Dynamic Performance Optimization for 100% Inverter-based Power Systems: Experiences from Hawai’i Island

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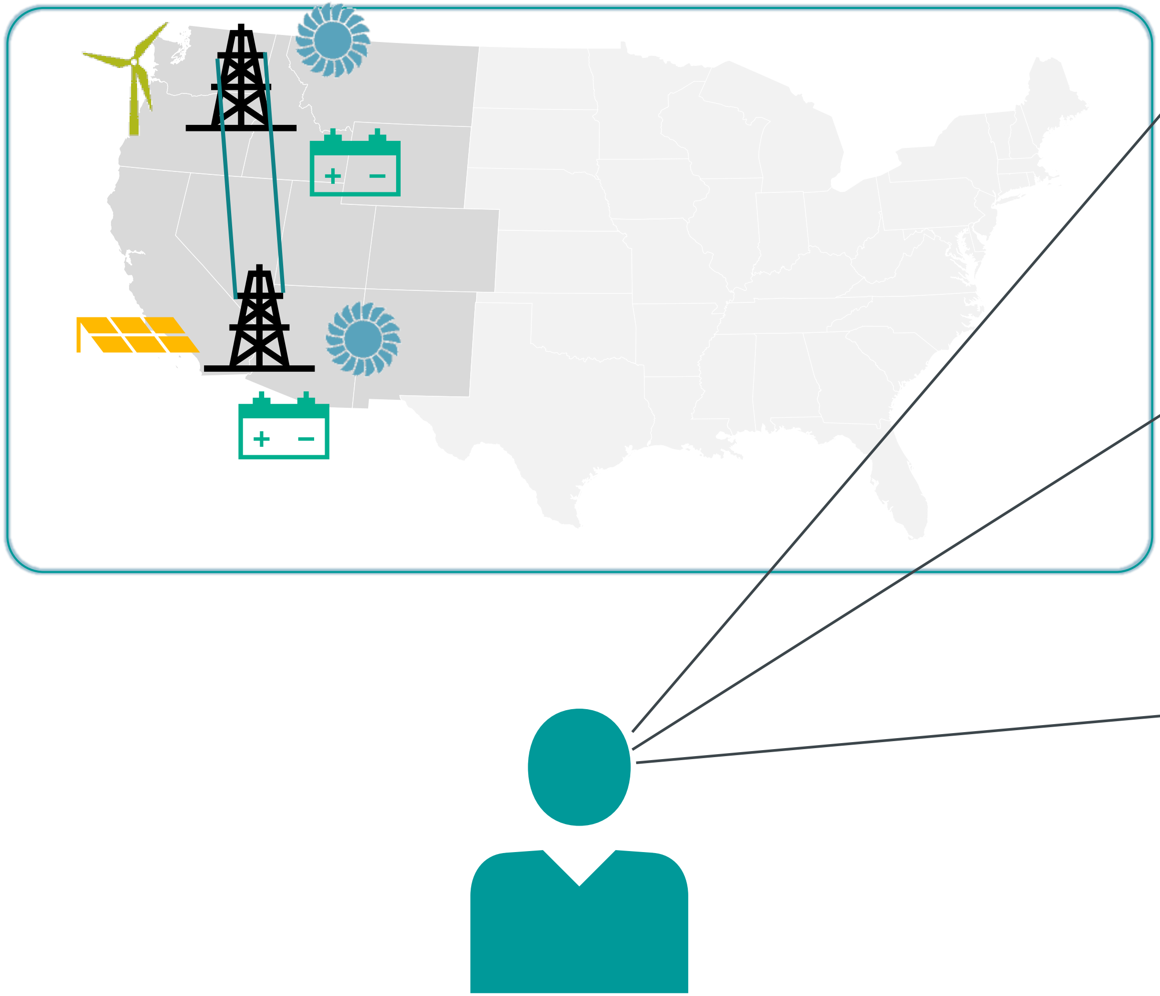
Overview for ESIG March 29, 2023

High renewable integration poses various operational challenges



Power Balance
Generation meets load

Power Transfer
Generation far from load

Power System Stability
N-1 security

Protection schemes

Focus of this presentation

Focus of our new project

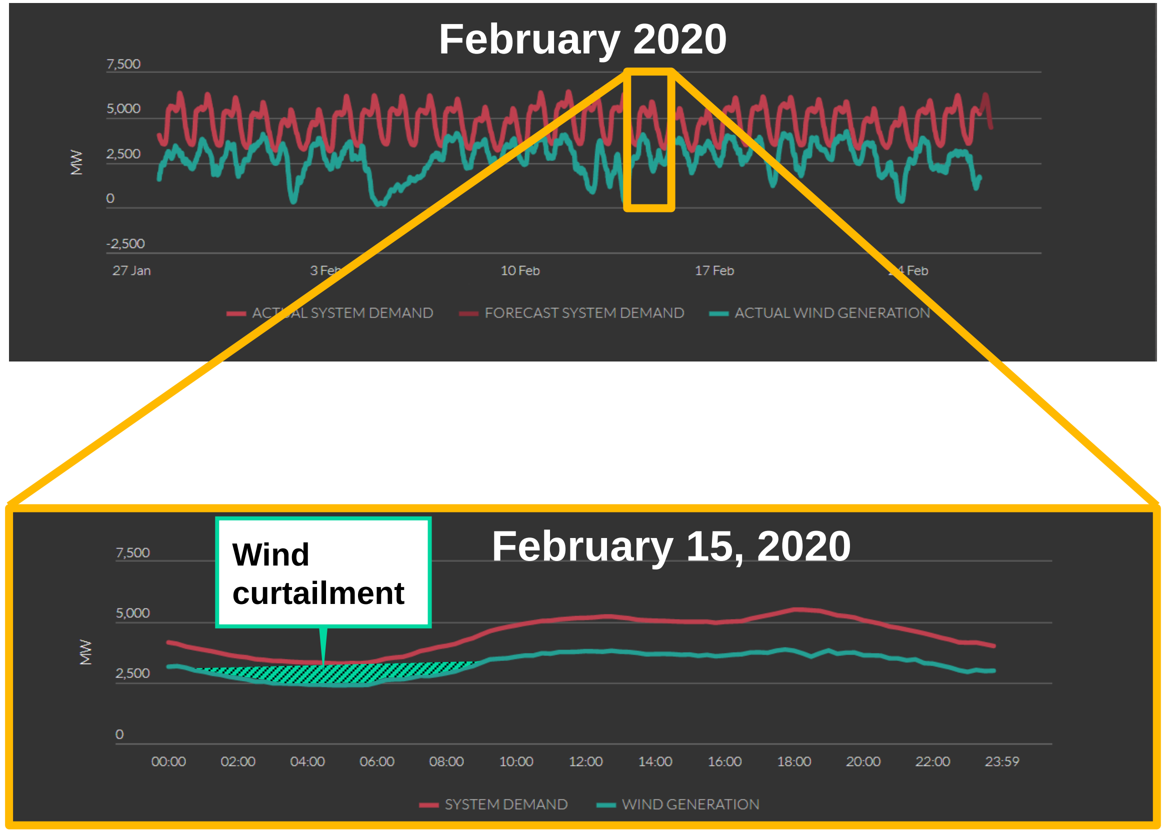
WHY

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

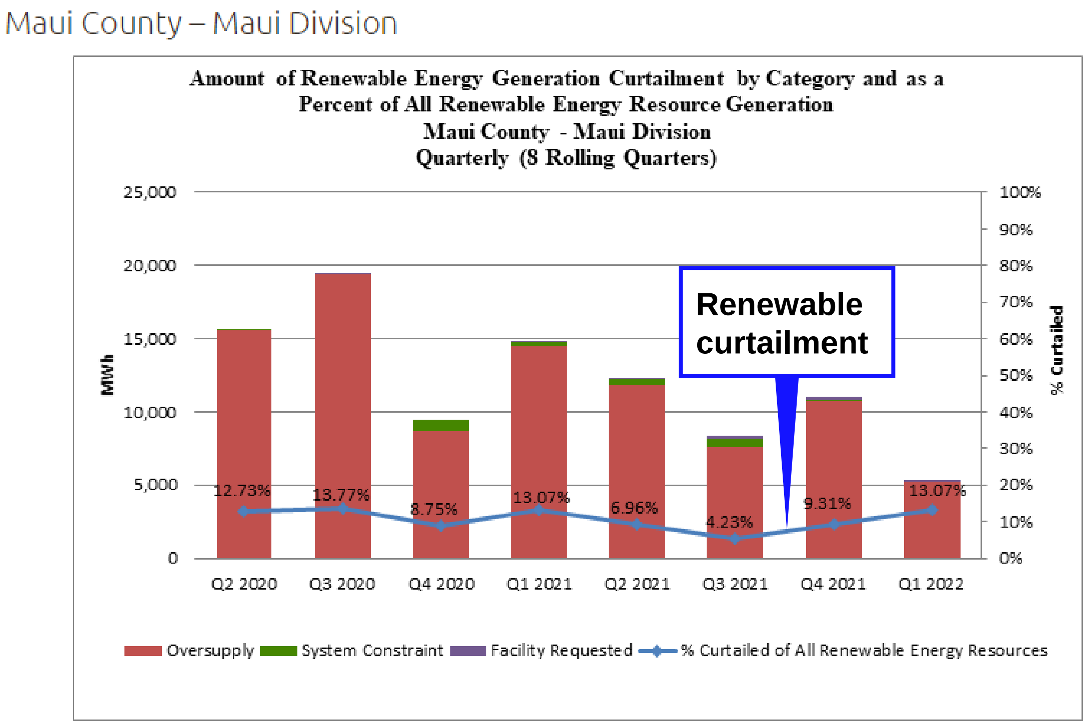
Renewables replaced by conventional generation on 20 of 28 nights



http://smartgriddashboard.eirgrid.com/

Maui

10% of renewable generation replaced by conventional generation



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

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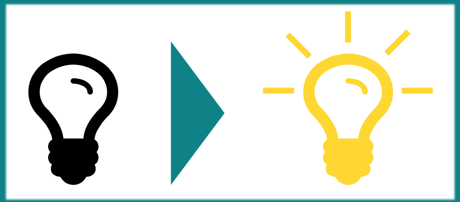
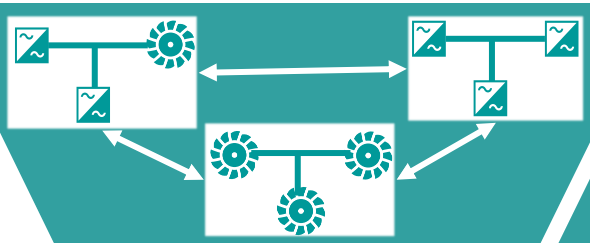
WHY
N-1 security of low-inertia system poses multiple challenges



Dynamic N-1 Security Optimization

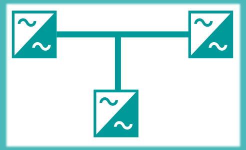
Online adaptation of eigenmode damping



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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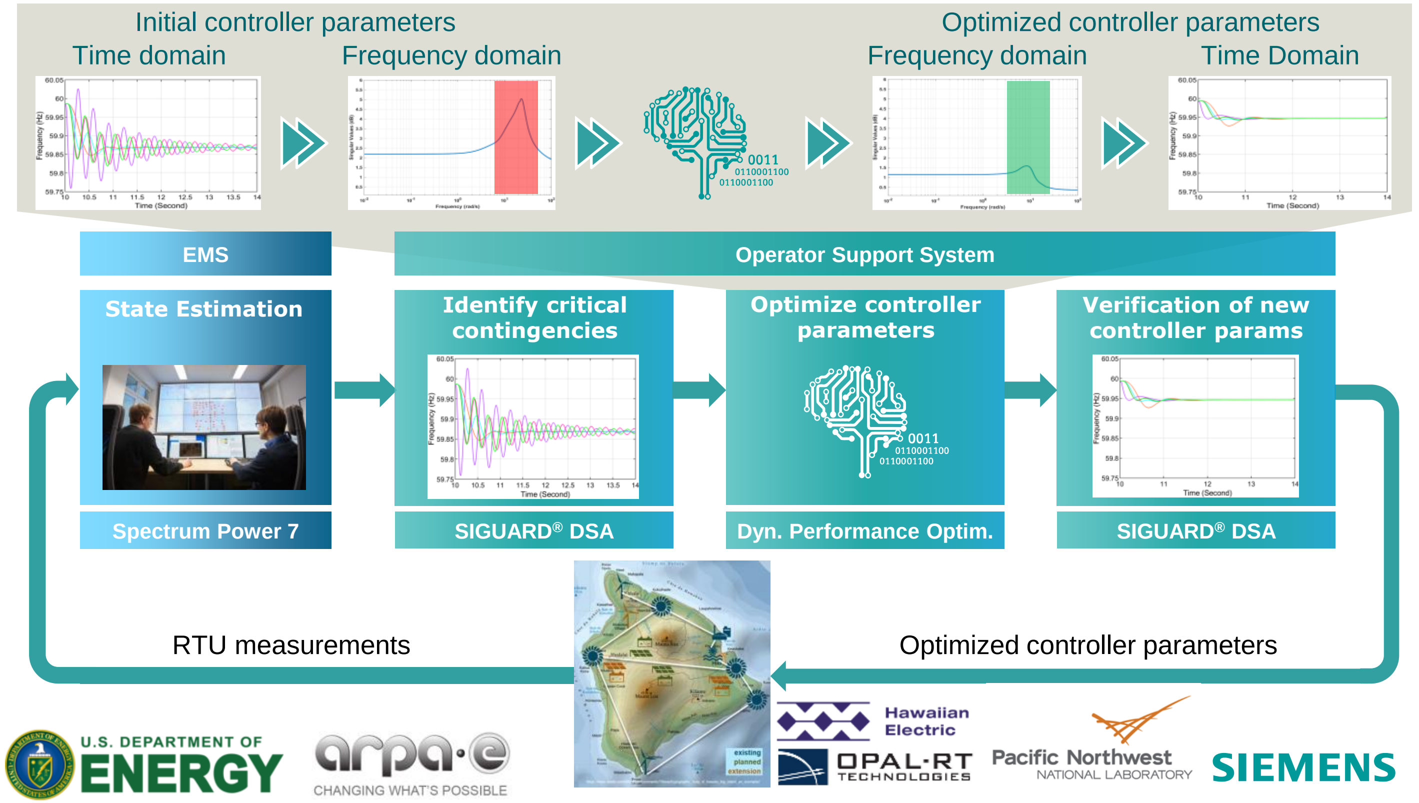
What & How

Our operator support system enables N-1 secure operation of low-inertia power systems based on a standard control center architecture

HECO needs

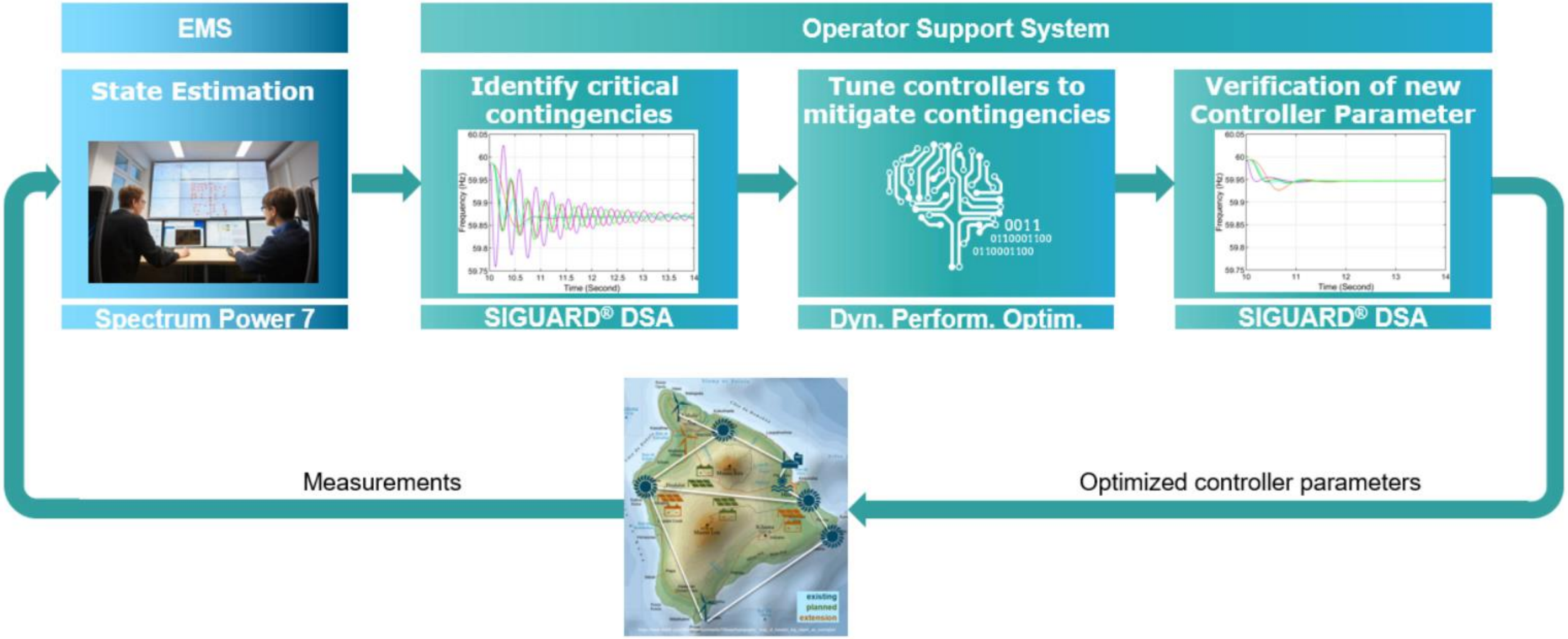
- **Maximize Renewables**
- **Resiliency & maintain security of supply**
- **Operation closer to system limits**
- **Manage higher system complexity**

We demonstrate N-1 secure operation of 100% inverter-based power system for Hawai'i Island (in virtual environment)



DSA: Dynamic Security Assessment; EMS: Energy Management System; RTU: Remote Terminal Unit

ReNew100 Operator Support System Demo

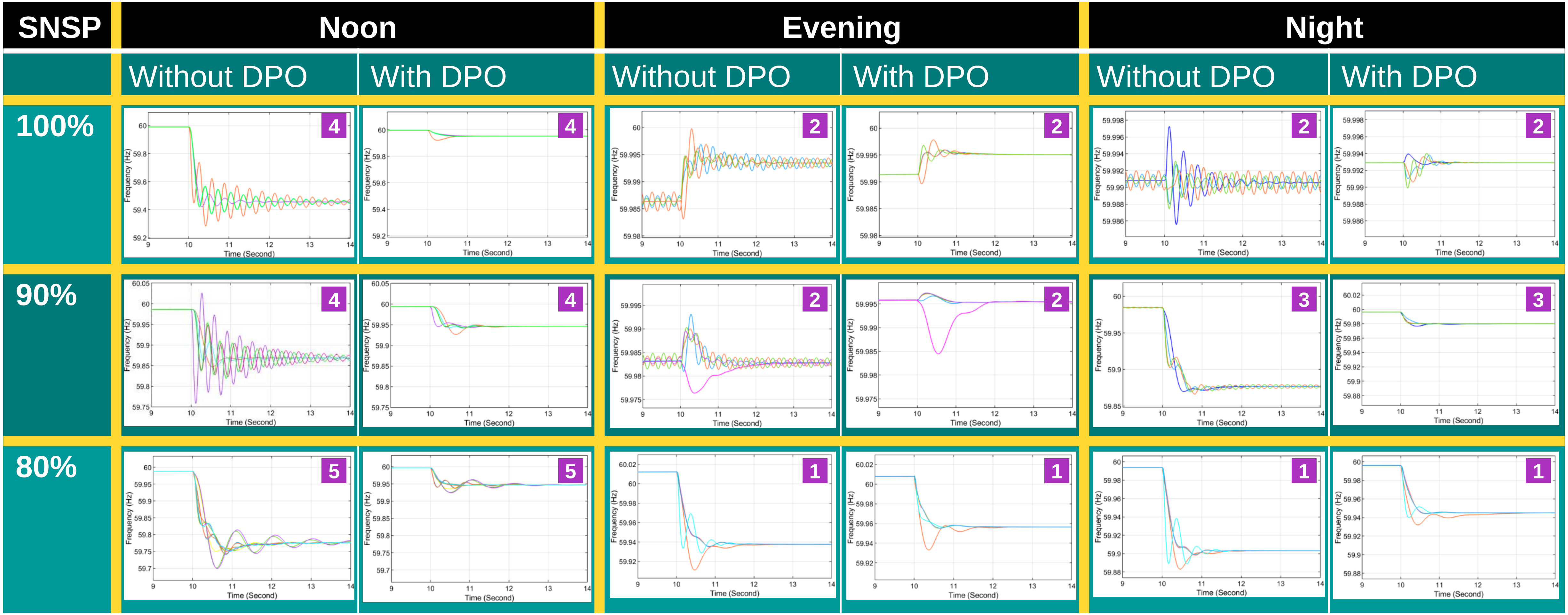


EMS: Energy Management System

DSA: Dynamic Security Assessment

Results

Dynamic Performance Optimization (DPO) successfully increases N-1 security for diverse scenarios and contingencies



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 Generation

What we learned …

… and what we need

What we learned …	… and what we need
We observe **time-varying eigenmodes** depending on dispatch	**Online assessment** and **performance optimization of dynamic stability / N-1 security** & online adaptation of IBR controller parameters
Accurate power system models are key for automatic assessment and performance optimization	**Calibration of dynamic power systems models** is a big gap
Inverter models are key for accurate power systems models	**White-box standard models for IBRs** similar to IEEE Std. 421.5-2016 for PSS

PSS: Power System Stabilizer

PI-Co Design: Protection-Inverter Co-Design for power system with 100% Renewable Power Systems

Project objectives

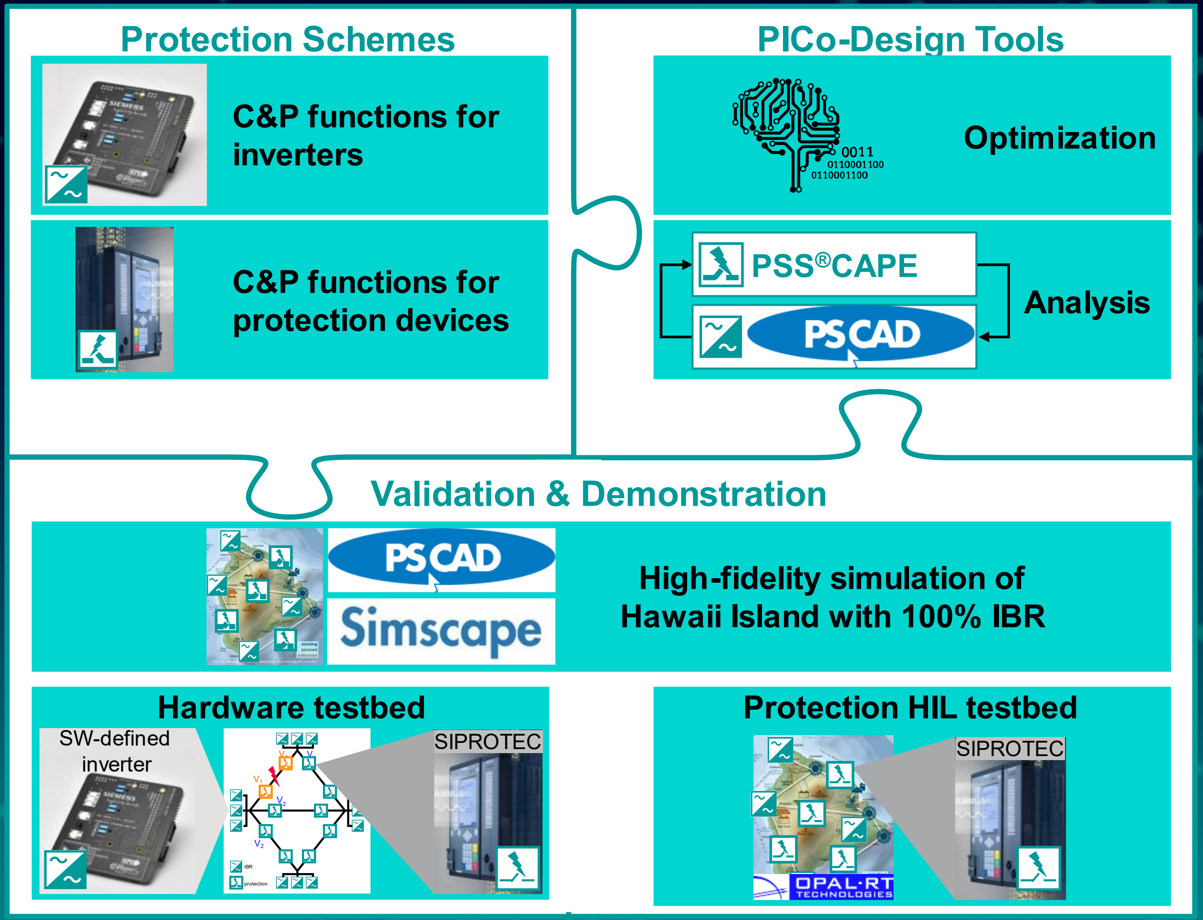
- Develop and validate **innovative protection schemes** for power systems with up to **100% IBR**

Main tasks

- Innovate **fault-detection functions** for protection devices
- Innovate **current-limiting & FRT functions** for inverters
- Innovate **hybrid Phasor/EMT modelling** for protection analysis
- **Optimization** for Protection-Inverter Co-Design
- Validation in **high-fidelity HW & PHIL testbed**

Project info

- Duration: 10/2022 – 09/2025
- Partners: Siemens, HECO, EPRI, SNL, MHI, Electranix



IBR: Inverter-based Resource; FRT: Fault-Ride Through; GFM: Grid-ForMing; GFL: Grid-FoLlowing; EMT: Electro-Magnetic Transient; PHIL: Protection Hardware in the Loop; HECO: Hawaiian Electric; EPRI: Electric Power Research Institute; SNL: Sandia National Lab; MHI: Manitoba Hydro International ; C&P: Control and Protection

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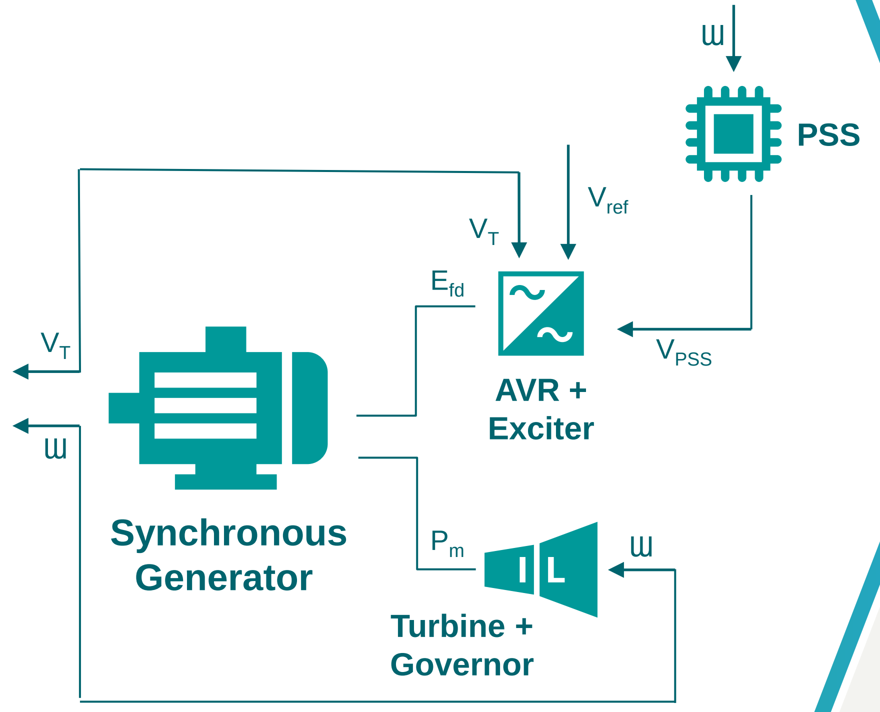
We tune detailed power plant models

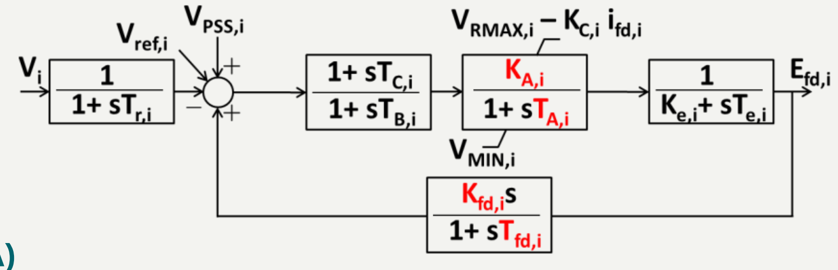
We optimize standard IEEE models

- ***19 states per generator***
- ***10 tunable controller parameters per generator***

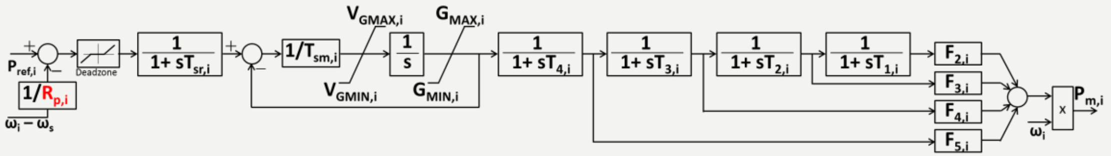
Decomposition of Generator



PSS (PSS1A)



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



Turbine + Governor
(IEEE G1)

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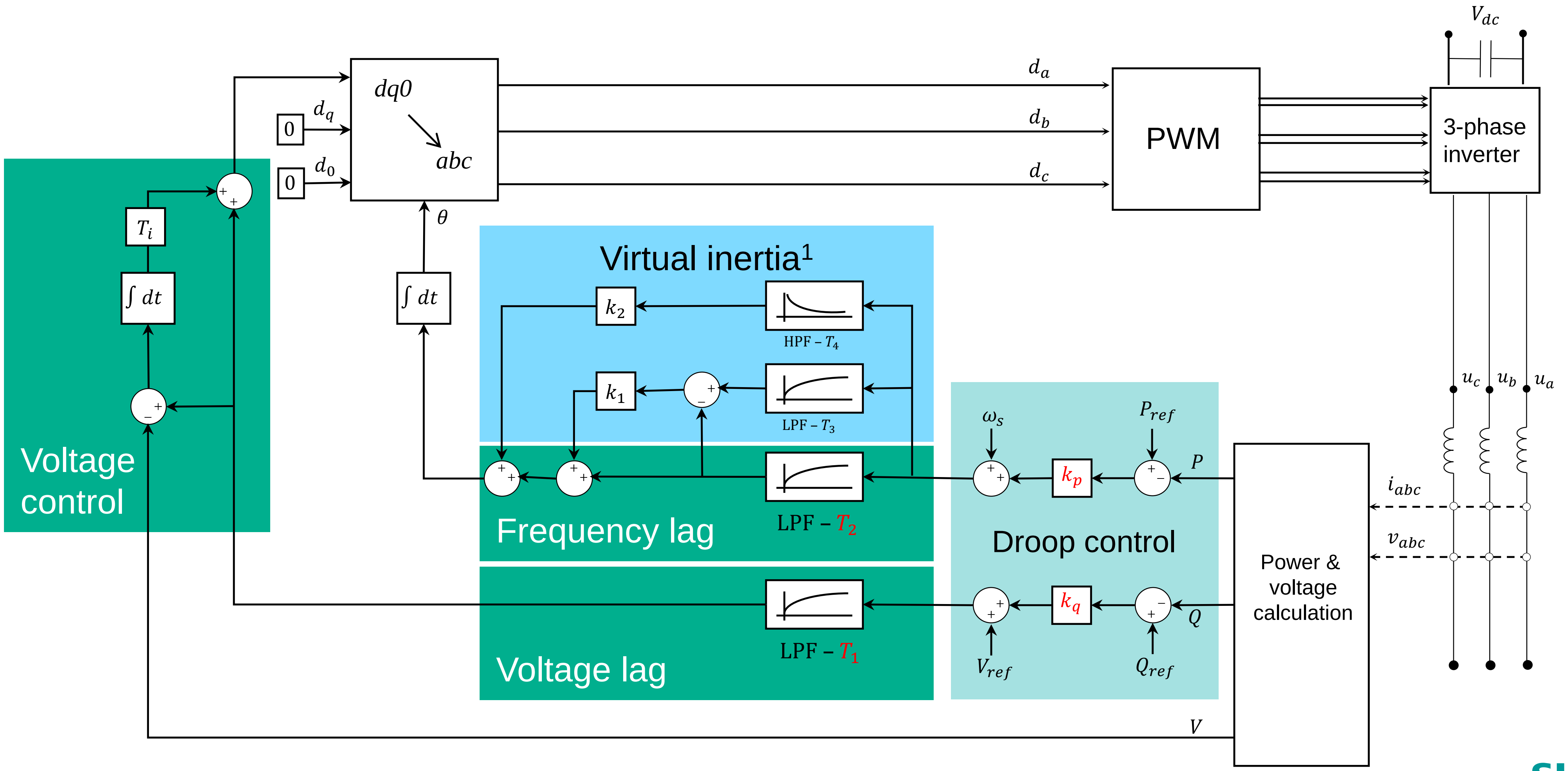
We tune detailed power plant models

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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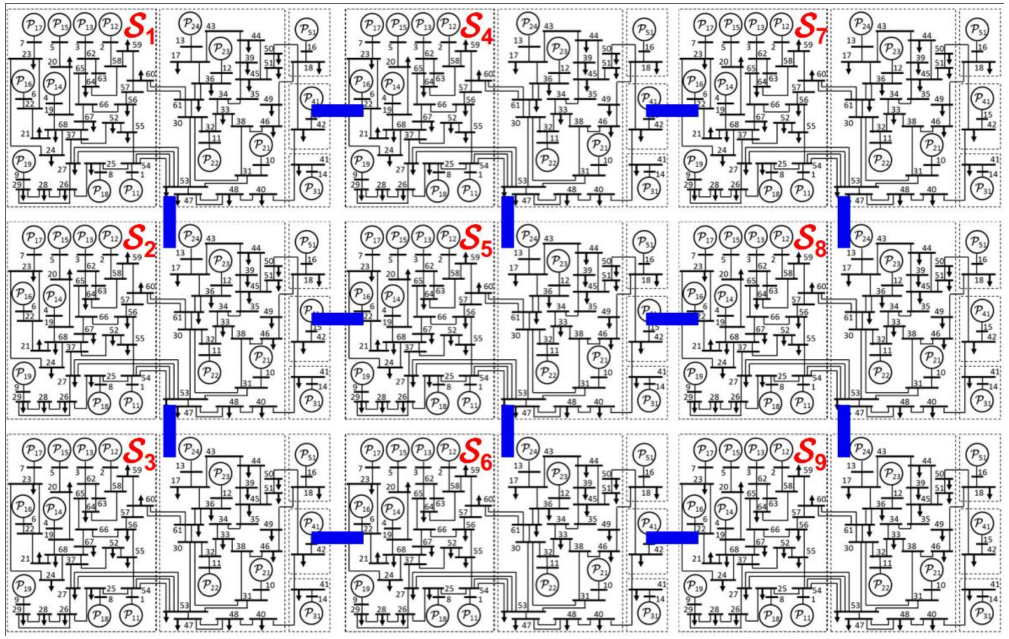
Dynamic Performance Optimization is scalable for large power systems

Successful application to 140+ power plant example

Power system model



Model obtained by coupling nine IEEE 68 bus systems

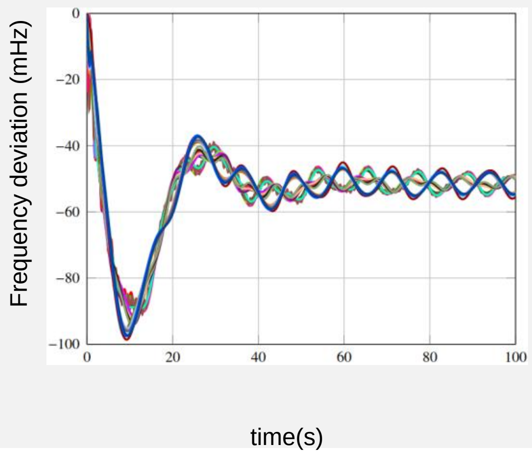
Hierarchical optimization with increased information security

Optimization Problem Characterization

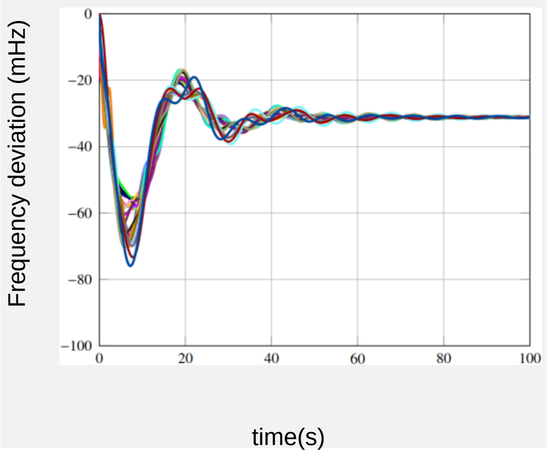
144 power plants

2520 states
1440 controller parameters

Initial Parameters



Optimized Parameters



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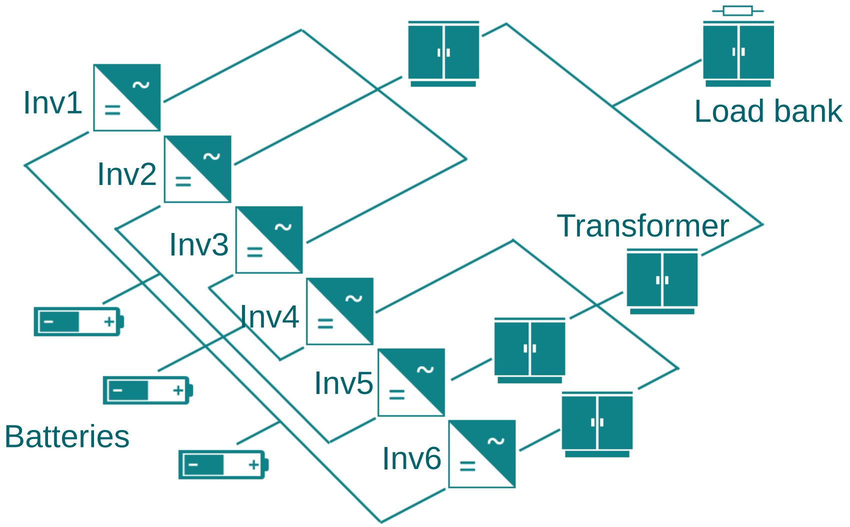
Dynamic Performance Optimization works in practice

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