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Changing the World's Energy Future

Aidan Christopher George Rigby, Vaclav Novotny, Daniel Mark Mikkelson, Rami M Saeed

Idaho National Laboratory

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Idaho Falls, Idaho 83415

http://www.inl.gov

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Aidan Rigby*, Vaclav Novotny†, Daniel Mikkelson†, Rami Saeed†

*University of Wisconsin-Madison, † Integrated Energy Systems, Idaho National Laboratory

Introduction

Improving the **flexibility** of nuclear reactors to meet fluctuating demand on grids with high renewable energy generation penetration is key to improving reactor economics. **Economic optimization** using the code **HERON** gives maximum profit of coupling high temperature gas reactors (**HTGRs**) to thermal energy storage (**TES**) systems in the configuration shown in Figure 1 when following the demand in Figure 3 [1][2]. We look to **model the physics** of operation for a HTGR-TES using the **HYBRID** library in the code **Modelica.**

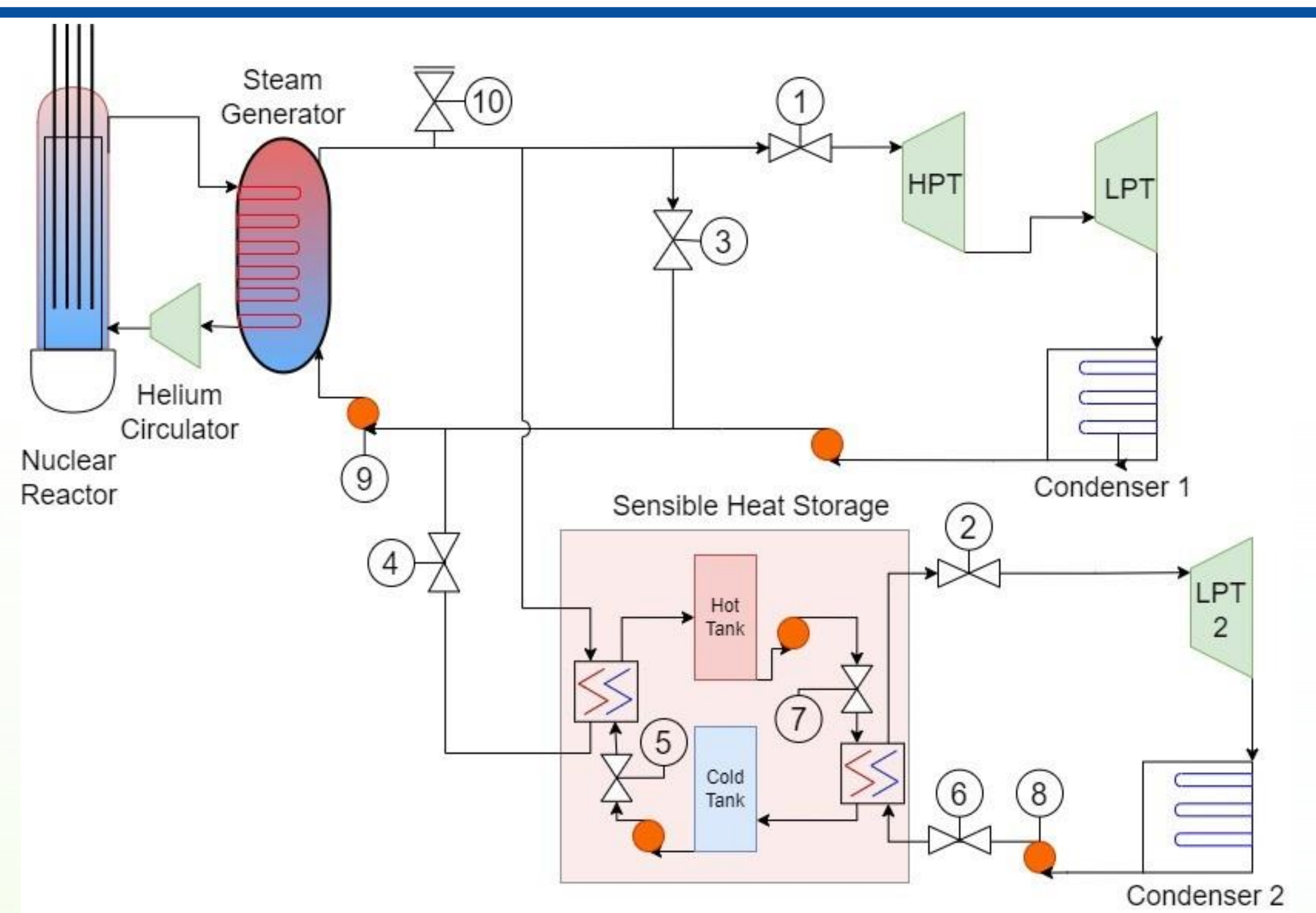

Figure 1: HTGR-TES layout with independent TES balance of plant

Motivation

The physics Modelica model aims to answer:

- How the system could be **controlled over time.**
- How the **efficiency** of the system changes when operating the balance of plant (**BOP**) at **off-design.**
- If there are **fundamental physical limits** breached during switching states.

Methodology

Figure 2 shows the state control decision logic with setpoints and actuators described in Table 2.

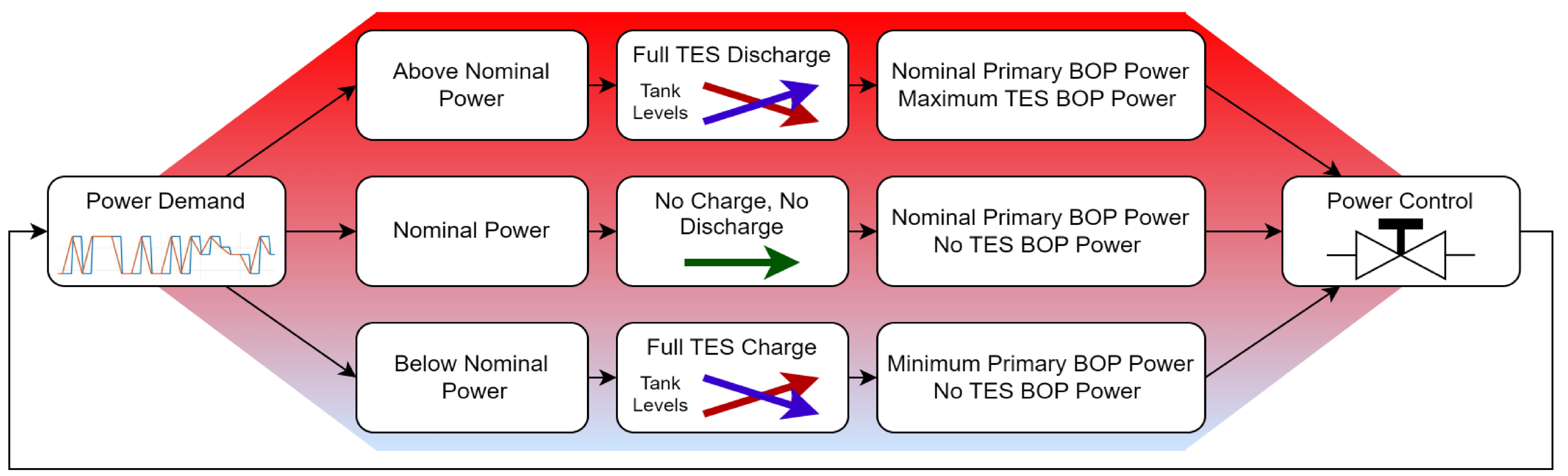

Figure 2: Power control as affected by the thermal energy storage

Table 1: Control Strategy for transient control: Q_{dem} is demanded power, Q_{nom} is nominal power of primary balance of plant = 83.16MW. Labels correspond to Figure 1.

Label	Name	Controlling	Setpoint
1	Turbine Control	Steam Inlet Pressure	34 bar
2	Discharge Turbine Control	Power	If $Q_{dem} > Q_{nom} = Q_{dem} - Q_{nom}$ else is 0.
3	Feedwater Heating	Feedwater Temperature	148°C
4	Turbine Bypass	Power	If $Q_{dem} > Q_{nom} = Q_{nom}$ else is Q_{dem}.
5	Charging Control	TES Hot Tank Temperature	240°C
6	Discharging Feedwater Control	Power	If $Q_{dem} > Q_{nom} = Q_{dem} - Q_{nom}$ else is 0.
7	Discharging Control	TES Cold Tank Entry Temp.	180°C
8	Discharging Feedwater Control	Steam Inlet Pressure	12 bar
9	Feedwater Control	Secondary Mass Flow	67 kg/s
10	Pressure Relief	Pressure Overloads	Release at 150 bar

Results and Conclusions

- **Efficiencies** for the primary BOP are: **39.49%** in full charge and **41.79%** at nominal power and for the TES BOP are **39.33%** at full discharge.
- Control system meets **power demand** with **10min ramp rates** between setpoints seen in Figure 3 keeping **reactor power constant at 203MW ± 0.1%.**
- Figure 4 shows the tank **charging level is periodic** and returns to original charge state.
- Some controlled parameters exhibit **large deviations** during transient operation including feedwater temperature shown in Figure 5.

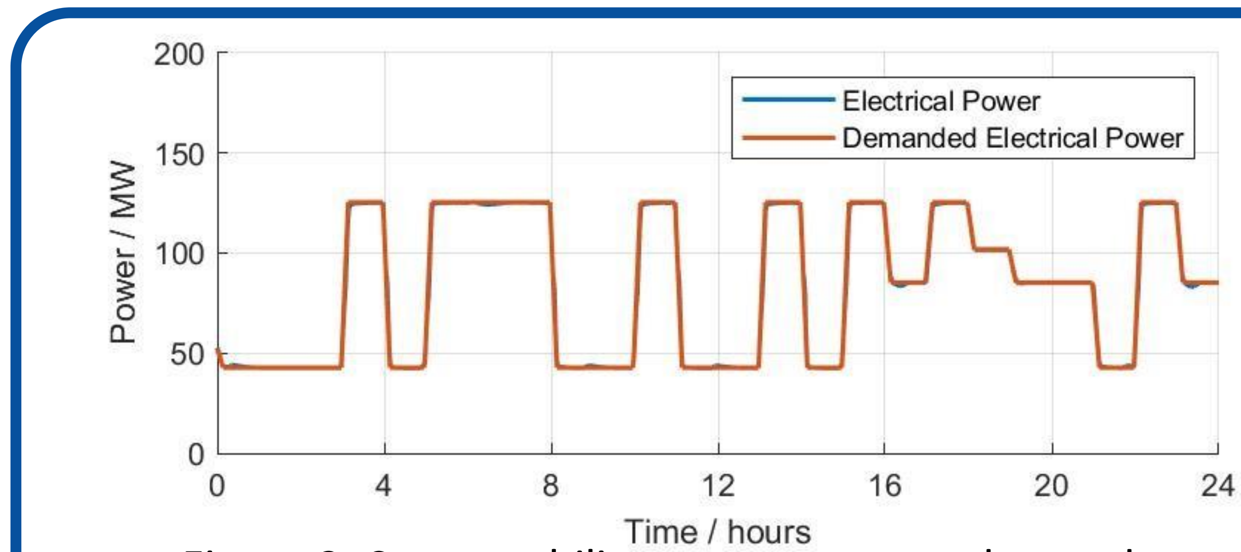

Figure 3: System ability to meet power demand

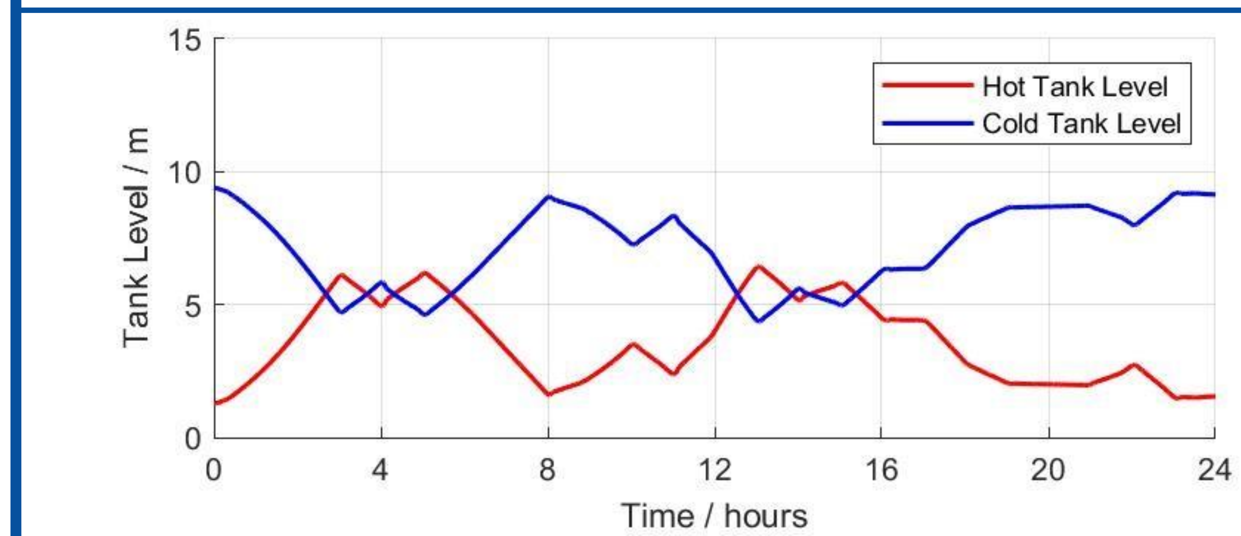

Figure 4: Charge Level of TES Tanks

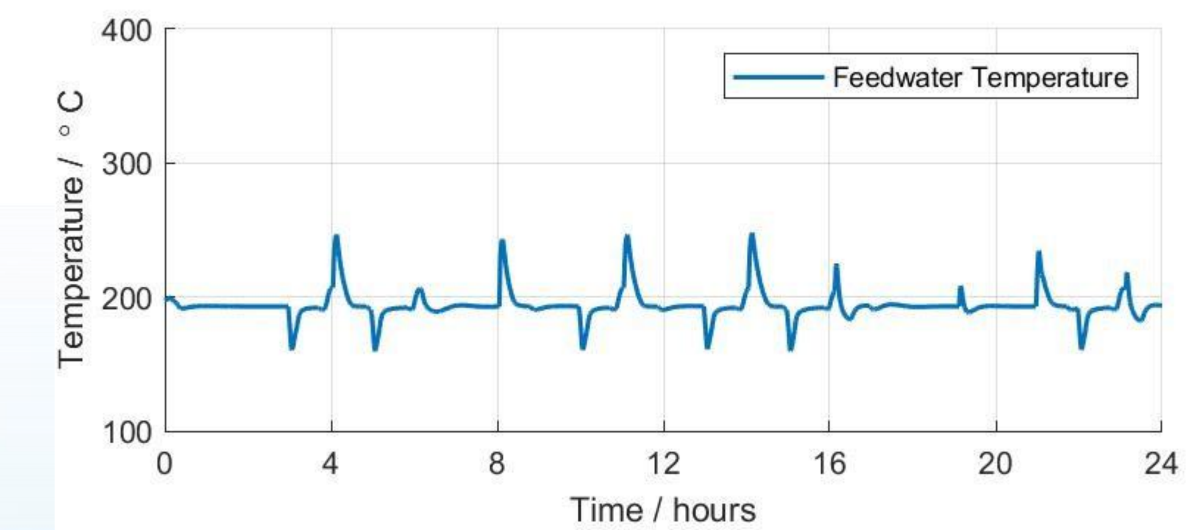

Figure 5: Feedwater Temperature during state switching

Significance and Future Work

- **Control system is sufficient** to maintain desired ramp rates and nominal operation.
- Fundamental limit to minimum power observed due to **feedwater overheating**.
- Future work to examine **control of the high volatility** in variables like feedwater temperature that results from low valve operating margins and feedback from returning steam bypassed to the TES .

1. Saeed, Rami M., Shigrekar, Amey, Mikkelson, Daniel Mark, George Rigby, Aidan Christopher, Yang Hui Otani, Courtney Mariko, Garrouste, Marisol, Frick, Konor L., and Bragg-Sitton, Shannon M. Multilevel Analysis, Design, and Modeling of Coupling Advanced Nuclear Reactors and Thermal Energy Storage in an Integrated Energy System. United States: N. p., 2022. Web. doi:10.2172/1890160.
2. Shigrekar, Amey, Toman, Jakub, and Saeed, Rami M. Synthetic Electricity Market Data Generation and HERON Use Case Setup of Advanced Nuclear Reactors Coupled with Thermal Energy Storage Systems. United States: N. p., 2023. Web. doi:10.2172/1960133.

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