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Multi-period GDP Optimization in IDAES: Simultaneous Design and Operation of an Integrated Fossil and Thermal Energy Storage System

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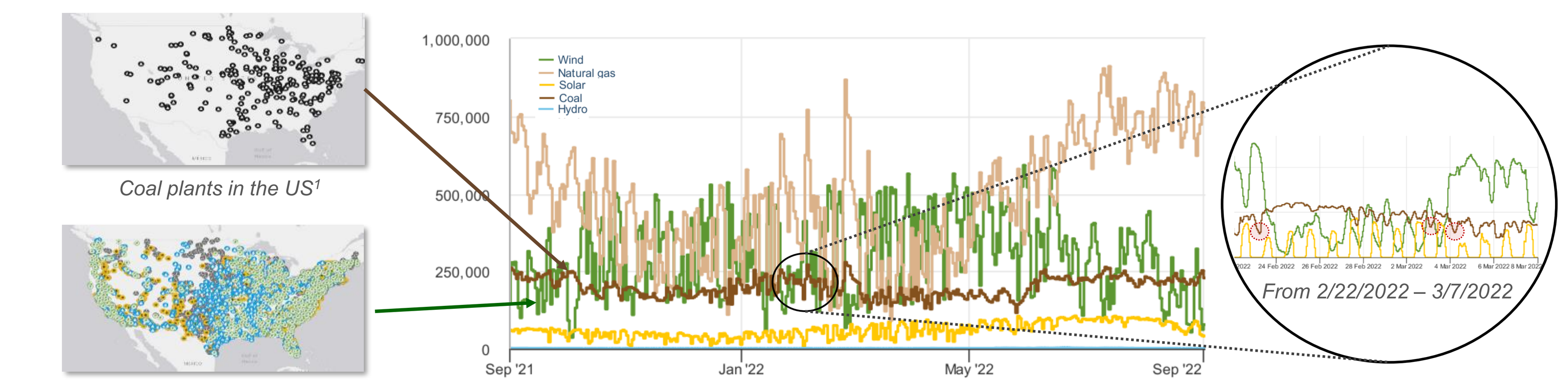
DISPATCHES Design Integration and Synthesis Platform to Advance Tightly Coupled Hybrid Energy Systems

Motivation

- Integration of variable renewable energy requires more flexible fossil generators
- Thermal energy storage systems allow generators to reduce frequent cycling and operate at higher efficiencies, reducing emissions



Coal plants in the US[1]

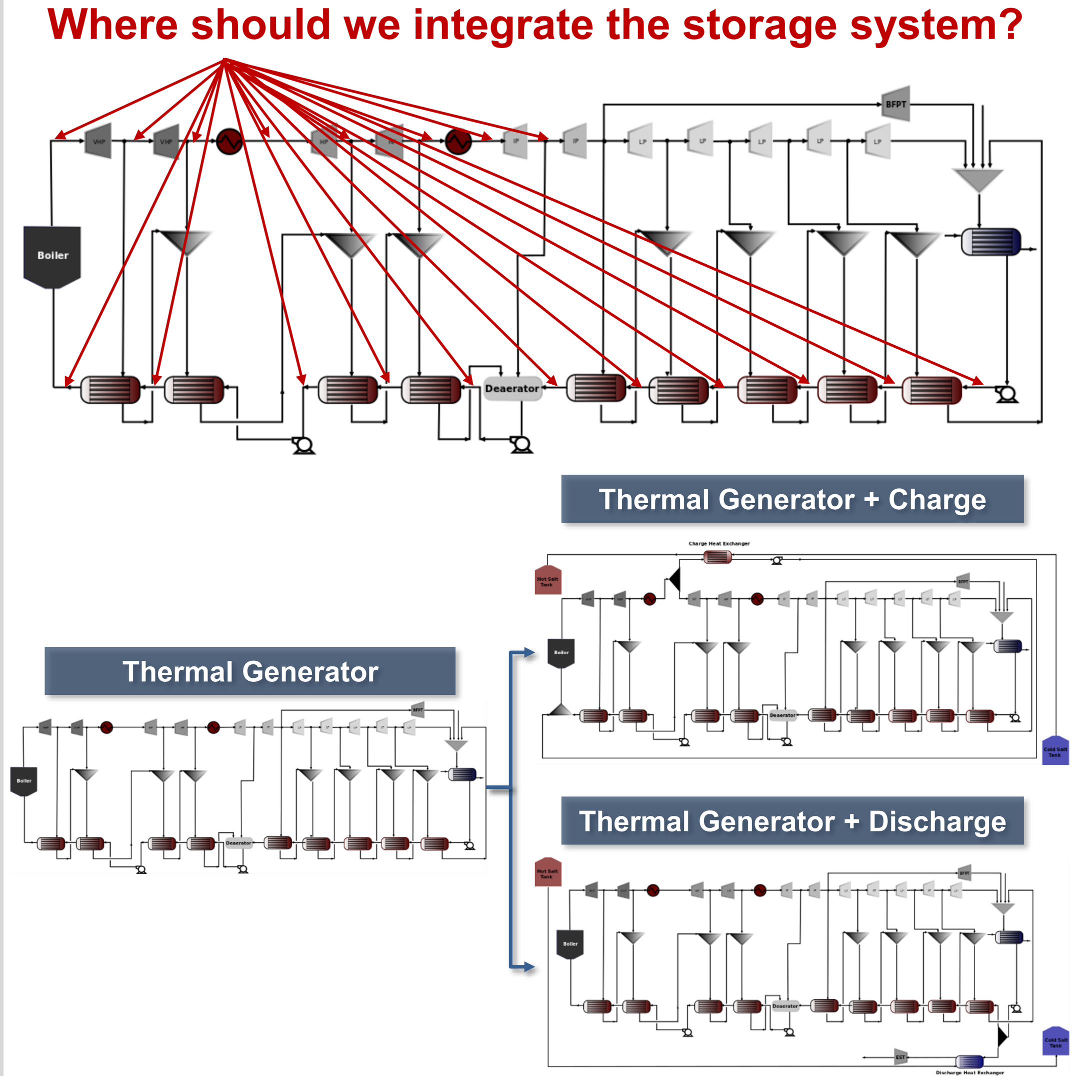
Natural gas, solar, and wind plants in the US[1]

Electric Reliability Council of Texas, Inc. (ERCO) electricity generation by energy source 9/1/2021 – 9/1/2022, Eastern Time[2]

[1] Source: U.S. Energy Information Administration. U.S. Energy Mapping System, https://www.eia.gov/state/maps.php. Accessed July 2, 2021. [2] Source: U.S. Energy Information Administration. Hourly Electric Grid Monitor, https://www.eia.gov/electricity/gridmonitor/expanded-view/custom/pending/GenerationByEnergySource-4/edit, Accessed September, 2022

Problem Statement

Where should we integrate the storage system?



Once the storage system is included, decide:

- What **storage medium** is the best and cheapest?
- What is the **best design** for the storage system itself?
- Where is the optimal integration point?

Once the storage system is integrated:

- **When** and **how** to deploy storage to maximize profit?

Methodology

- Conceptual design using a **Generalized Disjunctive Programming** (GDP) formulation to incorporate discrete design decisions as disjunctions
- Use rigorous **IDAES** models and advanced cutting-edge solvers, such as **GDPopt**, to explore design space

PYOMO GDP

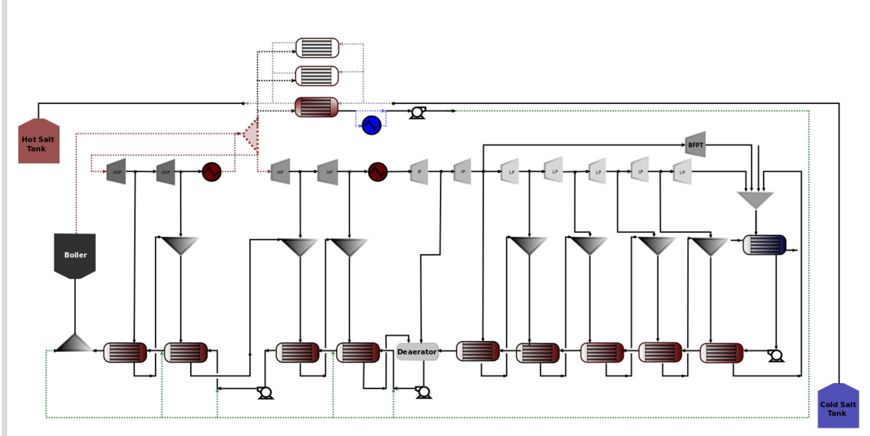
$$\begin{bmatrix} z_1 \\ h_1(x) = 0 \\ g_1(x) \le 0 \end{bmatrix} \vee \begin{bmatrix} z_2 \\ h_2(x) = 0 \\ g_2(x) \le 0 \end{bmatrix}$$

- Optimal schedule of energy system using a **multi-period approach** with a nonlinear programming (NLP) and GDP model formulation
- Pricetaker assumption that specifies electricity prices to determine the schedule of storage operating cycles

Methodology can be applied for designing storage systems for fossil, nuclear and geothermal energy systems

Conceptual Design of Energy Systems

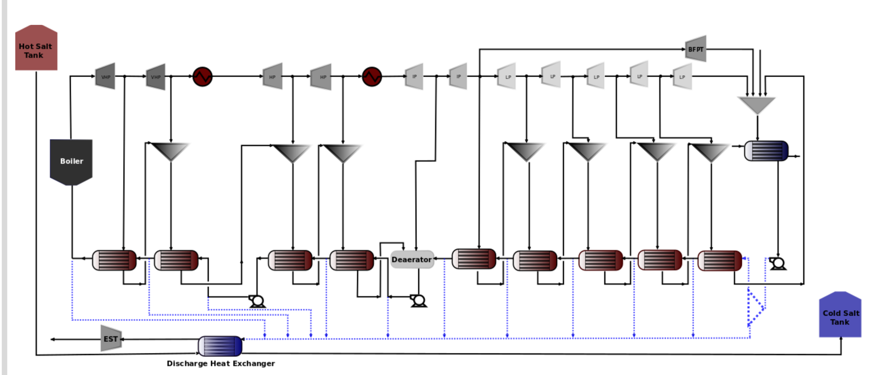
- Two superstructures to identify optimal points of integration of storage system with thermal generator
- Flowsheet consists of rigorous first-principle models for the steam cycle and storage system with accurate properties for steam/water using IAPWS95



Charge Cycle

Considers 60 alternative configurations for charging the storage system

- Optimal selection of storage material, steam source to heat up the storage material, condensed steam return point in steam cycle, and the use of a cooler in storage system



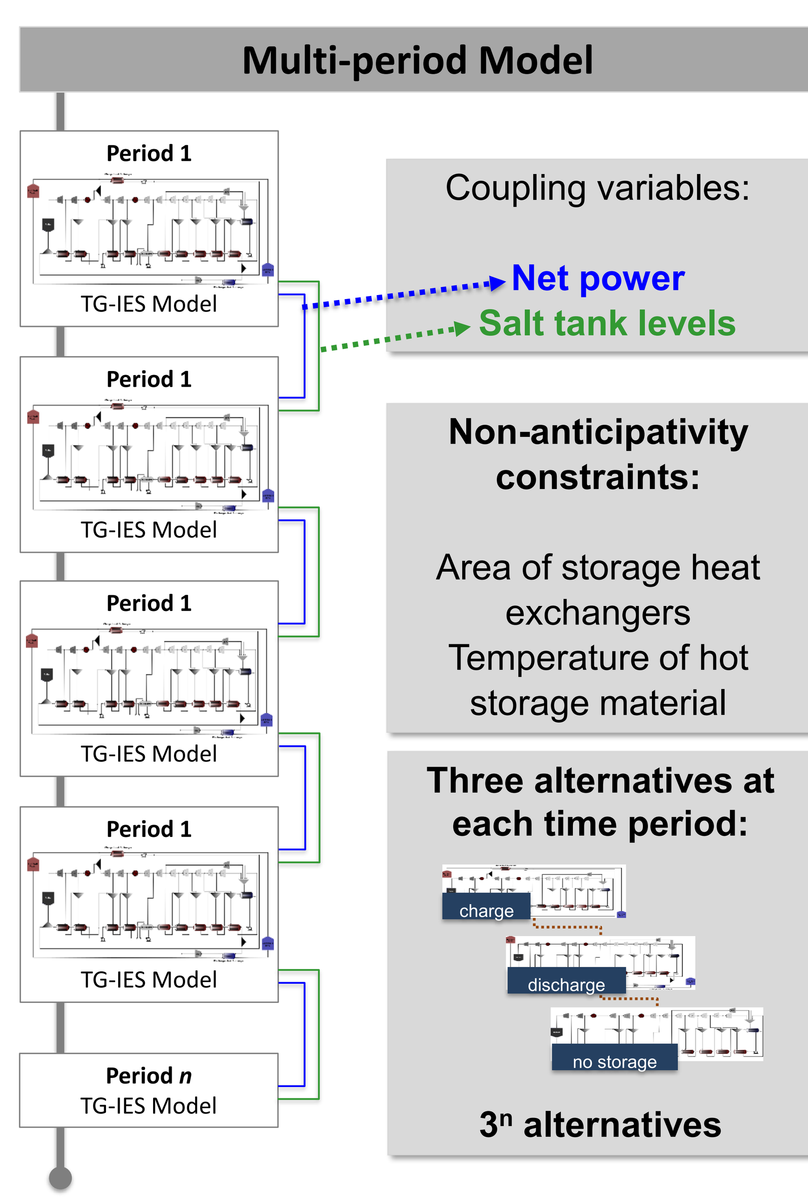
Discharge Cycle

Considers 11 alternative configurations for discharging the storage system

- Condensed steam source to be heated-up using the stored energy in the storage material
- Dedicated turbine connected to the discharge system

Multi-period Storage Schedule

- **Optimal design and operation** of the thermal generator and storage system in a given time horizon
- Fixed points of integration to the thermal generator obtained during GDP conceptual design
- **NLP** and **GDP** models to determine the optimal hourly operating design and schedule of the thermal energy storage system



NLP Model

- Includes charge and discharge cycles in the same flowsheet
- Minimum flow requirement for the storage operating cycles
- Simplified scheduling analyses

GDP Model

- Includes three operation modes to determine the storage operating cycle: charge, discharge, and no storage.
- Disjunction for the selection of operation mode
- Problem size ranging from **millions** to **quadrillions alternatives**.

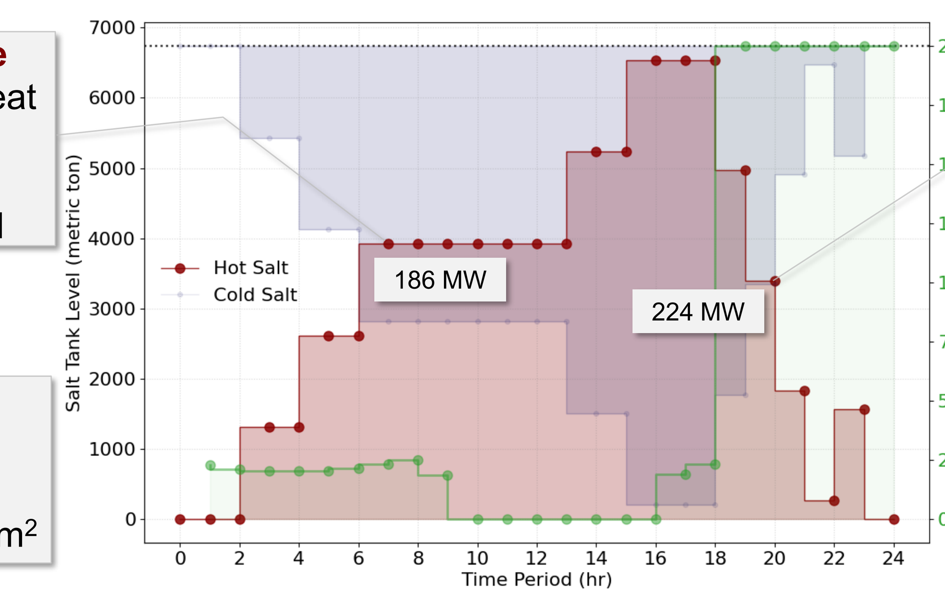
Results

Conceptual design of storage superstructures

- Optimal design for **charge superstructure**: Solar salt as storage material, a high pressure steam, condensed steam to return to the boiler, and no cooler
- Optimal design for **discharge superstructure**: Condensed steam source after condenser

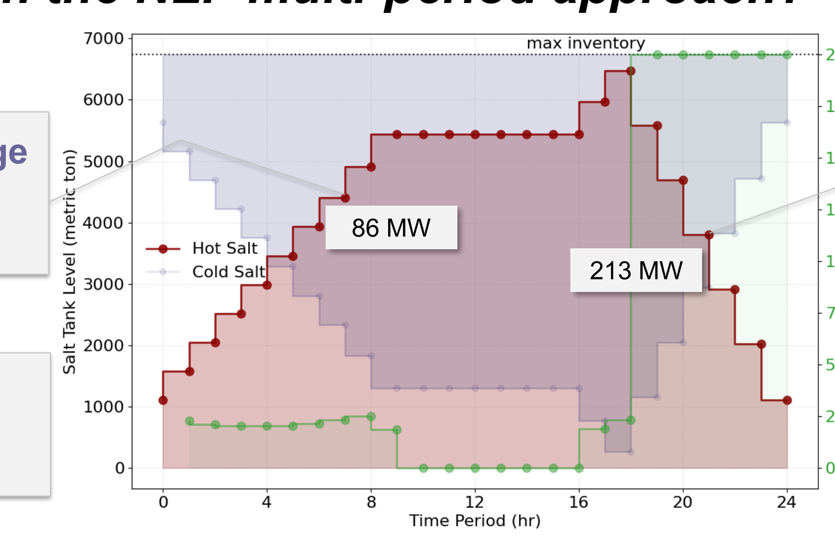
Multi-period Analysis for Storage Scheduling

- Determine heat exchanger areas and operating temperatures
- Conceptual design storage decisions vary according to the electricity prices
- GDP multi-period allows for the search when 3^{24} **alternatives** are available



24-hour analysis of GDP model for thermal generator with three operation modes

What happens in the NLP multi-period approach?



24-hour analysis of NLP model of thermal generator integrated with energy storage system

Future Work

- Include using discharge steam in CCS system as a potential design option
- Extend analysis of NLP and GDP multi-period models to consider electricity market surrogates, i.e. remove pricetaker assumption

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