INL/CON-23-75462-Revision-0

Flexible Fully-Decoupled Nuclear Plants with Thermal Energy Storage - Technoeconomic Optimization

November 2023

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Changing the World's Energy Future

Idaho National Laboratory

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

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Flexible Fully Decoupled Nuclear Plants with Thermal Energy Storage—Technoeconomic Optimization

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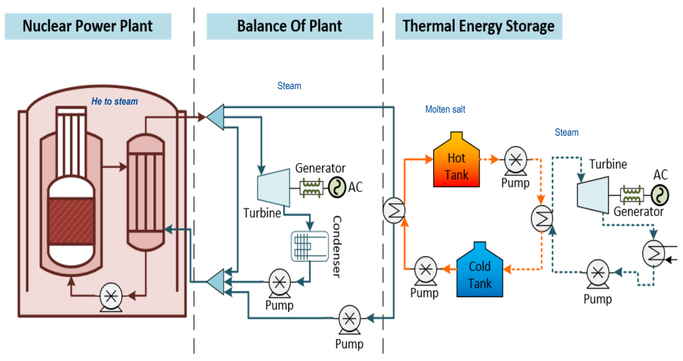
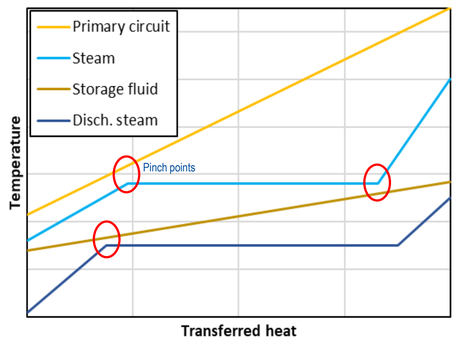
Motivation & Objective

- Future energy systems will require flexible generation
- How can nuclear plants be flexible? Answer is in integrating **thermal energy storage (TES)**
- TES-nuclear integration options:
  - **1. Steam-charged TES**
    - Exergy loss (unless PCM is used)
    - Minimum modification to nuclear primary/secondary HX

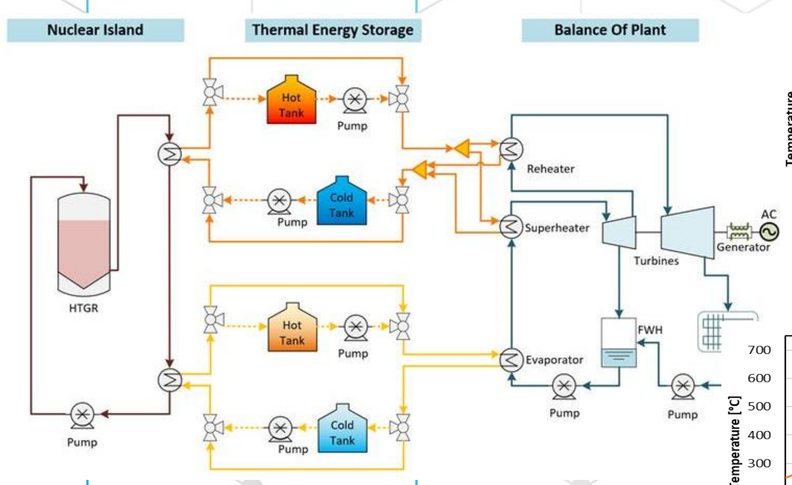


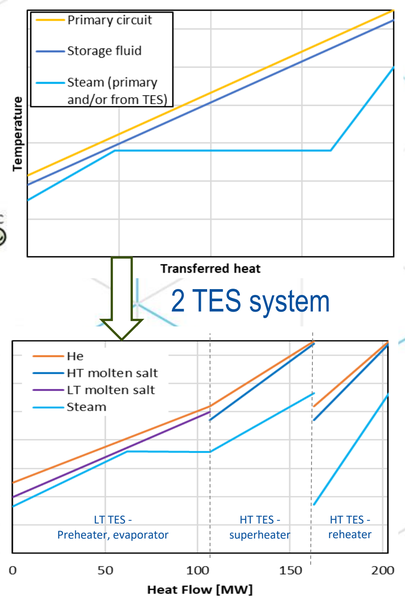


  - **2. Directly charged TES**
    - Modified HX from primary loop
    - Potential for higher efficiency – range of configuration options for steam cycle
    - Fully decoupled power from nuclear islands
    - Off-design at "nominal" parameters, constant turbine inlet parameters at varying load

Technical Solution

- **Explored for HTGR, 203 MWth, 750°C Helium outlet and 250°C return**
- Limitations on TES media ⇒ **2 TES systems**
  - High-*T*: $MgCl_2$-KCl, Low-*T*: HITEC (nitrate salt)
  - Careful distribution of heat to specific HXs
- **Simple reheat cycle** chosen as a primary focus

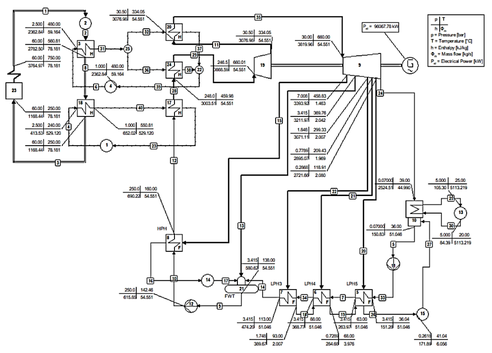




Thermodynamic Analysis

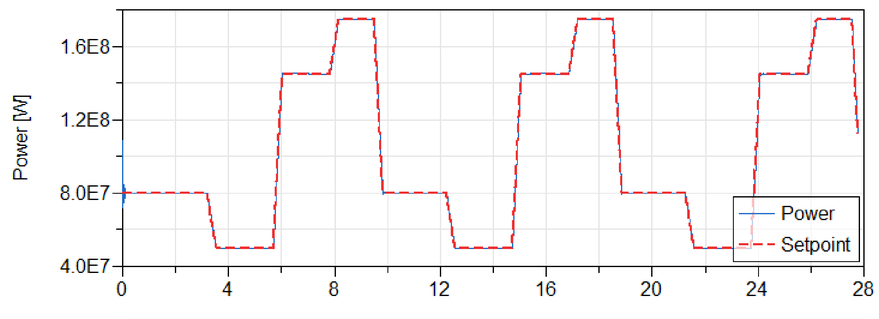
- Efficiency of alternative steam cycle configurations

Baseline	42.2%
Steam charged TES	39.5%
Decoupled, simple reheat	**43.1%**
Decoupled, reheat + FWH	43.7%
Decoupled, supercritical	46.3%
Decoupled, simple single TES	39.0%

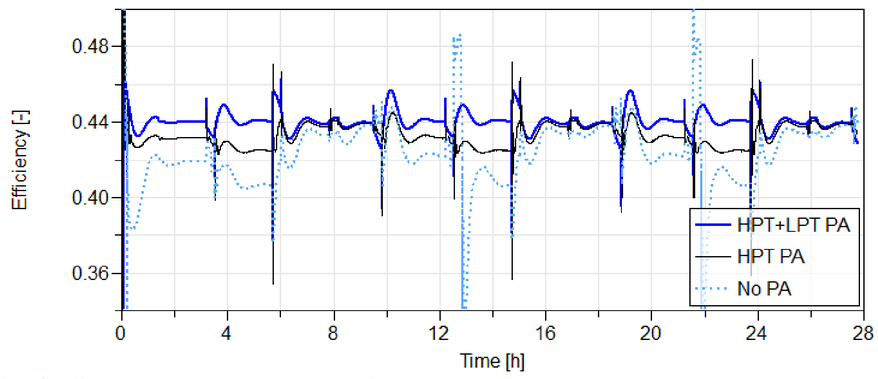


Dynamic Model Analysis

- Control/failsafe features (high/low TES systems balancing, undercharge/overcharge protection)
- Cycle control by turbine partial admission (options)



Demand can be well met

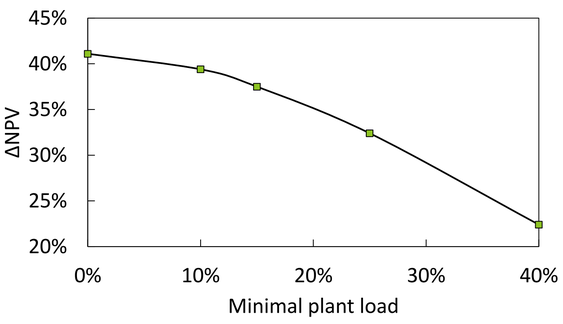


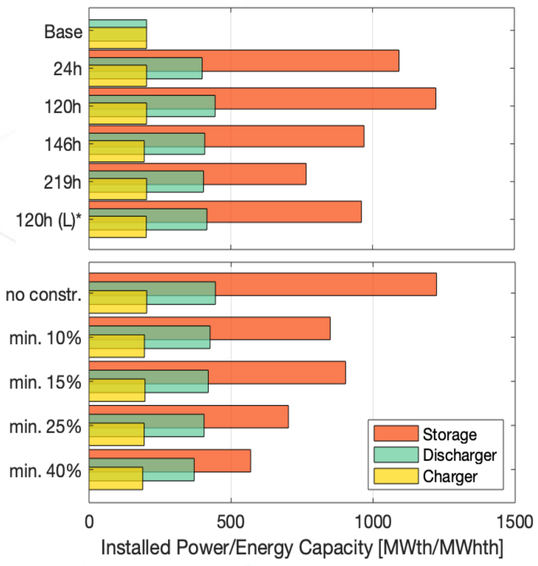
Partial admission impacts off-design efficiency

Size & Dispatch Optimization

1. Developed costing functions based on sub-systems size for optimization
2. Result is the difference in economic performance compared to steady nuclear production
3. Used HERON tool and synthetic electricity price history for energy arbitrage (case of ERCOT)

Market	Segment Length [hour]	ΔNPV [mil. USD]	ΔNPV [%]	NPV/ $MWht_h$ [mil. USD]
ERCOT	24	105	31.4	0.10
	120	147	41.1	0.12
	120 (L)	168	47.1	0.18
	146	145	40.6	0.15
	219	151	43.9	0.20





This manuscript was authored at Idaho National Laboratory by Battelle Energy Alliance LLC under contract no. DE-AC07-05ID14517 with the U.S. Department of Energy (DOE). This work was prepared for the U.S. DOE Office of Nuclear Energy (DOE-NE) via funding from the Integrated Energy Systems (IES) program.