Online Optimization-Based Adaptive Learning-Enabled Resilient Tuning (ALERT) Controls | Thrust 2

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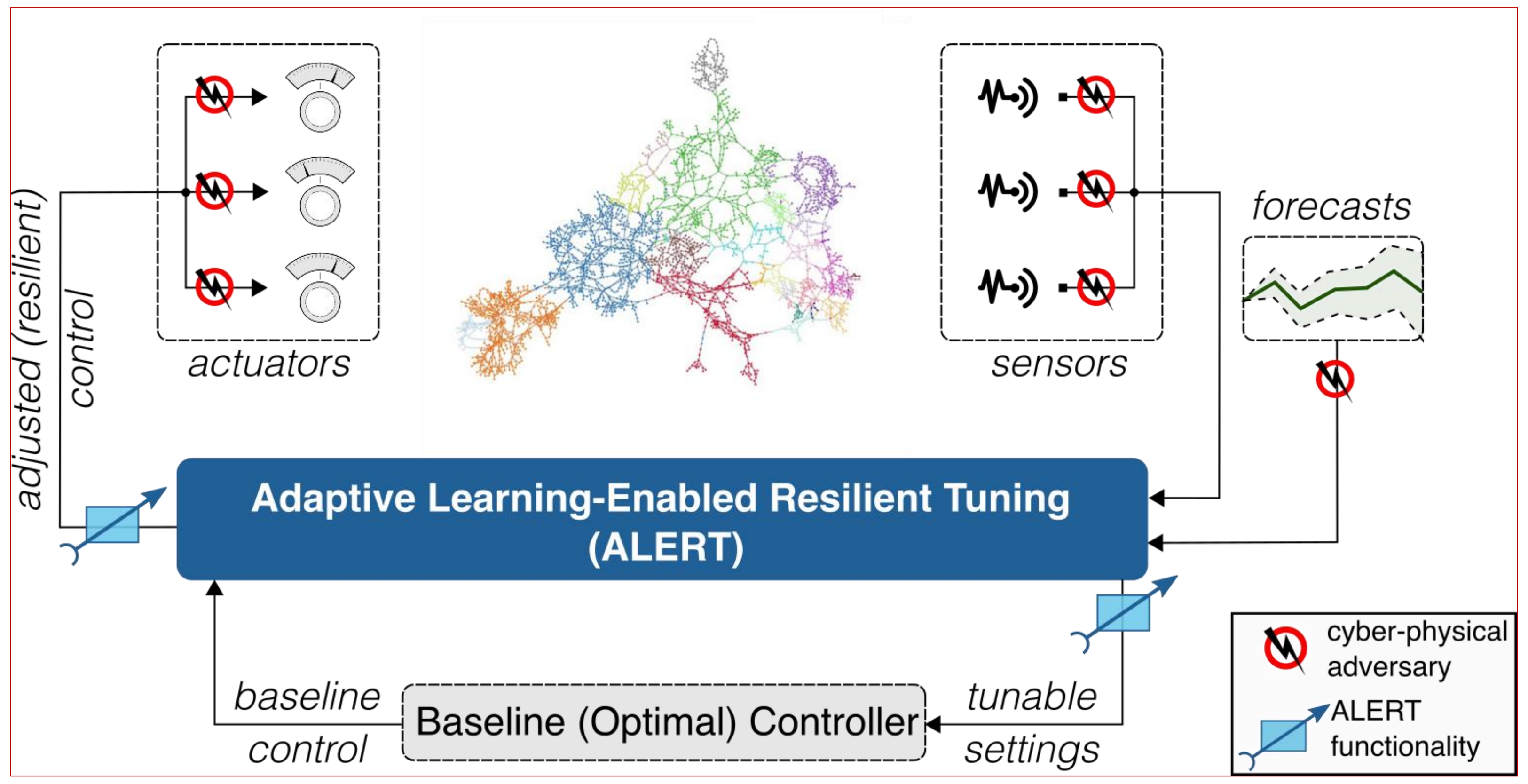


Proposed ALERT concept as resilient control adaptation of cyber-physical systems

OBJECTIVE

Design and demonstrate online strategies for **proactive and adaptive** tuning of existing optimal controls with **quantifiably assured margins of resilience** to cyber-physical adversarial events. Successful completion of this work will result in a **suite of Adaptive Learning-Enabled Resilient Tuning (ALERT) controls** with quantitative assurance of resilience, designed for cyber-physical systems and **demonstrated on microgrid use cases.**

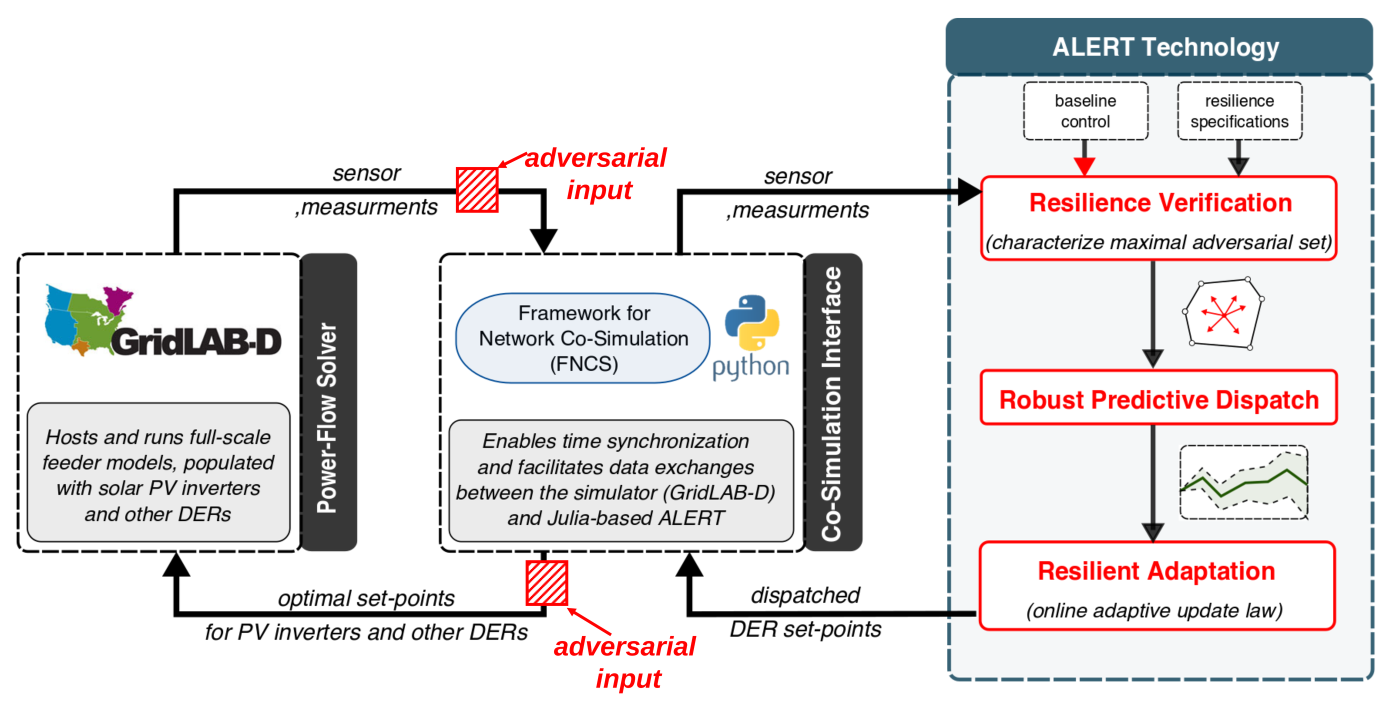
ACHIEVEMENTS

- Design and validation of a resilience verification and real-time resilient control adaptation algorithm on a modified IEEE 123-node microgrid, using the PNNL/DOE Framework for Networked Co-Simulation (FNCS) platform
- Two peer-reviewed articles on multi-timescale resilience assurance published at the IEEE American Control Conference (June 2022)
- Organized a session on resilient controls, optimization, and learning methods at the American Control Conference, with invited speakers from DOE national labs and academia
- One proposal (worth $2.8M) on cross-infrastructural resilience funded by the DOE Office of Electricity Sensors program
- One invited talk on distributed controls for resilience at the 5th Autonomous Energy Workshop by the DOE National Renewable Energy Laboratory

APPROACH

Implemented a **co-simulation setup**, connecting a power-flow solver (GridLAB-D), a Python-based co-simulation interface (FNCS), and a Julia-based optimization module to demonstrate the ALERT technology:

- An islanded 123-node microgrid with solar photovoltaics (PVs), storage, diesel generators (DGs), and flexible loads
- Generated adversarial scenarios **combining cyberattacks** (e.g., replay attack on load forecast) **with physical disruptions** (e.g., generation loss)



ALERT Technology

The ALERT technology consists of three sub-modules:

- **Robust Predictive Dispatch** to optimally allocate set-points and reserves to distributed energy resources (DERs)
- **Resilience Verification** via bi-level optimization to quantify the largest tolerable adversarial (w) set

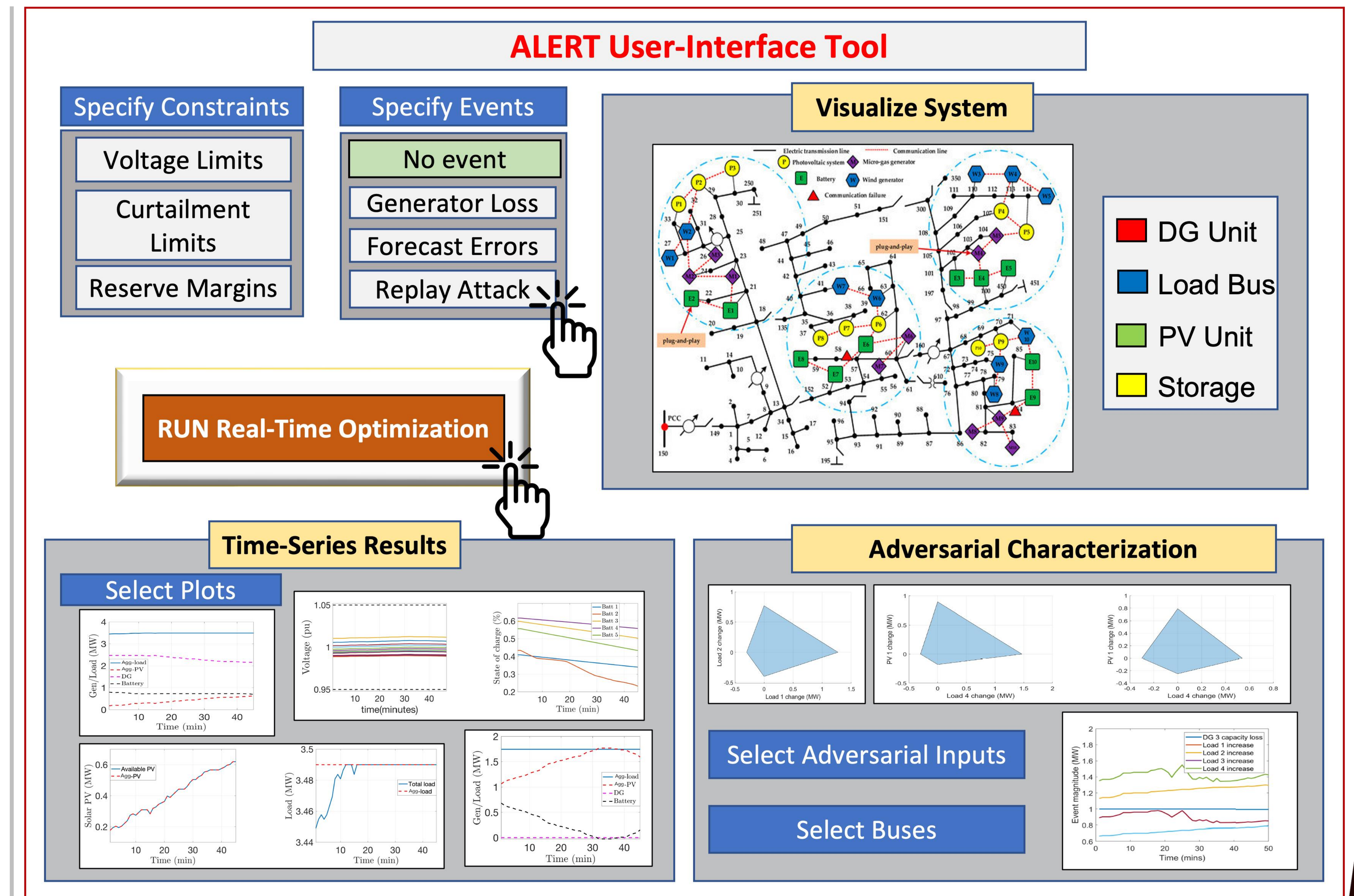
Solve for the largest perturbations in **w**: $\max\{r \mid R(x^*, w^*+r) \leq 0\}$

r: adversarial perturbation, *R(.): resilience measure,*
w**: best-known adversarial input,* *x*: dispatched set-points*

- **Resilient Online Adaption** of set-points via sensitivity-based feedback control to safeguard against adversarial events

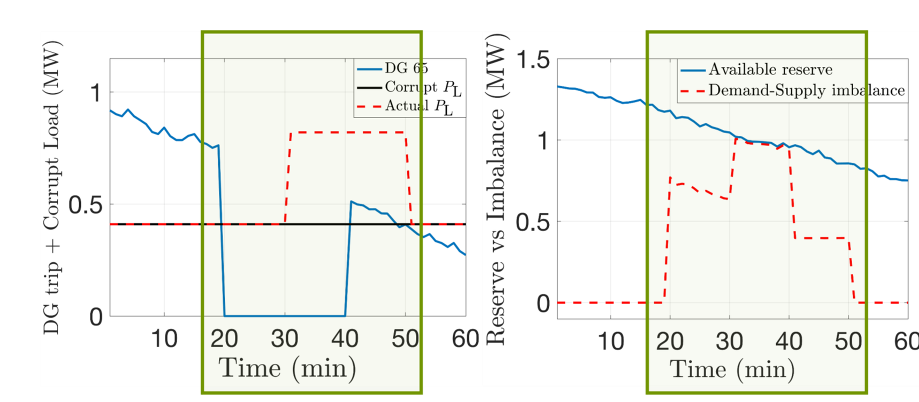
Real-time update of set-points via feedback: $x = x^* + M \cdot y(x, \mathbf{w})$

y(.): measurements, M: optimal feedback control gain,
x : dispatched set-points*



RESULTS/IMPACT

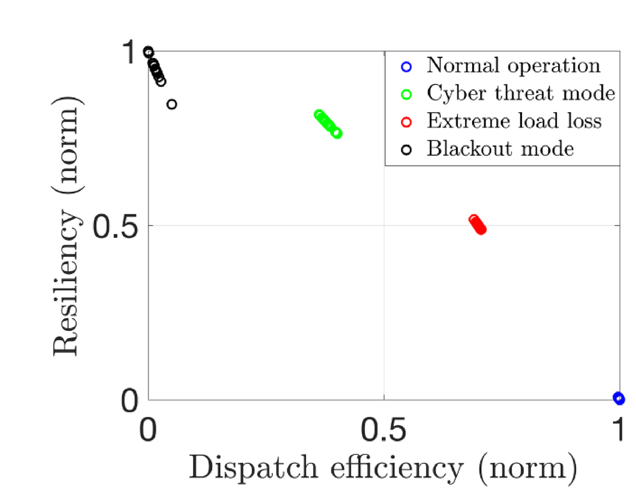
- Developed a **prototype user-interface ALERT tool** to allow operators to investigate the impact of various cyber-physical adversarial events
- Demonstrated the effectiveness of ALERT in **mitigating simultaneous cyber (load-masking attack) and physical (generation loss)** adversarial events



Left plot shows a DG loss at 20 min followed by an attack at 30 min masking the load increase

Right plot shows the use of PV and storage reserves via online adaptation to mitigate the adversarial impact

- Generated a pareto front to showcase the **trade-off between system operational efficiency and margin of resilience** under various operating conditions



Normal (i.e., no-threat/blue-sky) mode displays highest operational efficiency, with very little need for resiliency reserves

Extreme weather ("blackout") mode displays lowest operational efficiency, with a need for high-resiliency reserves

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