
# HybridSystemsSimulations.jl –

# Solving the merchant collocated facilities with JuMP

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Grid Planning and Analysis Center

*Photo by Dennis Schroeder, NREL 55200*

# Outline

- NREL-Sienna
- Market Operation Schemes for Hybrid Systems
  - Preliminary Results for Energy and Ancillary Services
- Dynamic Simulation Aspects for Inverter-Based Resources
  - Model complexity and fidelity
  - Dq0 dynamic phasor approach

NREL
Transforming ENERGY

# OPEN-SOURCE ECOSYSTEM FOR MODELING, SIMULATION, AND OPTIMIZATION OF POWER SYSTEMS

**PowerSimulations.jl**

Simulation of power systems operations across timescales and complexity

**PowerSystems.jl**

Data handling, model agnostic data container for reproducible research

**PowerSimulationsDynamics.jl**

Simulation of system dynamics geared towards the modeling requirements of systems with large shares of IBRs

**PowerGraphics.jl**

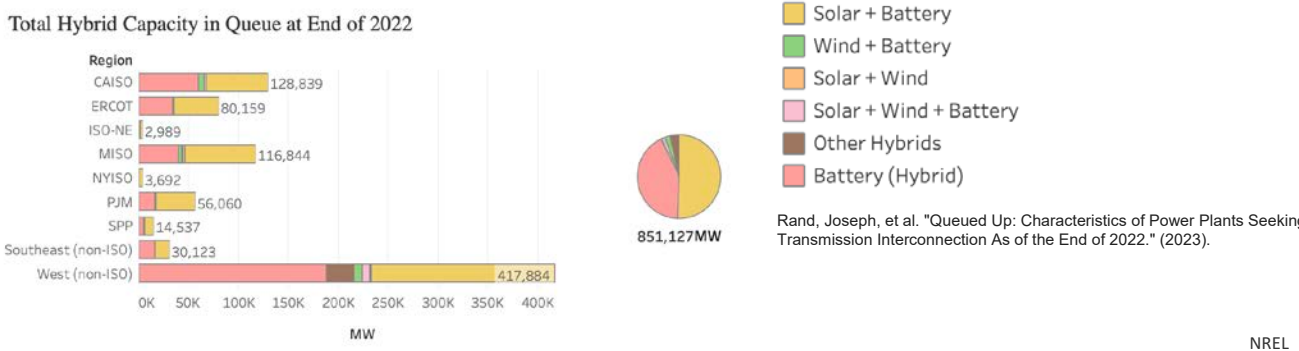
Results and summary statistics processing of simulations

**PowerFlows.jl**

Methods for the analysis and study of power flows in systems (in development)

# Value of Hybrid Systems

- Hybrid systems is the current terminology used to describe behind-the-meter microgrids that operate in an integrated fashion to supply power to the grid.
- These types of systems are some of the fastest growing generation architectures in the US grid due to their potential to provide flexibility during market operations.
- Many of these assets will be operated “algorithmically” employing portfolio-optimization style models to participate in energy and ancillary services markets.



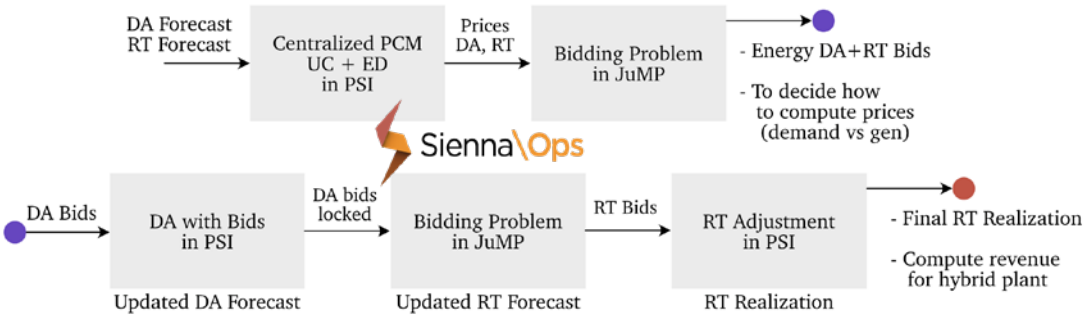

Rand, Joseph, et al. "Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection As of the End of 2022." (2023).

# Operation Schemes for Hybrid Systems

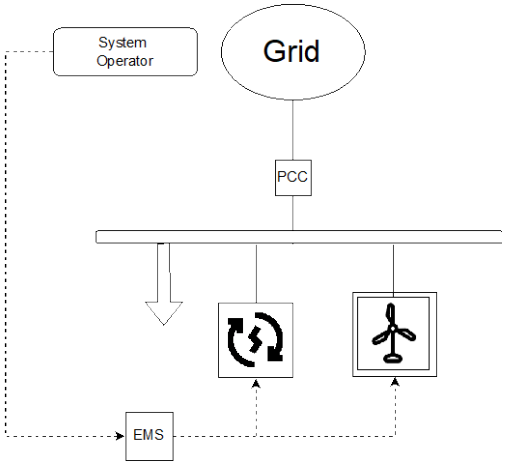
Optimization Models

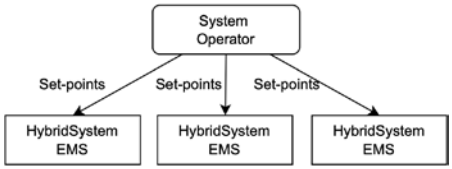
# In a Nutshell

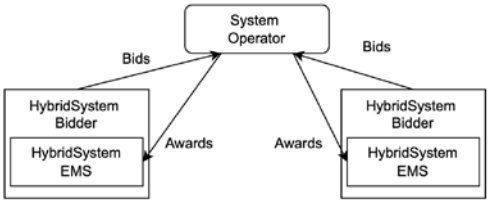
- **Emulate merchant participation** in energy markets and the effect on the system of their bidding strategies.
- Multiple market participation, e.g., DART arbitrage.
- Multiple Ancillary Services products, RegUp, RegDown, Spin, etc.
- Explore the value hybrid flexibility across different bidding strategies from the perspective of the asset and the system

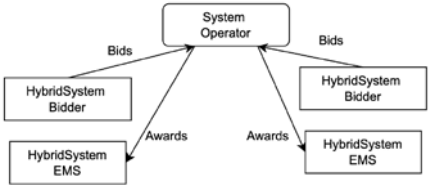


- We can identify three distinct operating modes for the hybrid system.
- Each operating mode will have different impact in the performance of the system and the hybrid's assets.




$$\begin{aligned} \underset{\boldsymbol{x},\,\boldsymbol{x}_h}{\text{minimize}} \quad & c^\intercal \boldsymbol{x} + c_h^\intercal \boldsymbol{x}_h \\ \text{subject to} \quad & A\boldsymbol{x} \leq b, \\ & A_h \boldsymbol{x}_h \leq b_h \end{aligned}$$

*Centrally Dispatched*

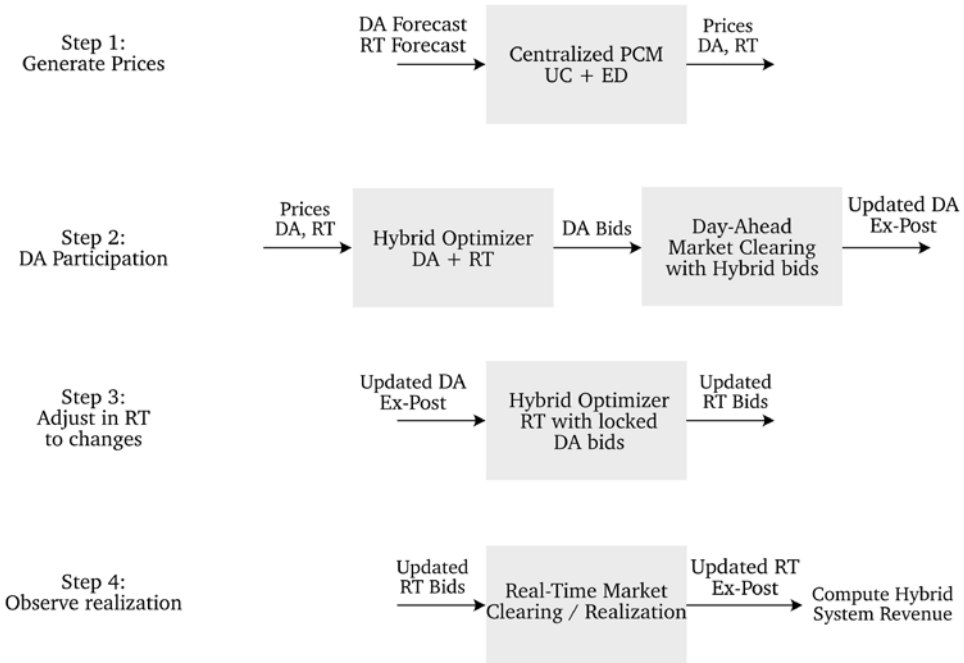
$$\begin{aligned} \underset{\boldsymbol{y},\,\boldsymbol{x}_h}{\text{maximize}} \quad & d^\intercal \boldsymbol{y} - c_h^\intercal \boldsymbol{x}_h \\ \text{subject to} \quad & A\boldsymbol{x} + M\boldsymbol{y} \leq b_h \end{aligned}$$

*Co-Optimization*

$$\begin{aligned} \underset{\boldsymbol{y}}{\text{maximize}} \quad & d^\intercal \boldsymbol{y} \\ \text{subject to} \quad & M\boldsymbol{y} \leq k \\ & \underset{\boldsymbol{x}_h}{\min} \quad c_h^\intercal \boldsymbol{x}_h \\ & \text{s.t.} \quad A\boldsymbol{x} \leq b_h - H\boldsymbol{y} \end{aligned}$$

*Bi-level Model*

# Experimental Set-up

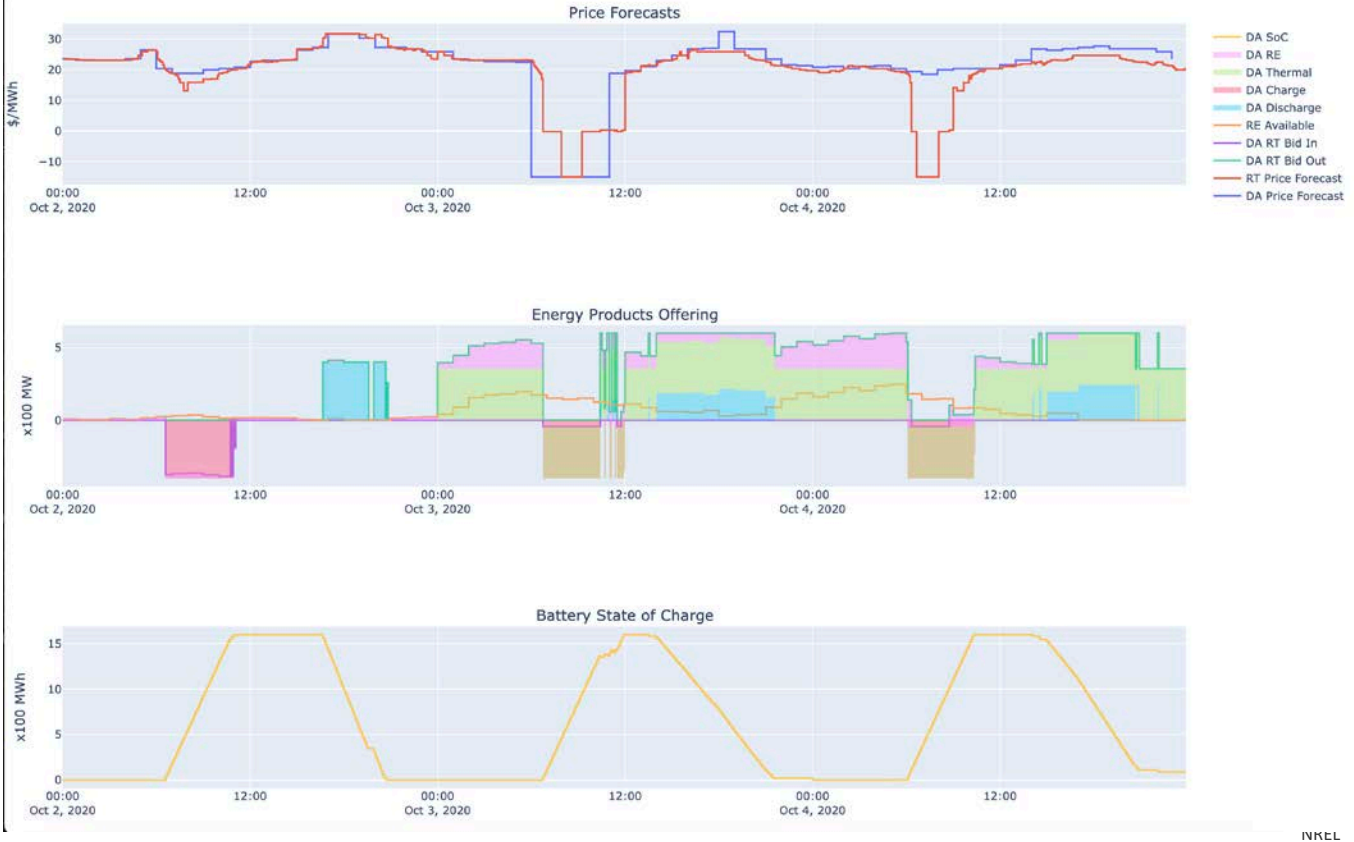



We developed an extension of PowerSimulations.jl (PSI) as part of Sienna\Ops to handle these types of simulation pipelines.

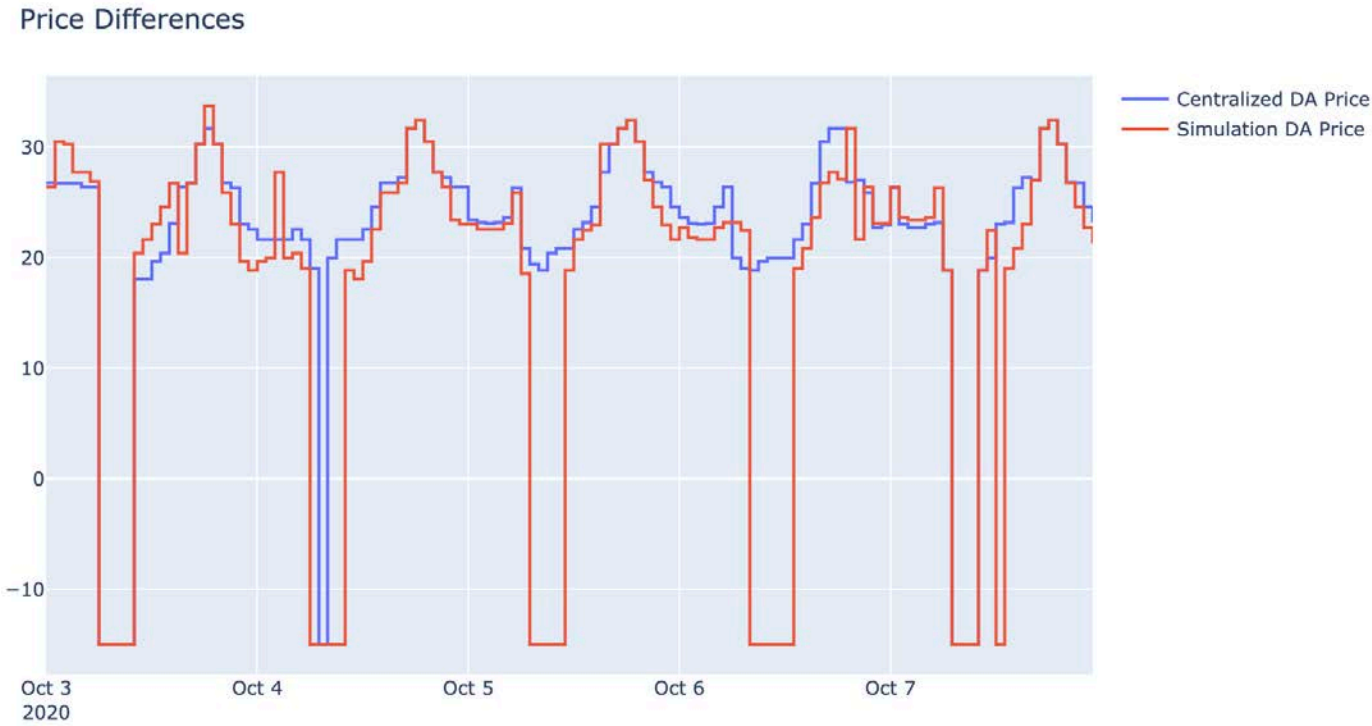
HybridSystemsSimulations.jl supports ongoing research in this area

# Results offering only energy products

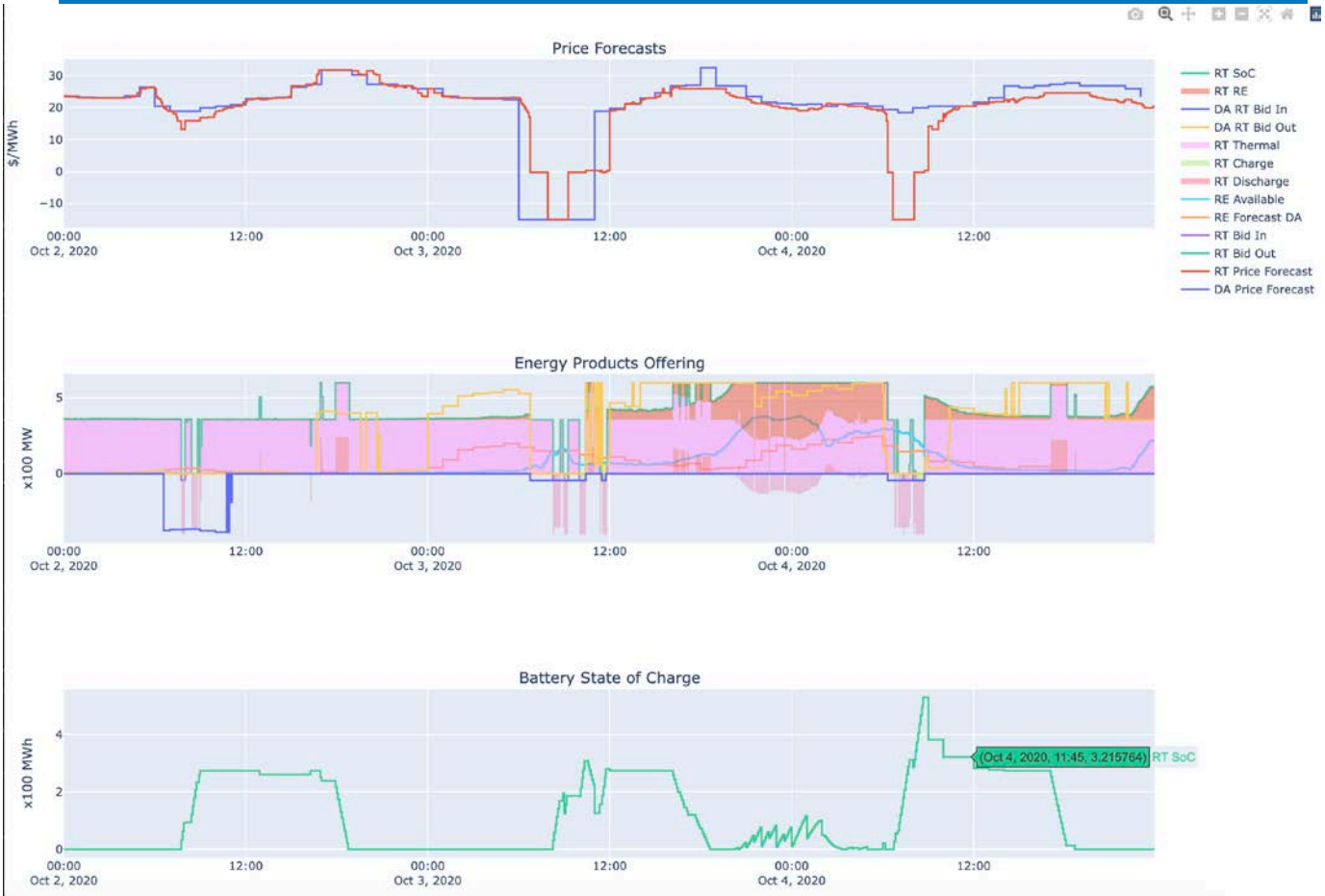
# DA-Ahead Bidding Results



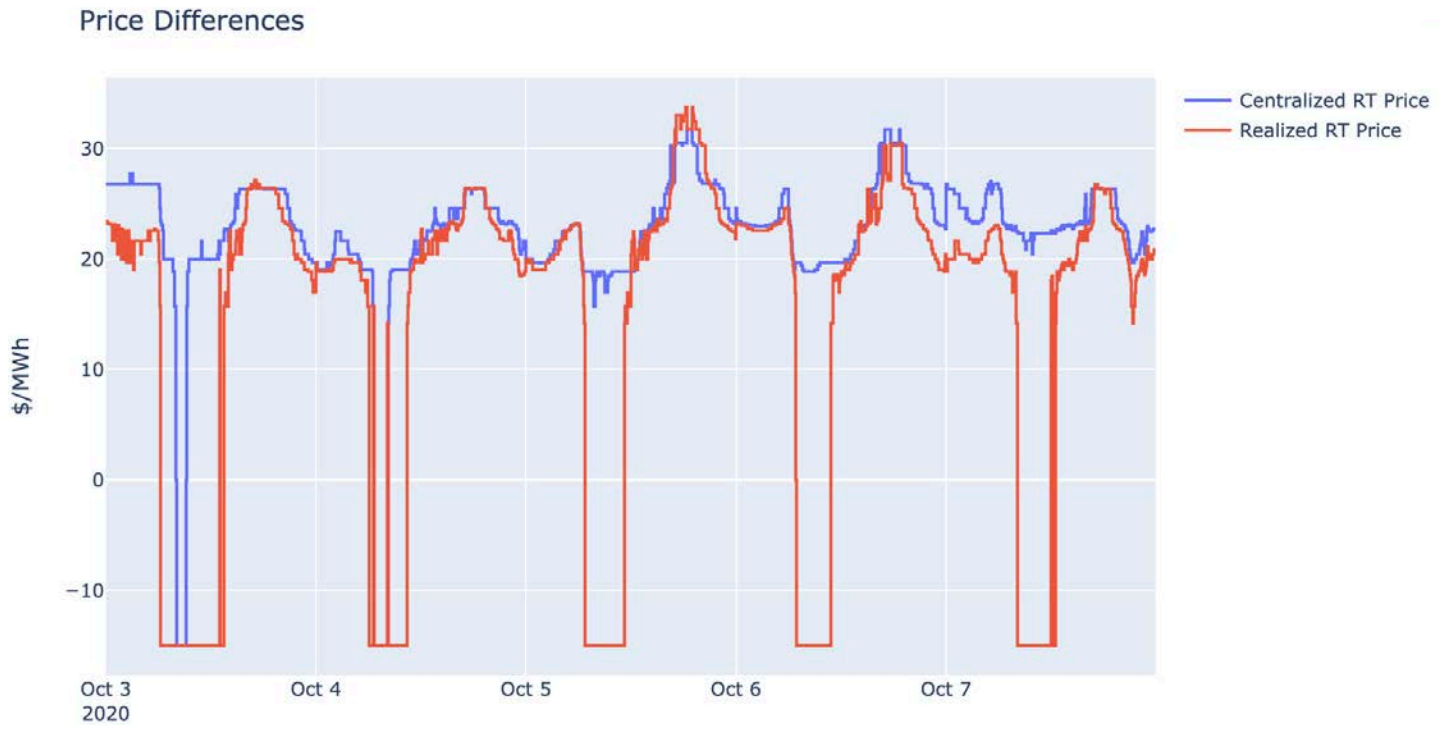
# DA-Ahead Bidding Results – DA Price



# RT Bidding Results



# DA-Ahead Bidding Results – RT Price

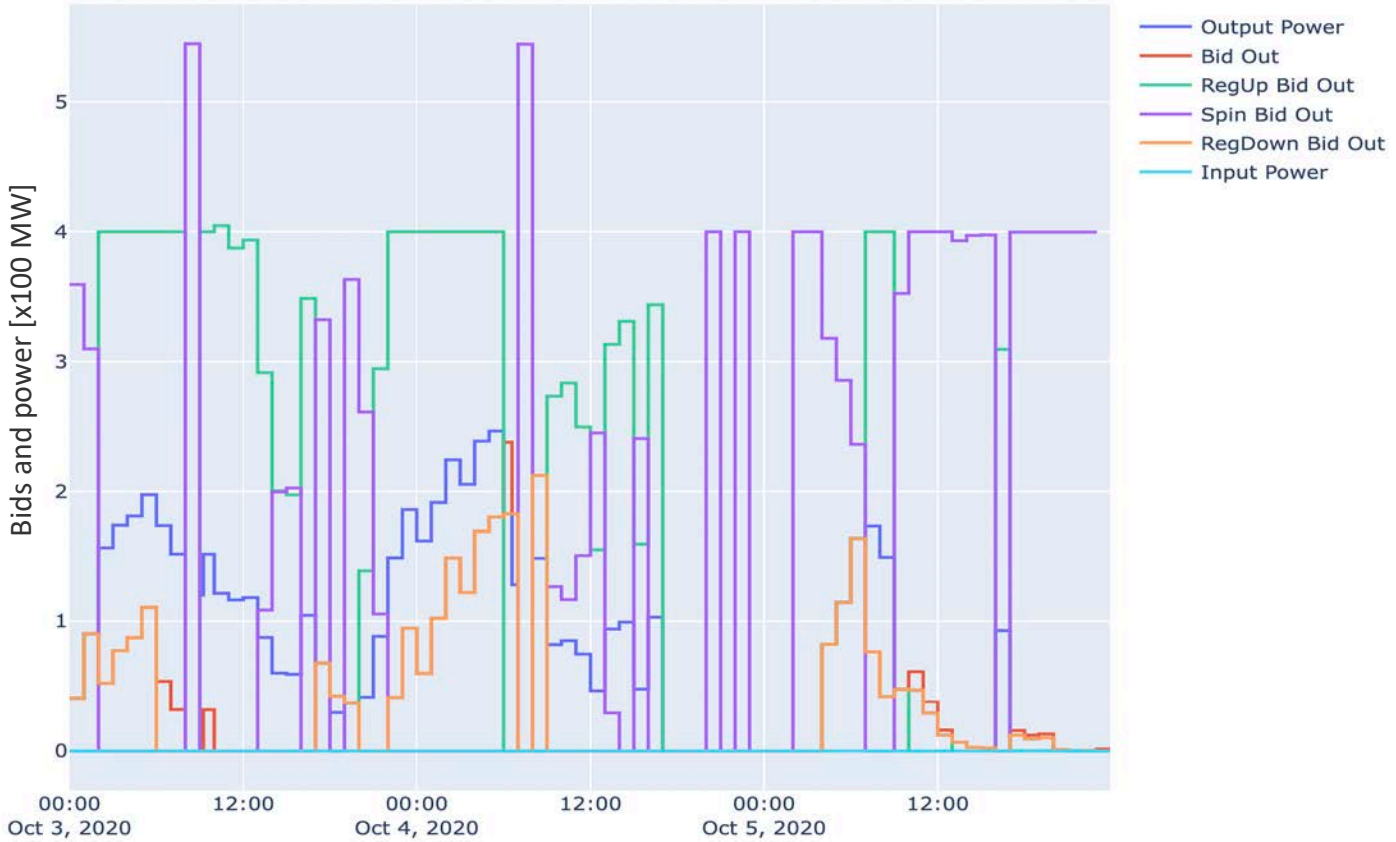


# Value of Flexibility

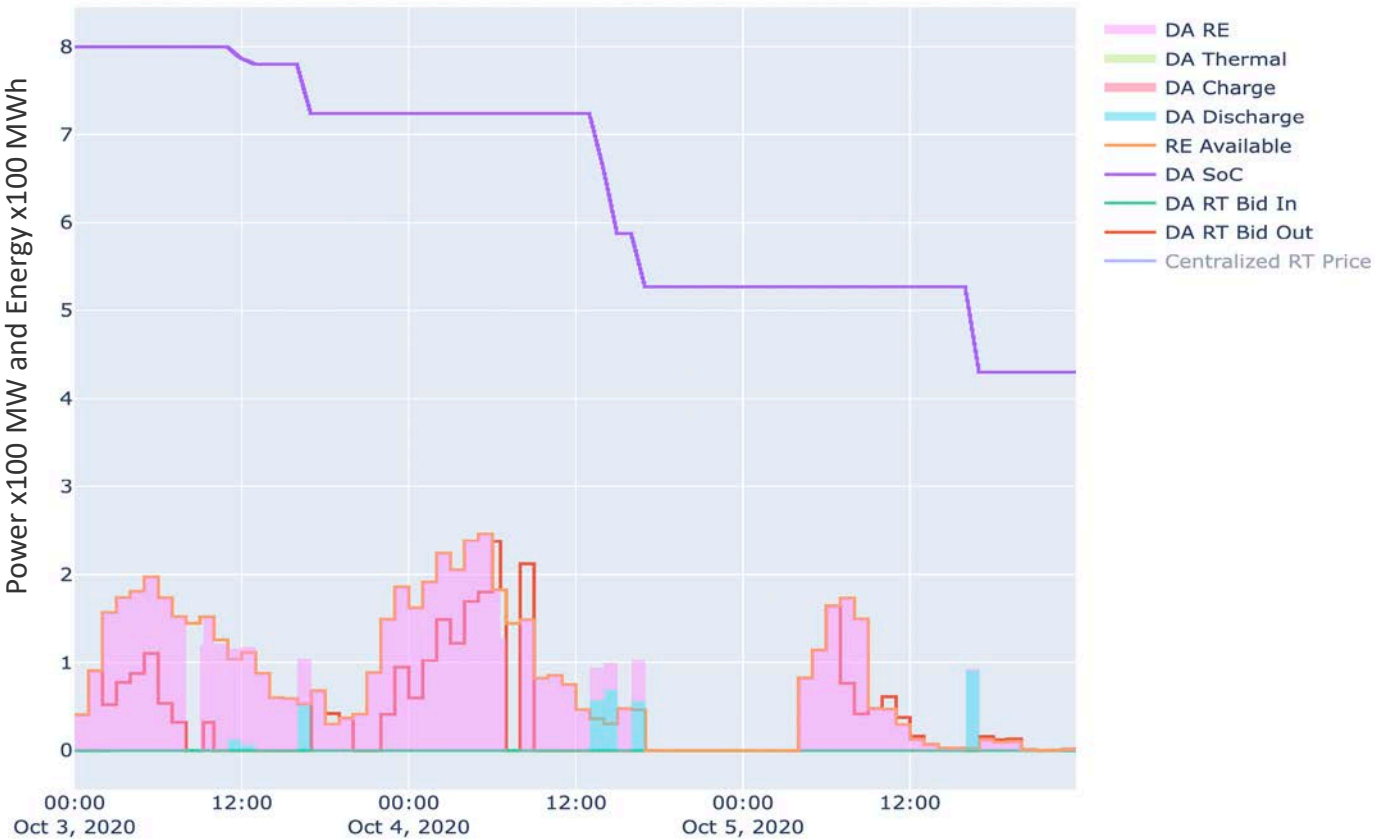
# Preliminaries on energy and ancillary services products joint offering

This work was presented in JuliaCon 2023.

# Co-optimizer Strategy – Bidding Behavior



# Co-optimizer Strategy – Product allocation Results



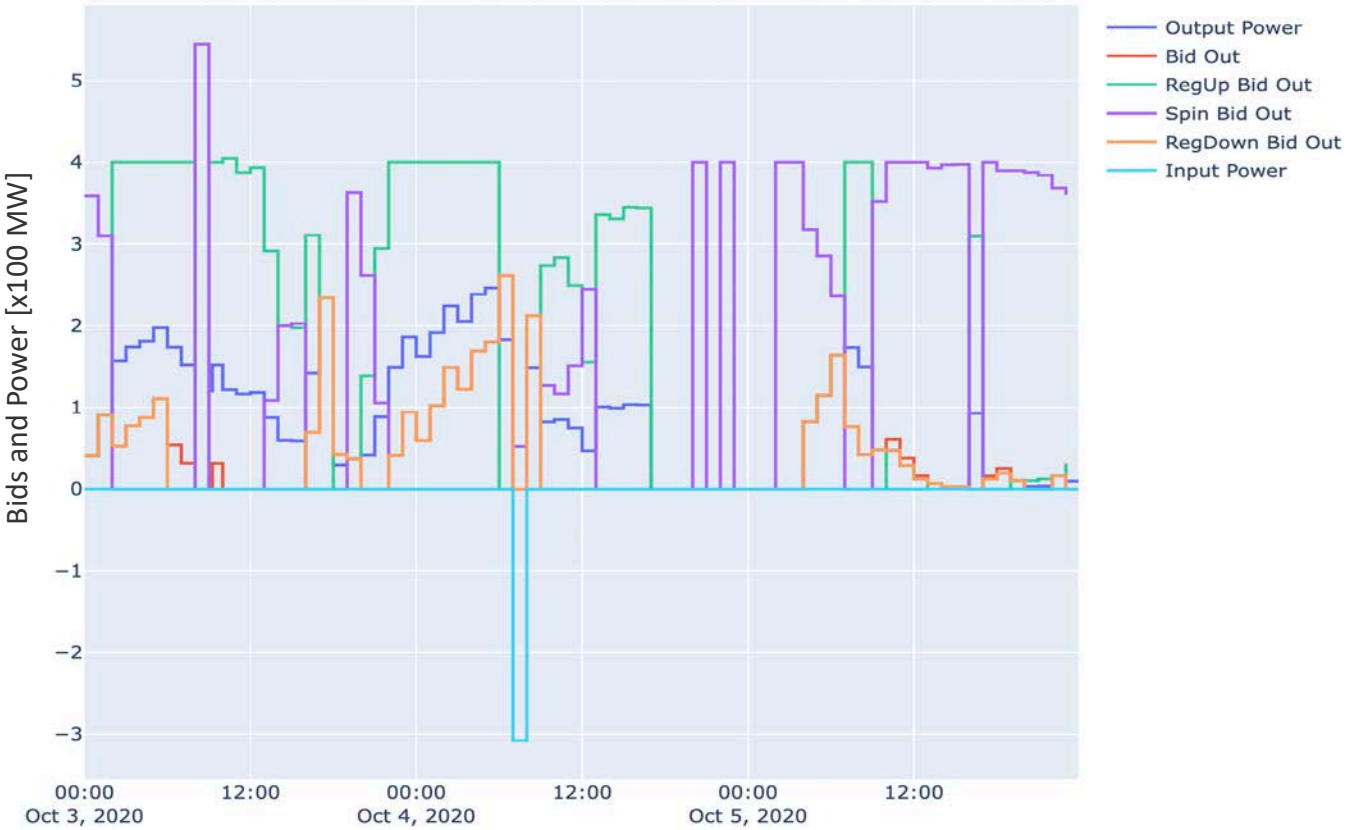
# Bi-Level Strategy

$$
\begin{aligned}
\underset{\boldsymbol{y}}{\text{maximize}} \quad & d^\intercal \boldsymbol{y} \\
\text{subject to} \quad & M\boldsymbol{y} \leq k \\
& \min_{\boldsymbol{x}_h} \quad c_h^\intercal \boldsymbol{x}_h \\
& \text{s.t.} \quad A\boldsymbol{x} \leq b_h - H\boldsymbol{y}
\end{aligned}
$$

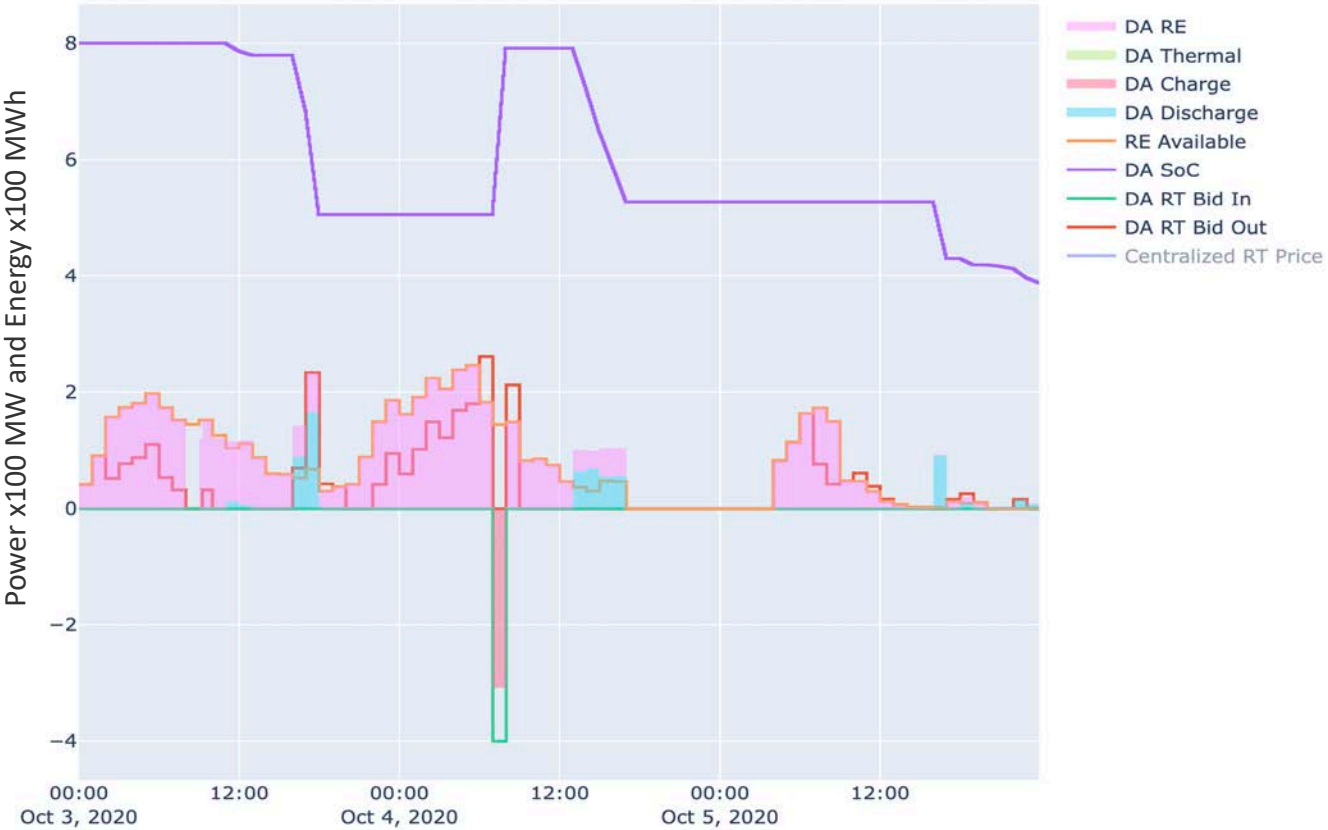
$$
\begin{aligned}
\underset{\boldsymbol{y}}{\text{maximize}} \quad & d^\intercal \boldsymbol{y} \\
\text{subject to} \quad & M\boldsymbol{y} \leq k \\
& A\boldsymbol{x} \leq b_h - H\boldsymbol{y} \\
& c_h^\intercal \boldsymbol{x}_h - A^\intercal \boldsymbol{\chi} = 0 \\
& \boldsymbol{\chi}^\intercal b_h - \boldsymbol{\chi}^\intercal H\boldsymbol{y} - c_h^\intercal \boldsymbol{x}_h \leq 0 \\
& \boldsymbol{\chi} \geq 0
\end{aligned}
$$

$$
\begin{aligned}
\underset{\boldsymbol{y}}{\text{maximize}} \quad & d^\intercal \boldsymbol{y} \\
\text{subject to} \quad & M\boldsymbol{y} \leq k \\
& A\boldsymbol{x} \leq b_h - H\boldsymbol{y} \\
& c_h^\intercal \boldsymbol{x}_h - A^\intercal \boldsymbol{\chi} = 0 \\
& \boldsymbol{\chi}^\intercal b_h - \boldsymbol{\chi}^\intercal H y^{ub} - c_h^\intercal \boldsymbol{x}_h \leq 0 \\
& b_h - H\boldsymbol{y} - A\boldsymbol{x}_h = \boldsymbol{a} \\
& \{\boldsymbol{a}, \boldsymbol{\chi}\} \in \text{SOS-1} \\
& \boldsymbol{\chi} \geq 0
\end{aligned}
$$

# Bi-level Strategy – Bidding Behavior



# Bi-level Strategy – Product allocation Results



# Next Steps

- Run the energy only simulation on the North California System.
- Incorporate ancillary services bids into an ancillary services market simulation.
- Study effect in the system of the use of Hybrids for ancillary services considering deployment of regulation reserves based on previous works*
- Incorporate battery SoC management, cycle limit constraints and energy.

*J. D. Lara, R. Henriquez-Auba, D. S. Callaway and B. -M. Hodge, "AGC Simulation Model for Large Renewable Energy Penetration Studies," 2020 52nd North American Power Symposium (NAPS), Tempe, AZ, USA, 2021, pp. 1-6, doi: 10.1109/NAPS50074.2021.9449687.

# Conclusions and future work

- Merchant models solved outside of the centralized optimization problem can provide better insights about the operation of these assets than centralized dispatch models
- The value of using of a bi-level problem to solve the bidding problem depends on the storage participation in the AS offers and the business model used for the bidding.

# Thank You

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