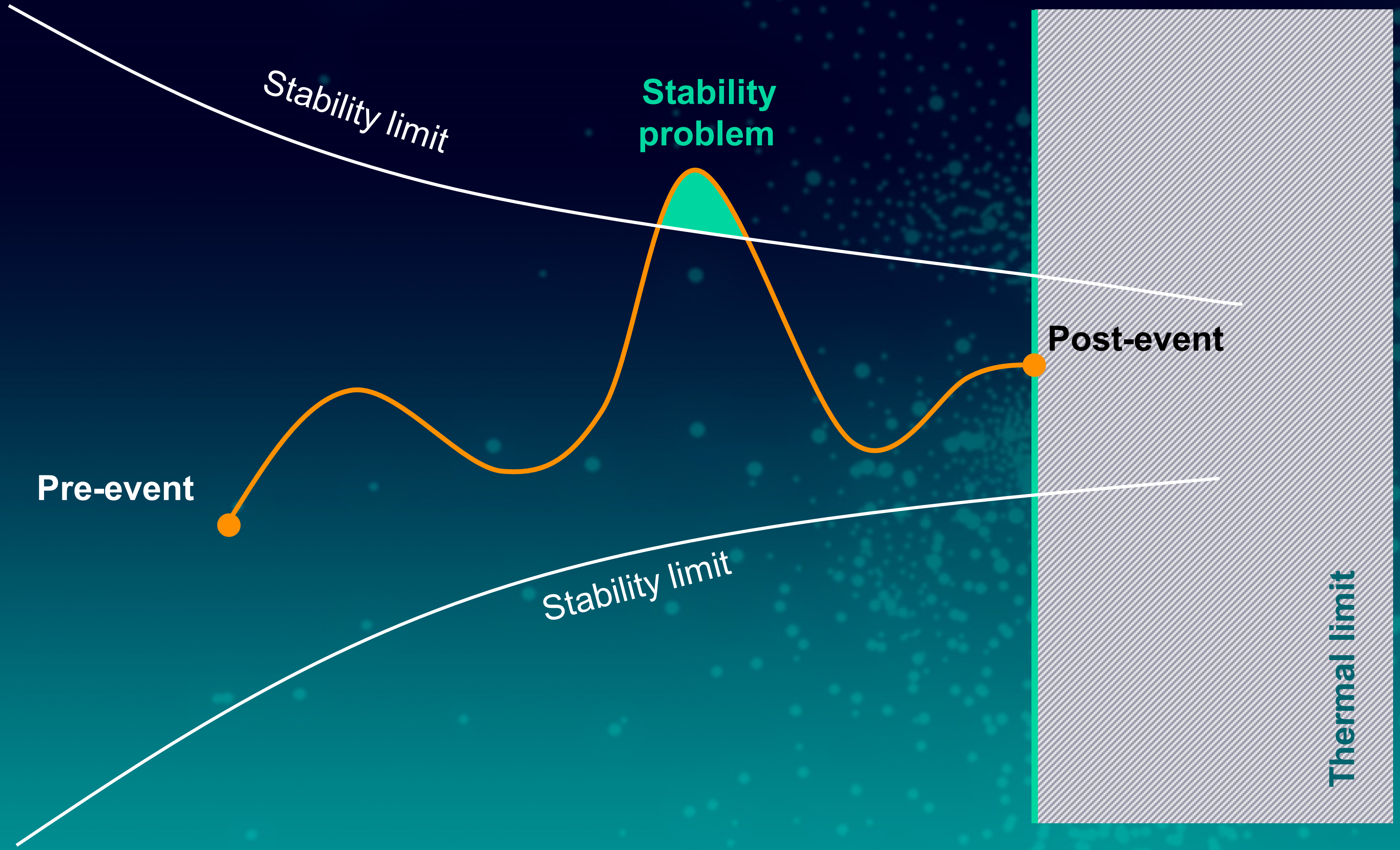
High renewable integration requires dynamic N-1 security assessment
Security Constraint Optimal Power Flow (SCOPF) algorithms



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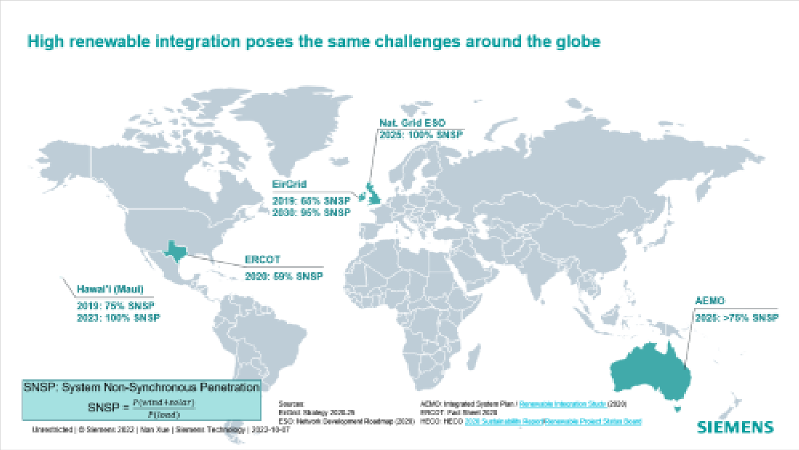
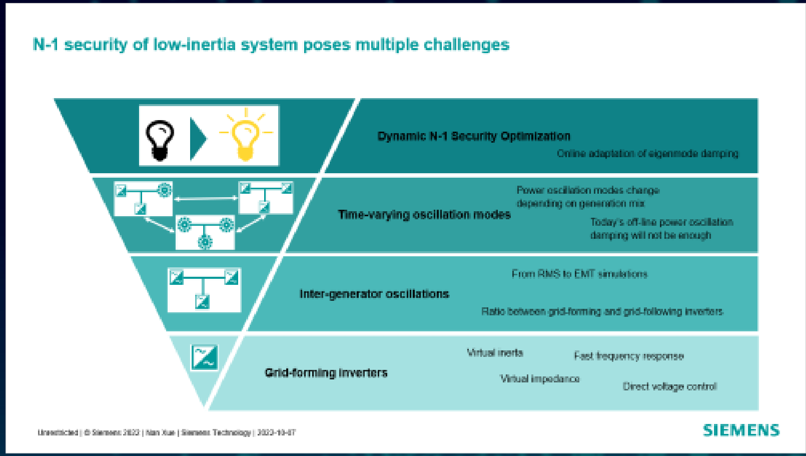
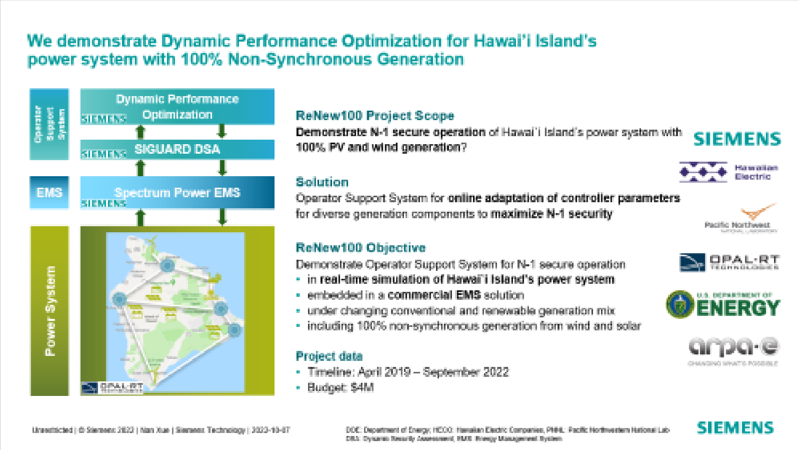
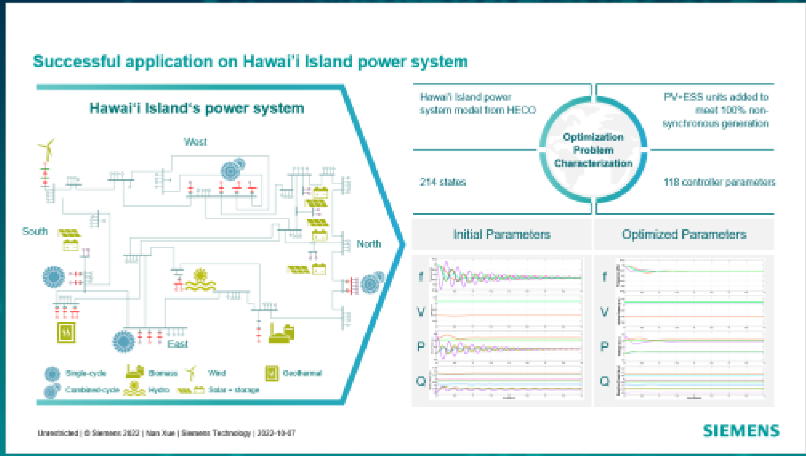
Agenda









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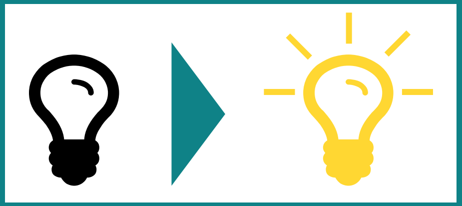
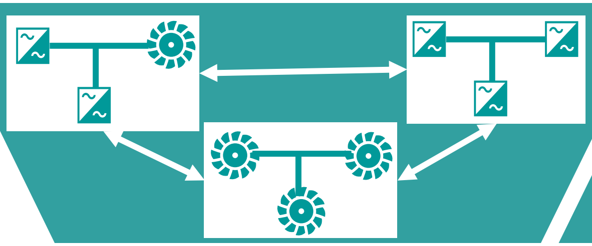
N-1 security of low-inertia system poses multiple challenges



Dynamic N-1 Security Optimization

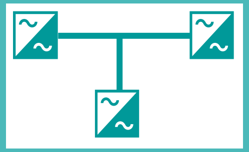
Online adaptation of eigenmode damping



Time-varying oscillation modes

Power oscillation modes change depending on generation mix

Today‘s off-line power oscillation damping will not be enough



Inter-generator oscillations

From RMS to EMT simulations

Ratio between grid-forming and grid-following inverters

Grid-forming inverters

Virtual inerta

Fast frequency response

Virtual impedance

Direct voltage control

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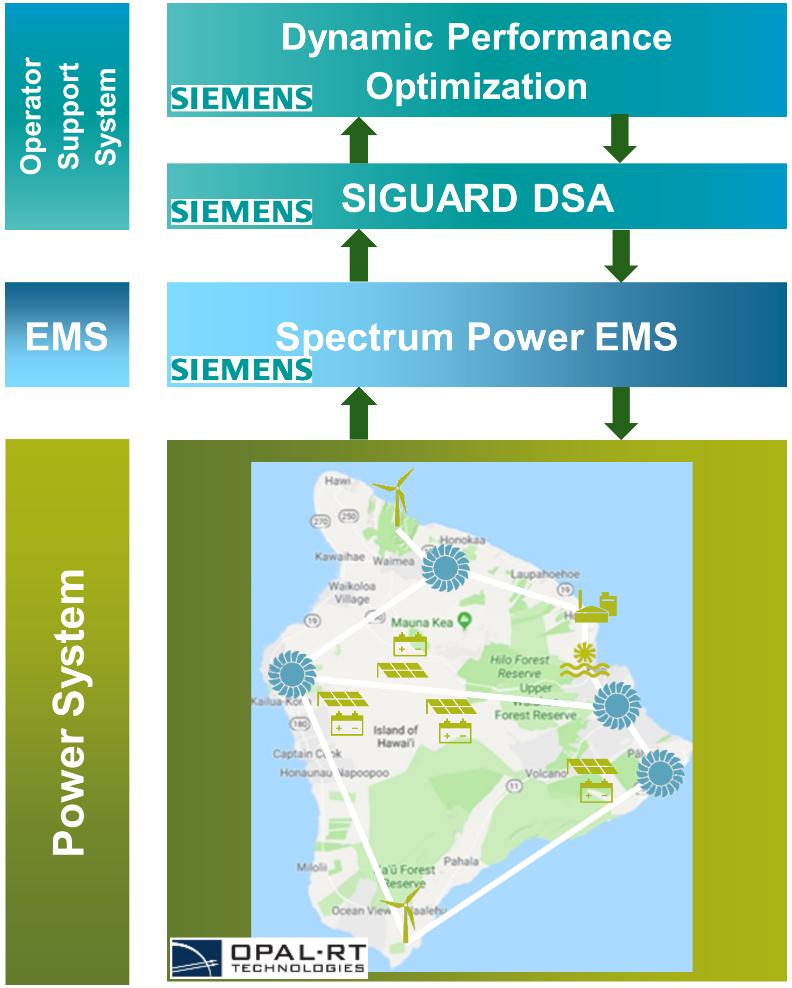
We demonstrate Dynamic Performance Optimization for Hawai’i Island’s power system with 100% Non-Synchronous Generation



ReNew100 Project Scope

Demonstrate N-1 secure operation of Hawai`i Island’s power system with **100% PV and wind generation**?

Solution

Operator Support System for **online adaptation of controller parameters** for diverse generation components to **maximize N-1 security**

ReNew100 Objective

Demonstrate Operator Support System for N-1 secure operation

- in **real-time simulation of Hawai`i Island’s power system**
- embedded in a **commercial EMS** solution
- under changing conventional and renewable generation mix
- including 100% non-synchronous generation from wind and solar

Project data

- Timeline: April 2019 – September 2022
- Budget: $4M

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Hawaiian Electric

Pacific Northwest NATIONAL LABORATORY

OPAL-RT TECHNOLOGIES

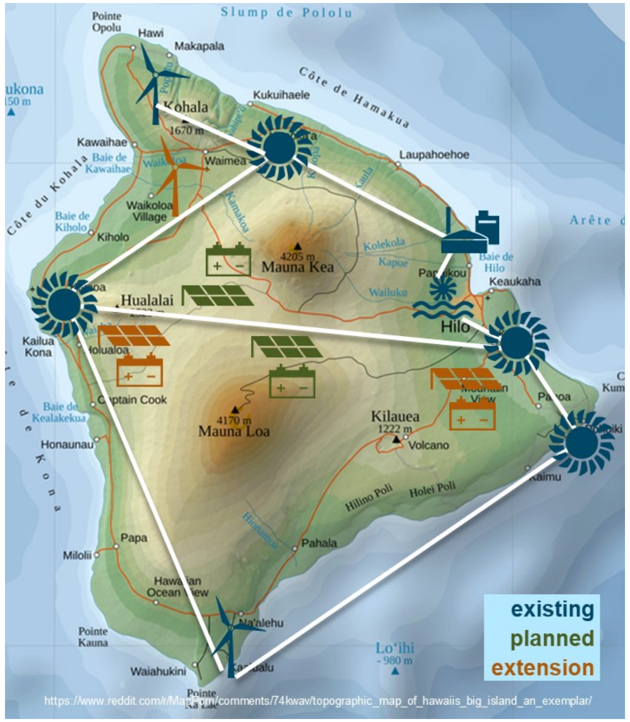
U.S. DEPARTMENT OF ENERGY

arpa·e CHANGING WHAT’S POSSIBLE

DOE: Department of Energy; HECO: Hawaiian Electric Companies, PNNL: Pacific Northwestern National Lab
DSA: Dynamic Security Assessment; EMS: Energy Management System

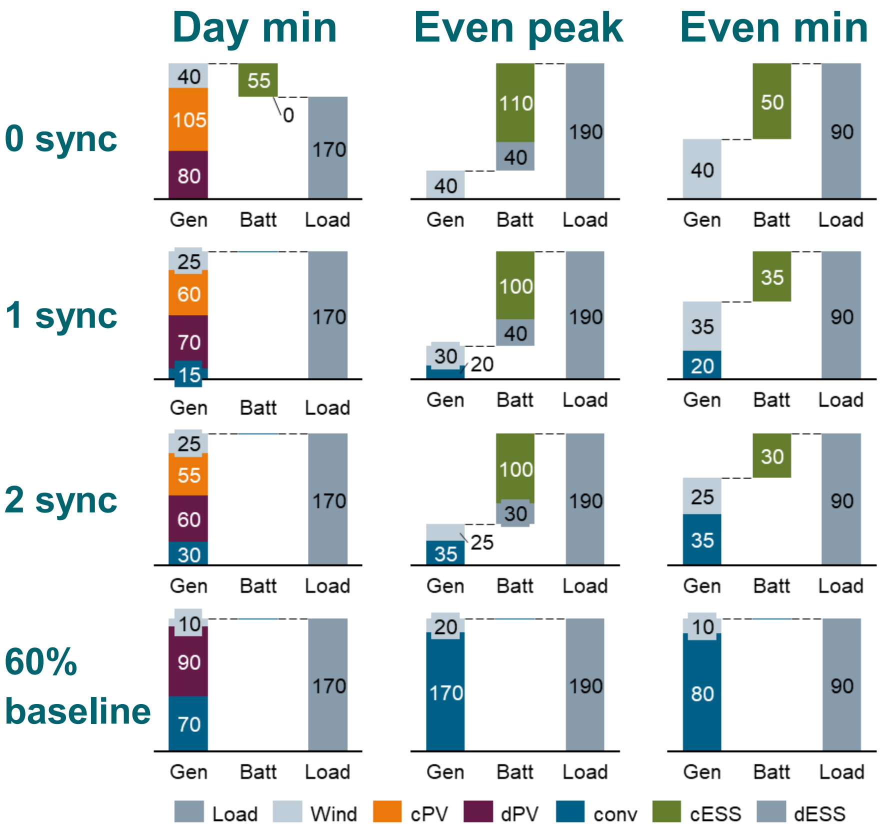
Modification of Hawai'i Island's power system leads to a power system with various zero-inertia cases

Hawai'i Island power system



Test scenarios for N-1 reliable operation

Generation	Capacity
Wind	50MW
Centr. PV	120MW
Distrib. PV	110MW
Centr. ESS	120MW
Distrib. ESS	40MW
Synchr. Renew.	90MW
Conventional	160MW



cPV: centralized PV; dPV: distributed PV; conv: conventional generation; cESS: centralized Energy System Storage; dESS: distributed Energy System Storage

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Operator Support System builds on standard architecture to achieve resilient operation of low-inertia power system

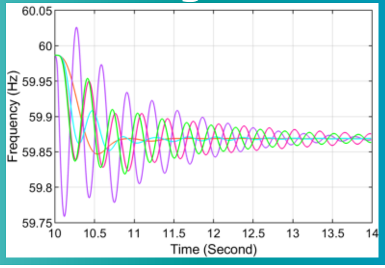
EMS

State Estimation

Spectrum Power 7

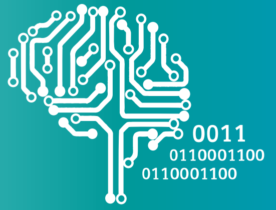
Operator Support System

Identify critical contingencies



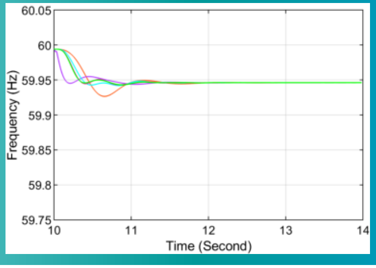
SIGUARD® DSA

Tune controllers to mitigate contingencies



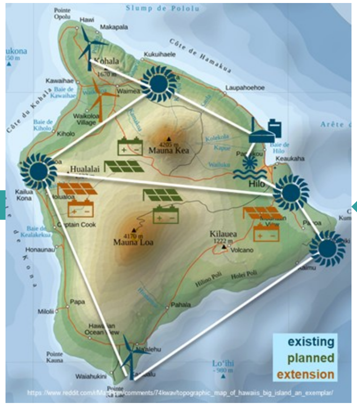
Dyn. Perform. Optim.

Verification of new Controller Parameter



SIGUARD® DSA

RTU measurements



Optimized controller parameters

DSA: Dynamic Security Assessment

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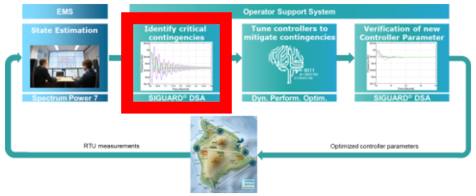
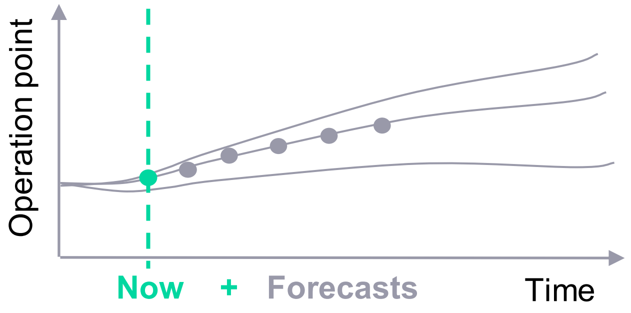
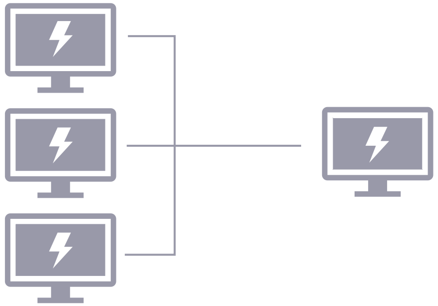


Siguard® Dynamic Security Assessment (DSA) analyzes dynamic system behavior and suggests measures to improve N-1 security

System state



Dynamic analysis



Measures

- Re-dispatch
- Dynamic Performance Optimization
- …

Visualization

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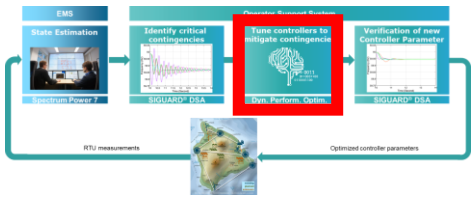
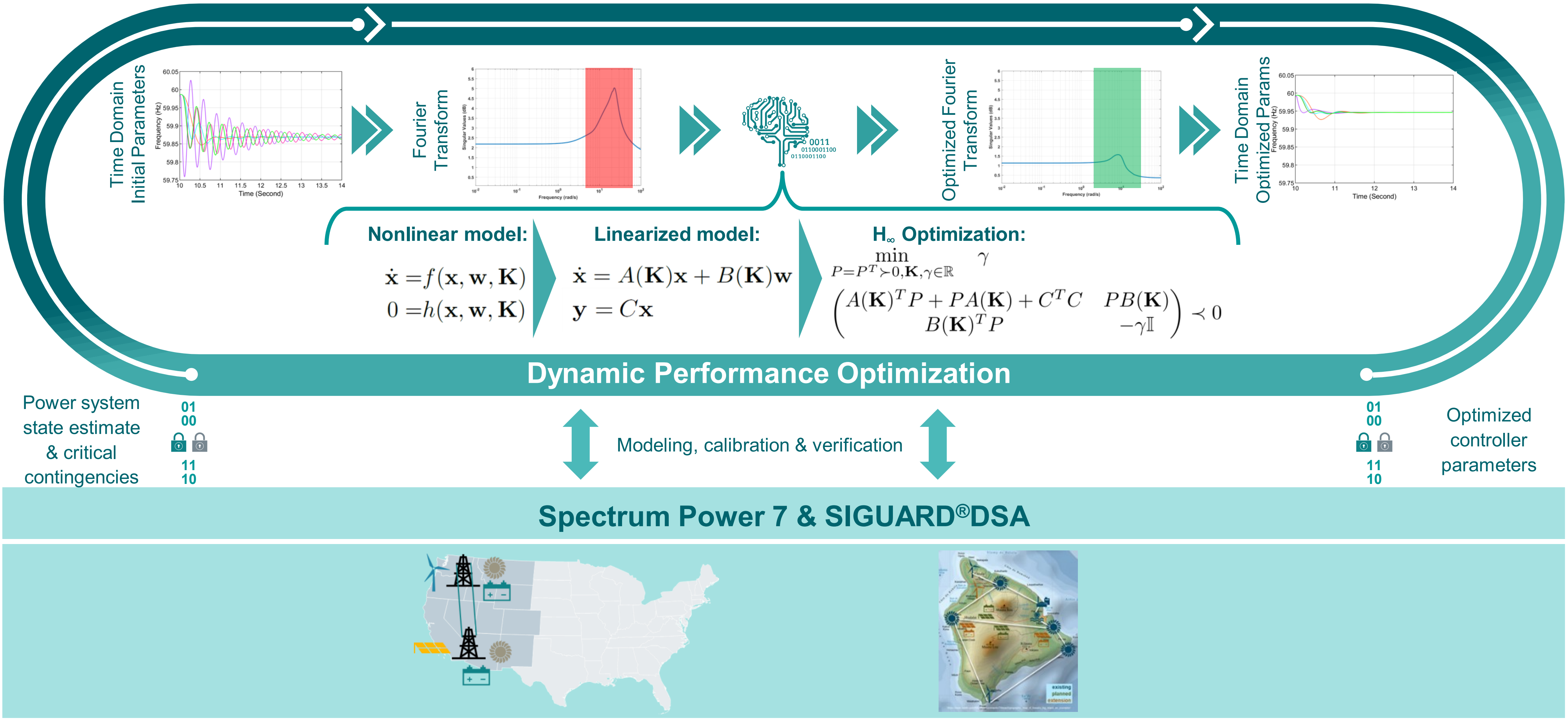


Dynamic Performance Optimization automatically tunes generator controller parameters to improve dynamic system behavior



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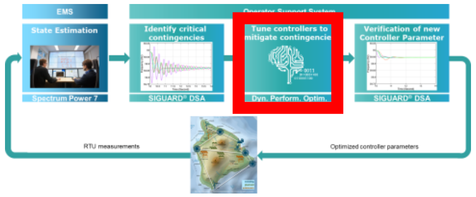
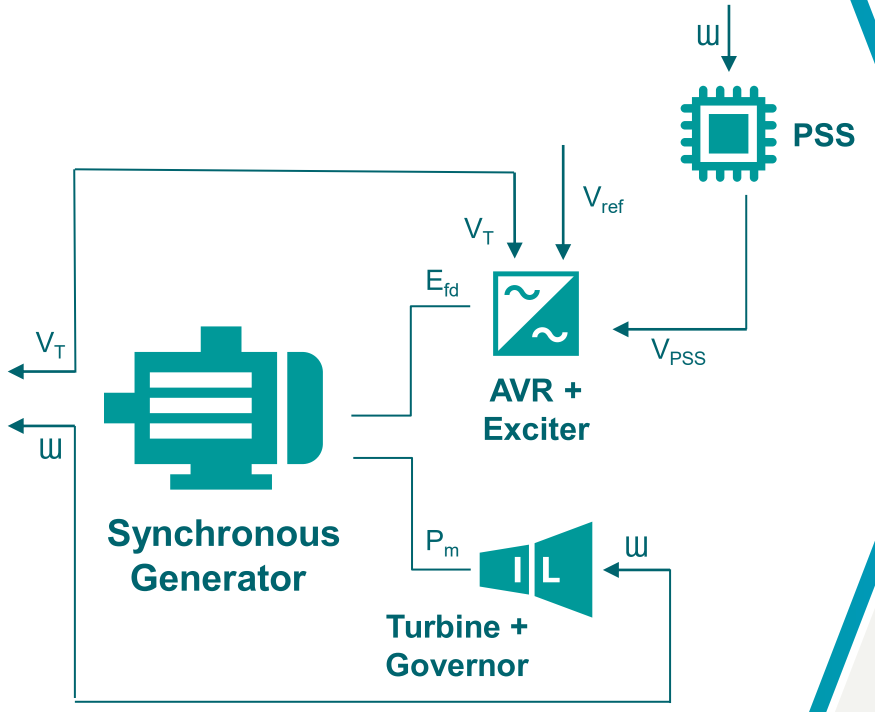


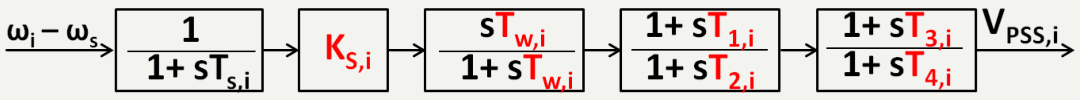
We tune detailed power plant models
We optimize standard IEEE models

❖ ***19 states per generator***

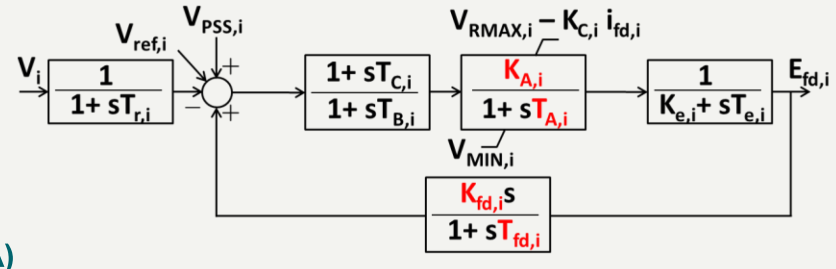
❖ ***10 tunable controller parameters per generator***

Decomposition of Generator

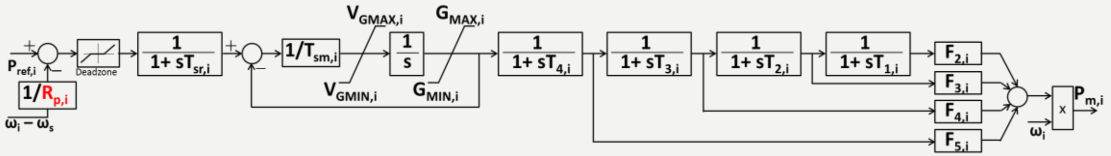




PSS (PSS1A)



Automatic Voltage Regulator
+ Exciter Model (IEEE X1 / DC1A)



Turbine + Governor
(IEEE G1)

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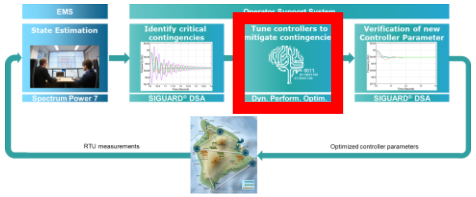
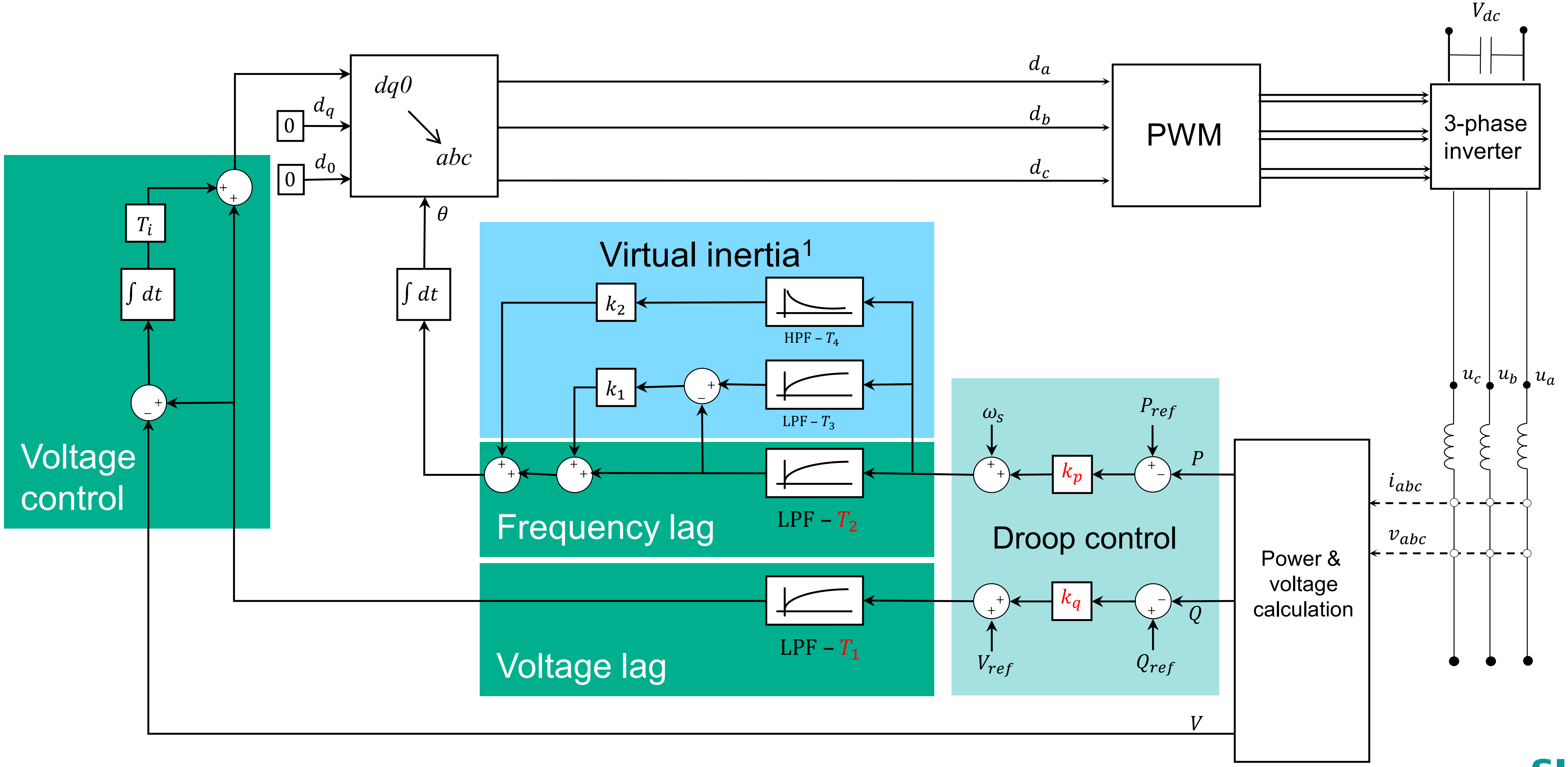


We tune detailed power plant models
We optimize flexible grid-forming inverter models



LPF: Low-Pass Filter; PWM: Pulse Width Modulation; [1]Virtual inertia is not used in the current analysis

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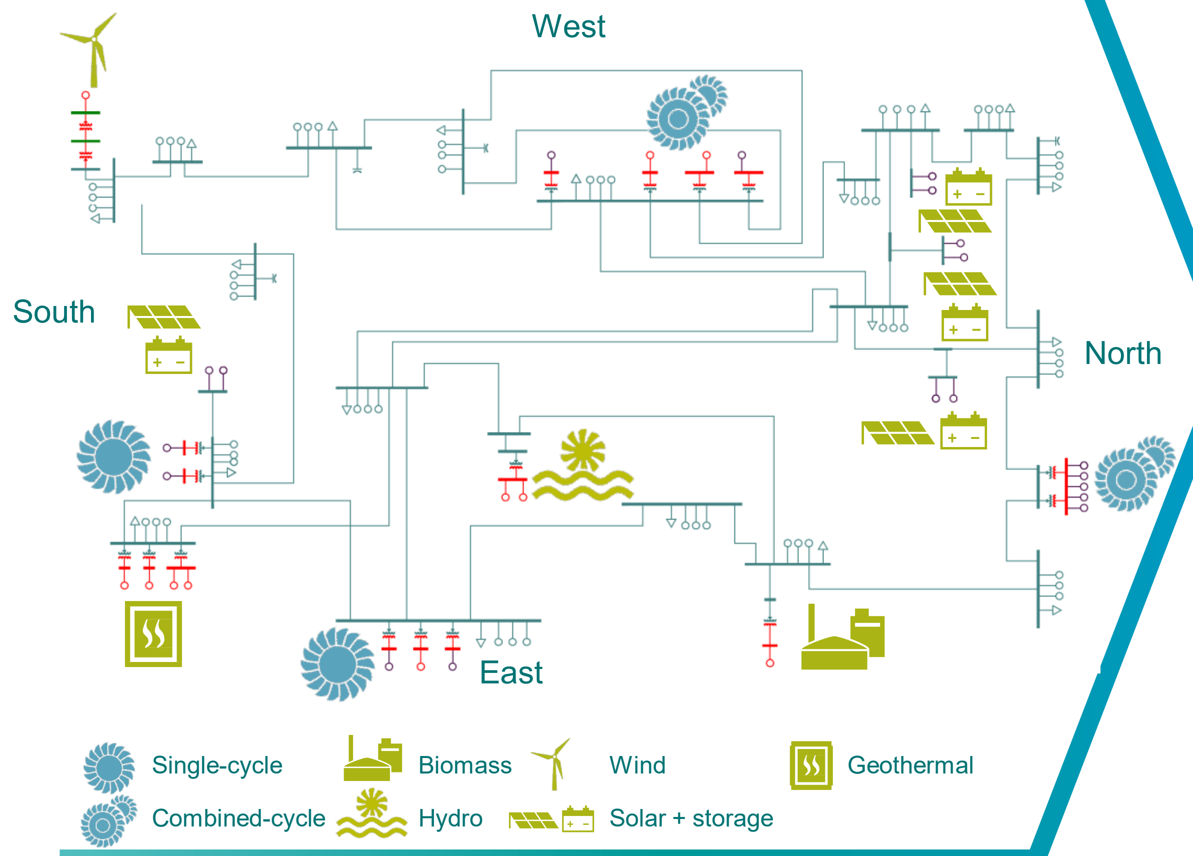
Successful application on Hawai'i Island power system

Hawai'i Island's power system



Hawai'i Island power system model from HECO

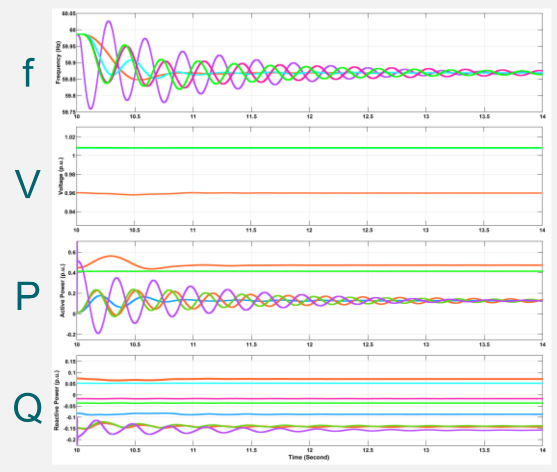
PV+ESS units added to meet 100% non-synchronous generation

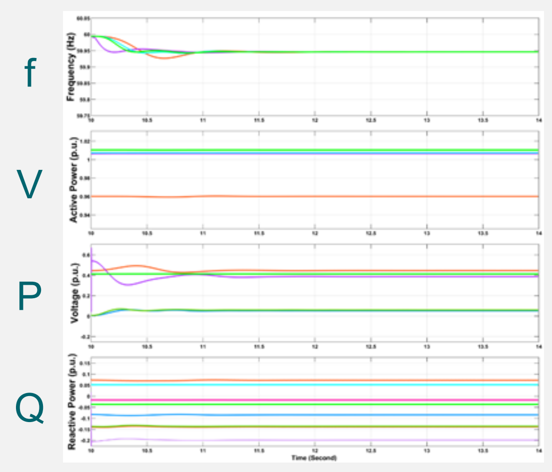
Optimization Problem Characterization

214 states

118 controller parameters

Initial Parameters	Optimized Parameters





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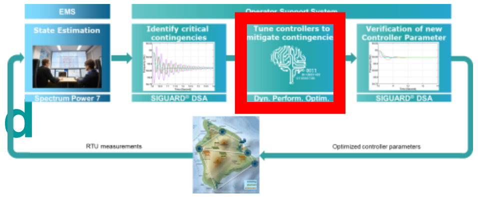
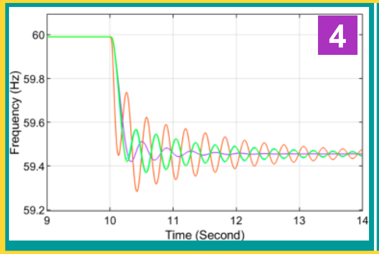
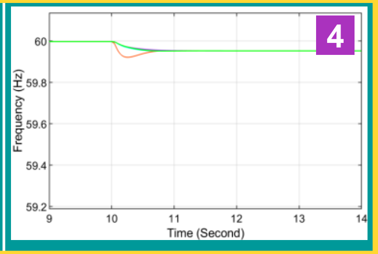
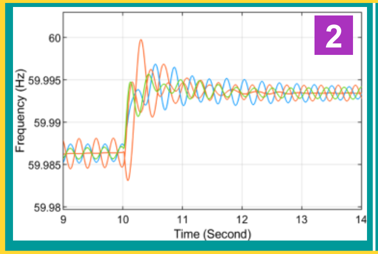
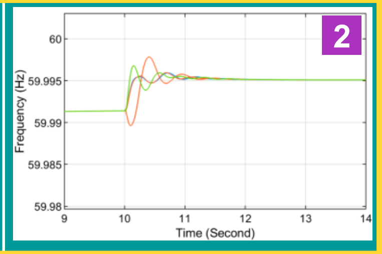
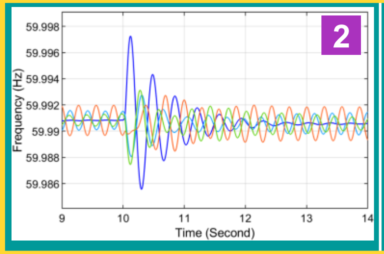
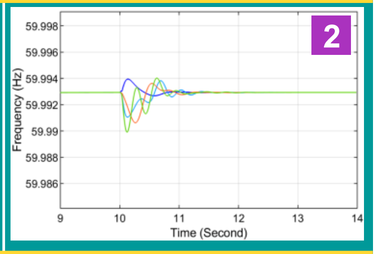
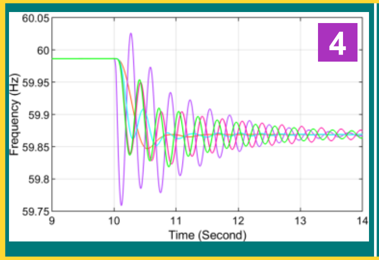
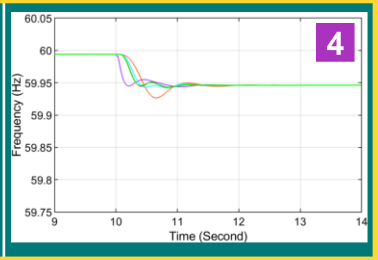
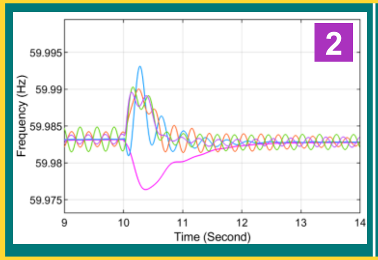
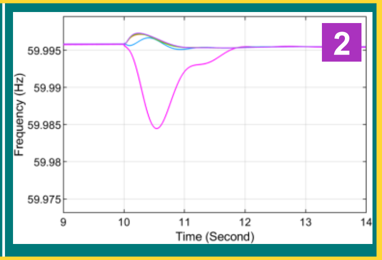
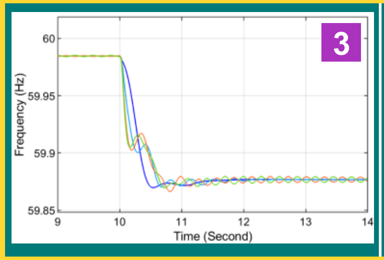
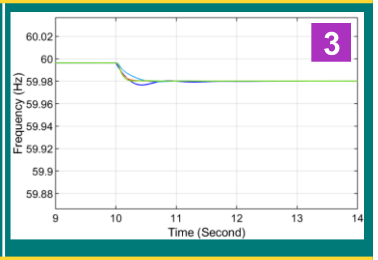
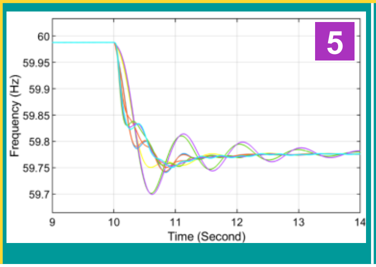
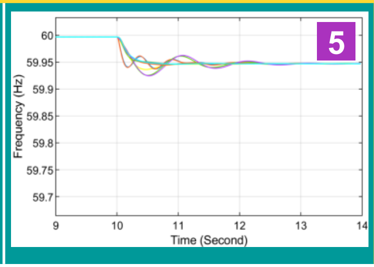
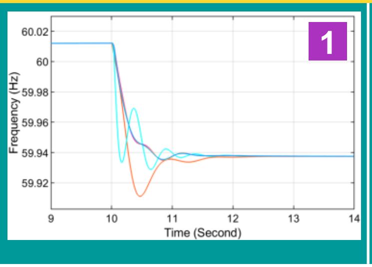
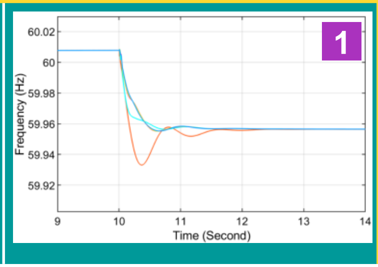
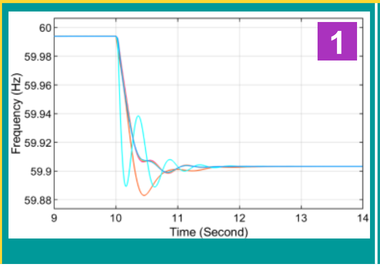
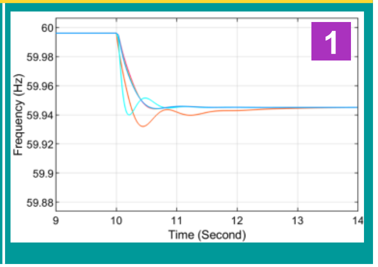
Dynamic Performance Optimization (DPO) successful for diverse scenarios and contingencies



SNSP	Noon		Evening		Night	
	Without DPO	With DPO	Without DPO	With DPO	Without DPO	With DPO
100%						
90%						
80%						

Contingencies: 1 Loss of largest synchronous unit 2 Loss of power line 3 Loss of grid-forming ESS 4 Loss of centralized PV 5 Loss of 50% distributed PV

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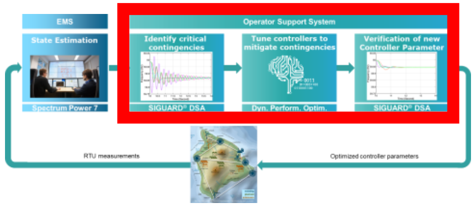
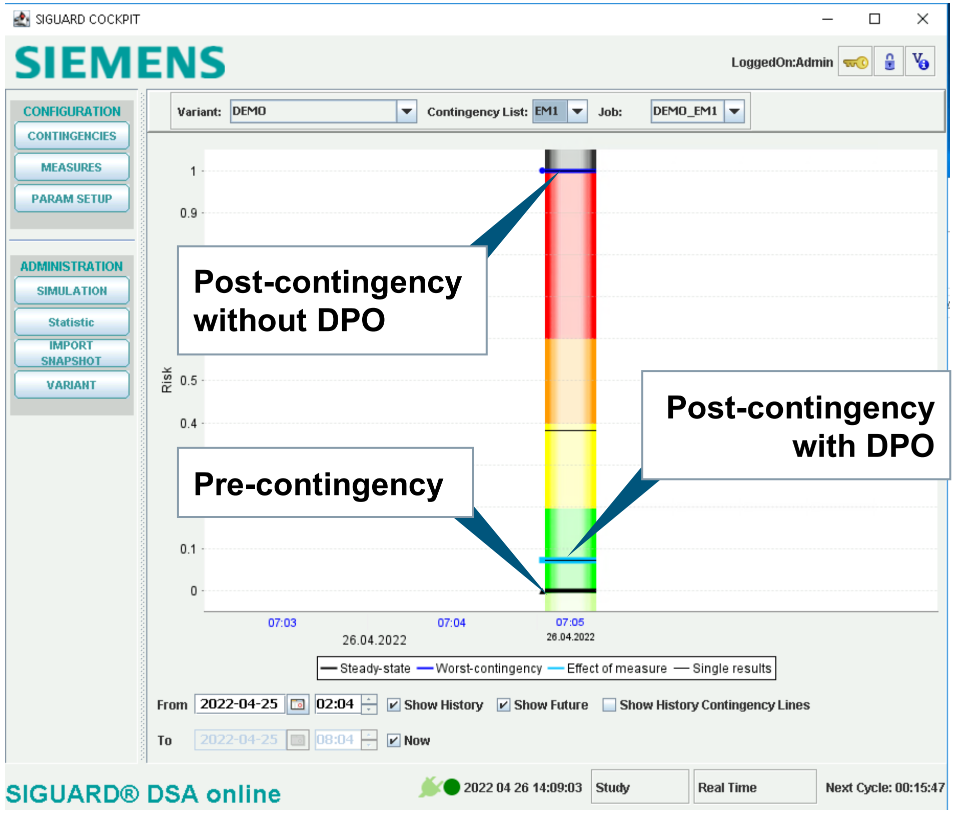
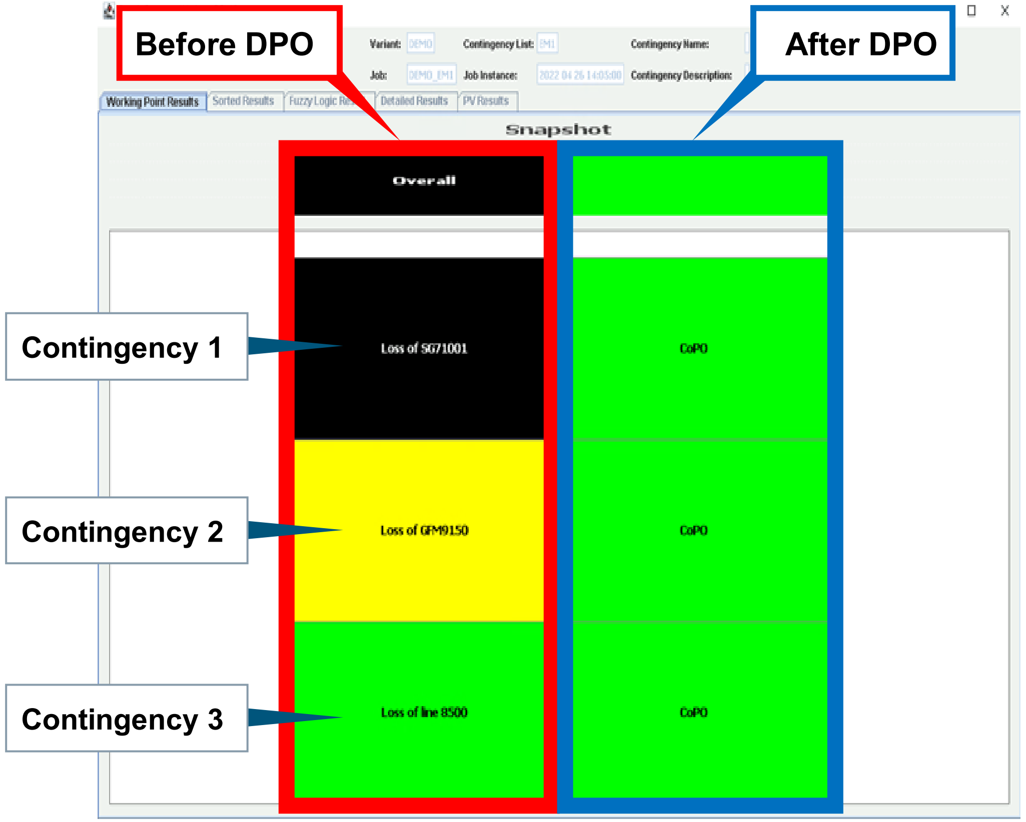
Siguard® Dynmic Security Assessment validates Dynamic Performance Optimization (DPO) and shows results to operator

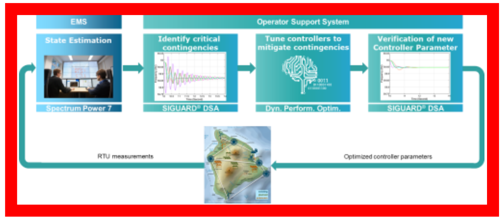


Siguard® DSA Cockpit

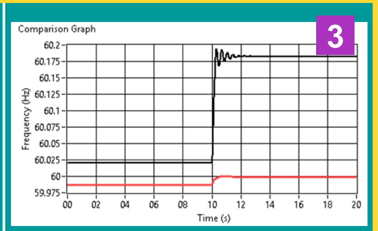
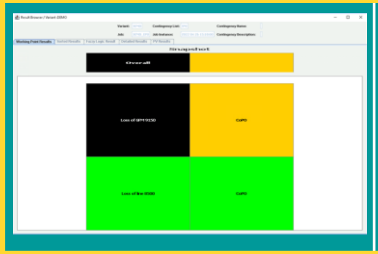
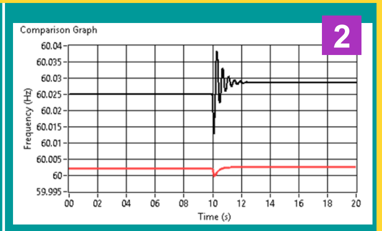
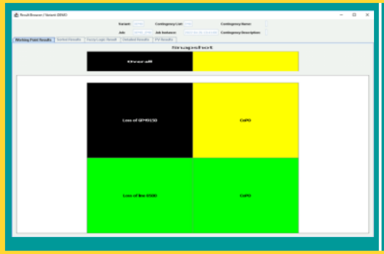
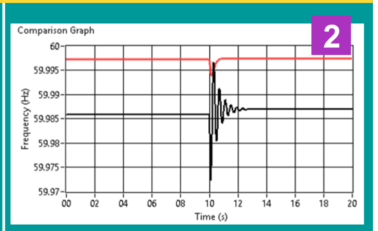
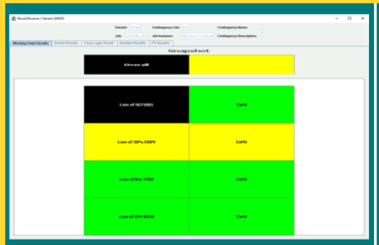
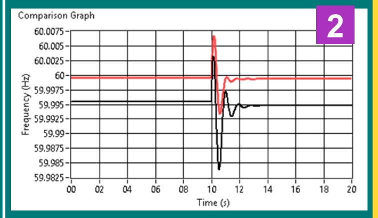
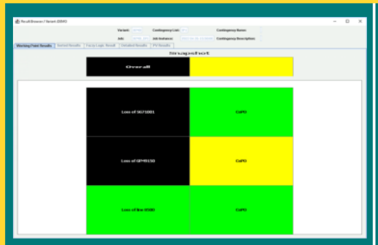
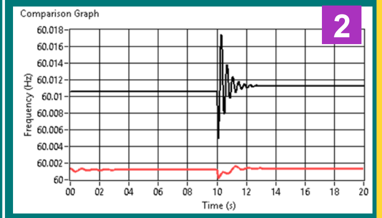
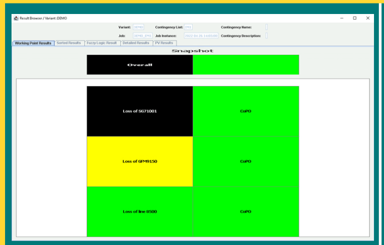
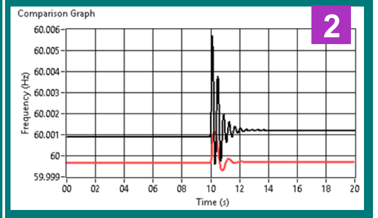
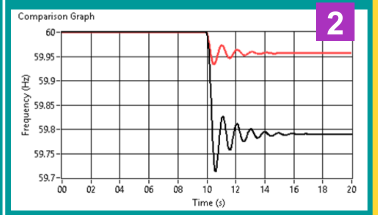
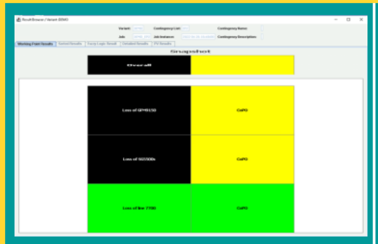
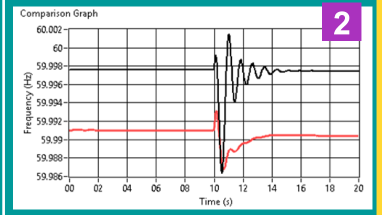
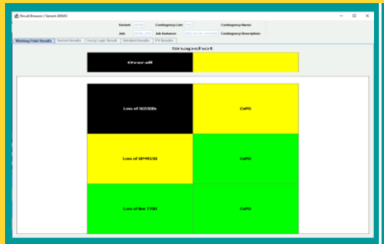
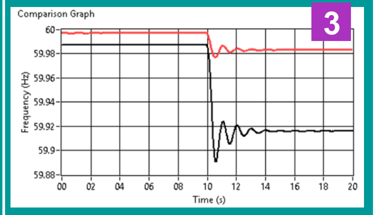


Siguard® DSA contingency analysis





Dynamic Performance Optimization successfully validated in demonstrator

SNSP	Day Minimum		Evening Peak		Evening Minimum	
	DSA Cockpit	Validation	DSA Cockpit	Validation	DSA Cockpit	Validation
100%						
90%						
80%						

Contingencies: 1 Loss of largest synchronous unit 2 Loss of power line 3 Loss of grid-forming ESS 4 Loss of centralized PV 5 Loss of 50% distributed PV

SNSP: System Non-Synchronous Penetration;
Validation plots: **Black**: before DPO; **Red**: after DPO (DPO: Dynamic Performance Optimization)

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Quick Demo

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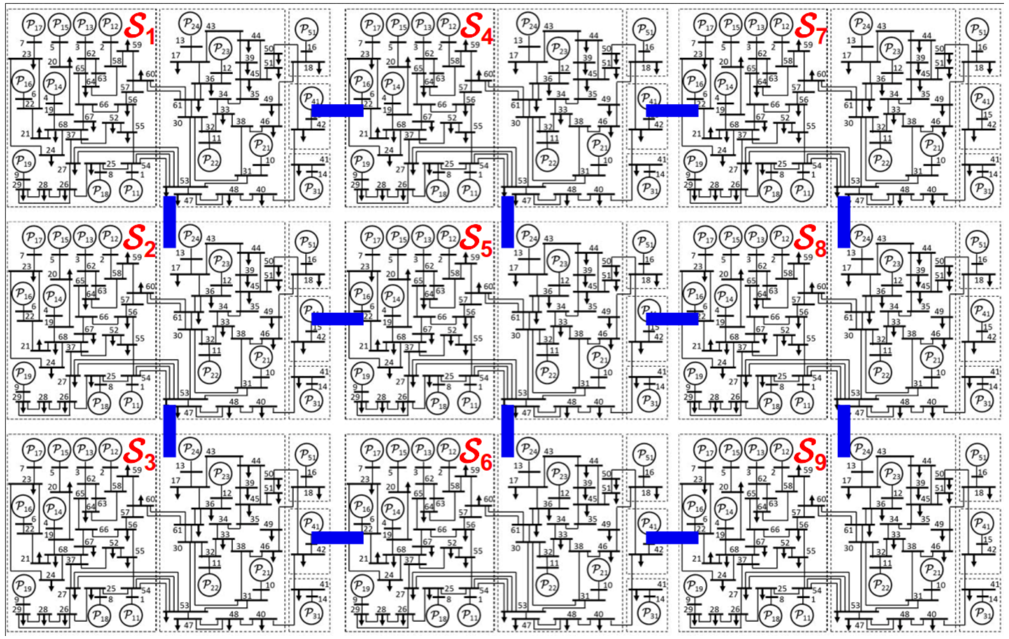
Dynamic Performance Optimization is scalable for large power systems

Successful application to 140+ power plant example

Power system model



Model obtained by coupling nine IEEE 68 bus systems

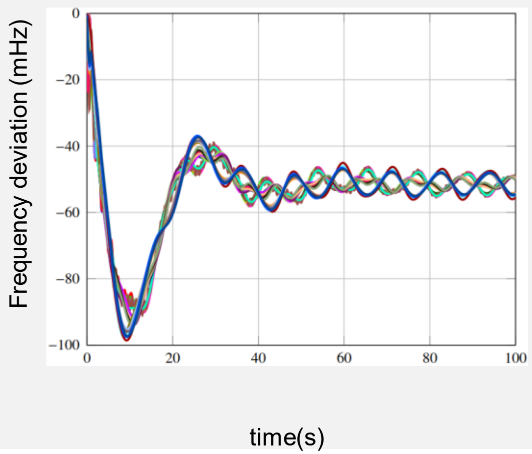
Hierarchical optimization with increased information security

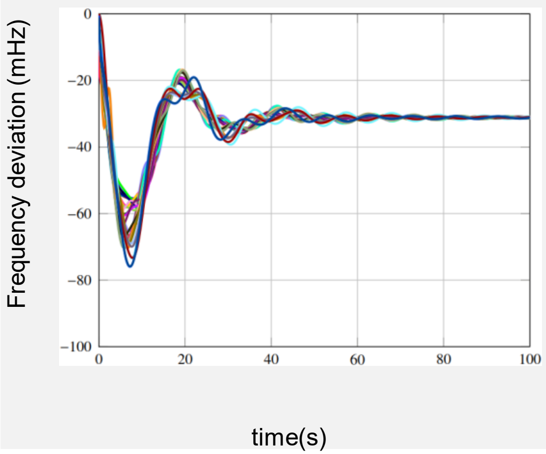
Optimization Problem Characterization

144 power plants

2520 states
1440 controller parameters

Initial Parameters	Optimized Parameters





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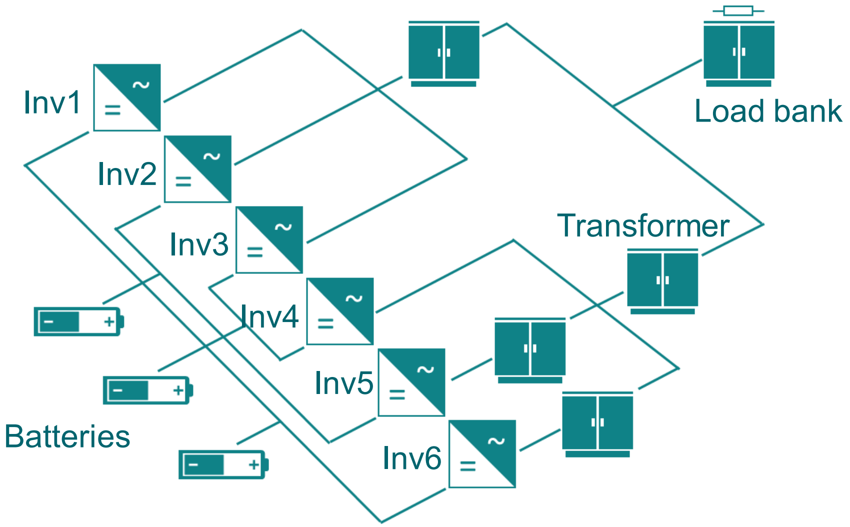
Dynamic Performance Optimization works in practice

Successful validation in field test in Wildpoldsried, Germany



Key results

- Controller parameter optimization works in practice
- Accurate modelling is key for successful optimization

Initial Parameters	Manually Tuned Parameters	Optimization /wo Droops	Optimization /w Droops