Simultaneous Design and Operation of a Coal-fired Hybrid Energy System with Integrated Thermal Energy Storage

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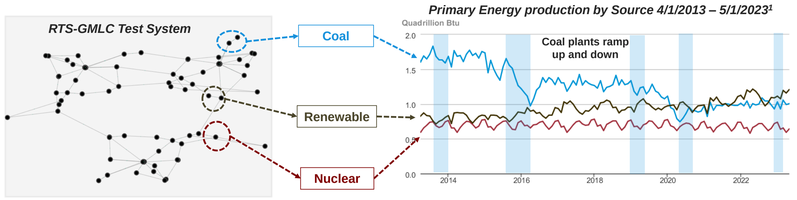
IDAES Institute for the Design of Advanced Energy Systems

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

Motivation

- The decarbonization of the electrical grid requires base load fossil generators to be more flexible
- Thermal energy storage (TES) systems help reduce frequent cycling of power plants and allow operating at higher efficiencies



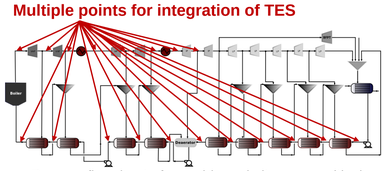
[1] Source: U.S. Energy Information Administration. https://www.eia.gov/totalenergy/data/browser/?tbl=T01.02#/?f=M&start=201304&end=202305&charted=1-2-3-4-6-13, Accessed September, 2023

Problem Statement

Challenge 1

- What are the **optimal integration** points to add and remove heat from the plant?
- What is the best and cheapest **storage material**?

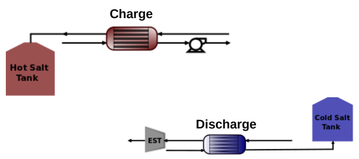
Multiple points for integration of TES



Process flowsheet of a coal-based ultra-supercritical power plant

Challenge 2

- What is the **optimal size** of TES when considering dynamic electricity markets?
- **When** and **how** to deploy storage to maximize profit?



TES for charge and discharge processes

Methodology

Generalized optimization approach consists of two steps:

1. Conceptual design using a **Generalized Disjunctive Programming** (GDP) to incorporate discrete design decisions as disjunctions
2. Optimal design and schedule of integrated energy system using a **multi-period formulation** under a price-taker assumption

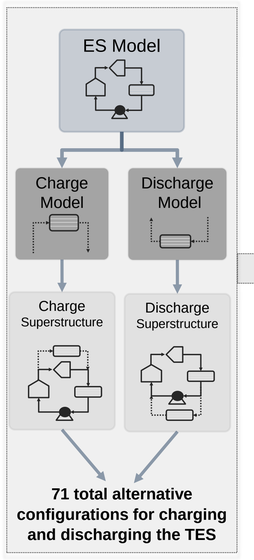
PYOMO GDP

*Use rigorous **IDAES** and DISPATCHES models and advanced cutting-edge solvers, such as **GDPopt***

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

Step 1: GDP Design

GDP superstructure optimization to determine discrete design decisions for integration of TES with thermal generator

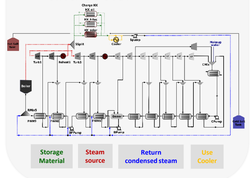


Integrated Energy System (IES)

- First-principle models with rigorous property calculations using IAPWS95
- Two GDP superstructures to identify optimal points of integration of TES

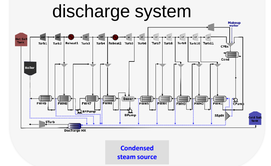
Charge Superstructure

- Four decisions: Storage material, steam source, return of condensed steam, and cooler



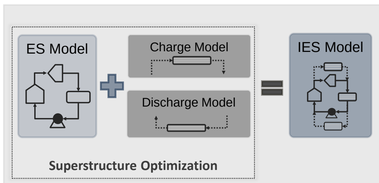
Discharge Superstructure

- One decision: Condensed steam source
- Storage turbine connected to the discharge system



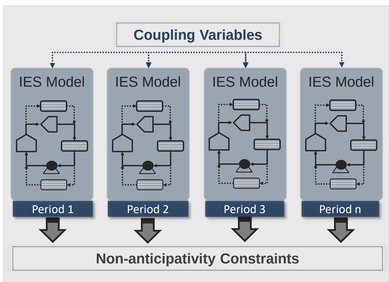
Step 2: Multi-period under Price-taker

Determine continuous design decisions, such as **size and operational conditions** of TES when considering **dynamic electricity market**



Integrated Model

- Fixed points of integration of TES from GDP design
- Charge and discharge in the same flowsheet with minimum flow constraints



Price-taker Assumption

- Average electricity prices for one representative day and week of the year
- Expected behavior: Store energy at low electricity prices
- Consider two cases:

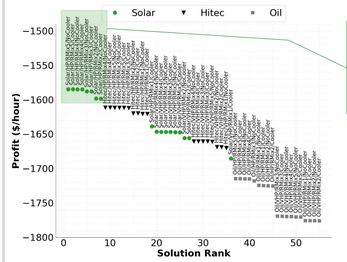
Operation-only	Simultaneous D&O
Fixed design from Step 1	Determine design and operation (D&O) using dynamic electricity prices

Results

Step 1: GDP Design

- Systematically evaluate multiple flowsheet configurations within two models
- Rank all alternative solutions for integrating TES in terms of their net profit.

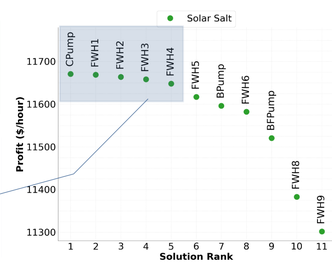
Charge Ranking



Higher profit when selecting Solar salt HP steam

Higher profit when selecting low pressure steam from feed water train

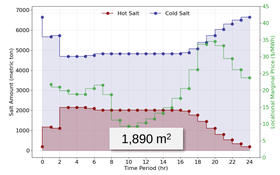
Discharge Ranking



Step 2: Multi-period under Price-taker

- Considering time-varying electricity prices prevents over-sizing TES
- Longer time horizons better capture dynamic electricity prices to increase operational profit in IES

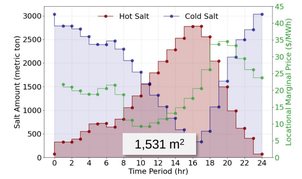
Operation-only

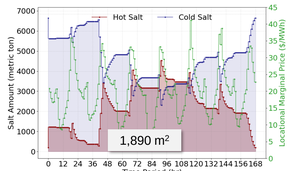


Storage utilization 32% (left) vs. **89%** (right)

Capital cost $676 (left) vs. **$395** (right)

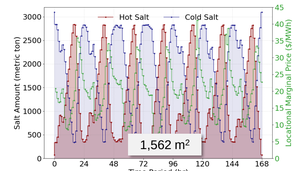
Simultaneous D&O





Salt profiles for operation-only for an average-day and week of the IES

Up to **19%** profit increment



Salt profiles for simultaneous design and operation for an average-day and week of the TES

Future Work

- Explore use of surrogate models to extend the analysis to longer time horizons with seasonal variations and historical data for electricity prices.
- Extend study beyond price-taker assumption by explicitly including market interactions of the designed IES.

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Acknowledgments

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