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Development and Analysis of Control Systems for Thermal Energy Storage System

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Introduction

· The **sodium** as a working fluid for TES has a **wide operating temperature range**, so it is highly usable. There is an advantage of **increasing the energy storage density** by operating a large temperature difference between the hot tank and cold tank.

· The layout of the sCO_2 Brayton cycle suitable for the TES was selected as the **partial heating cycle** due to its good efficiency [2].

· Purpose: Development the **control systems** for TES and power generation system as a buffer for intermittent and volatility of the power grid

sCO_2 cycle layout for TES (Partial heating cycle)

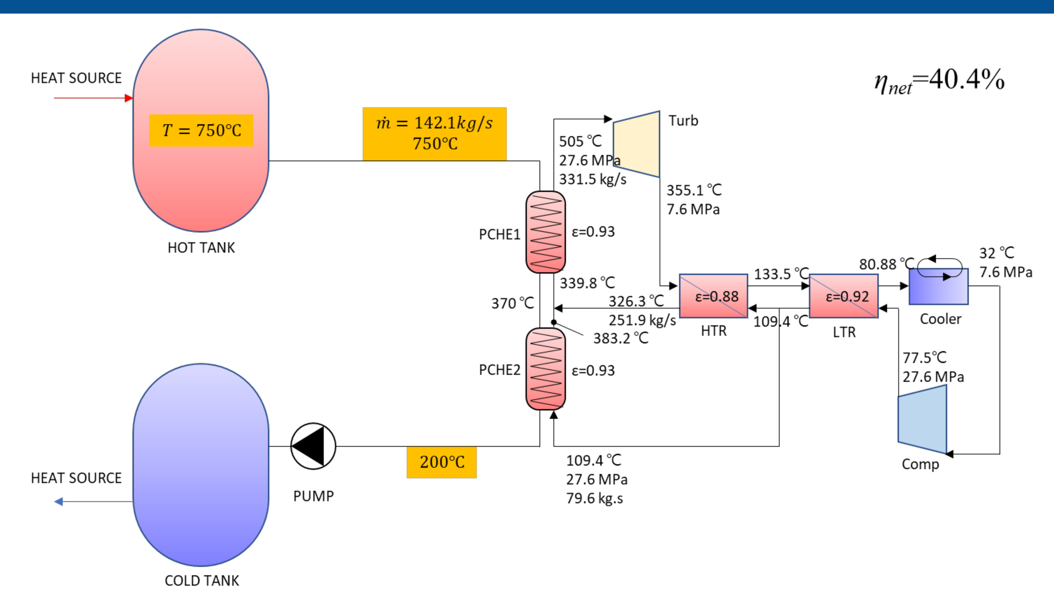

Fig. Heat balance of Partial heating cycle for thermal energy storage system

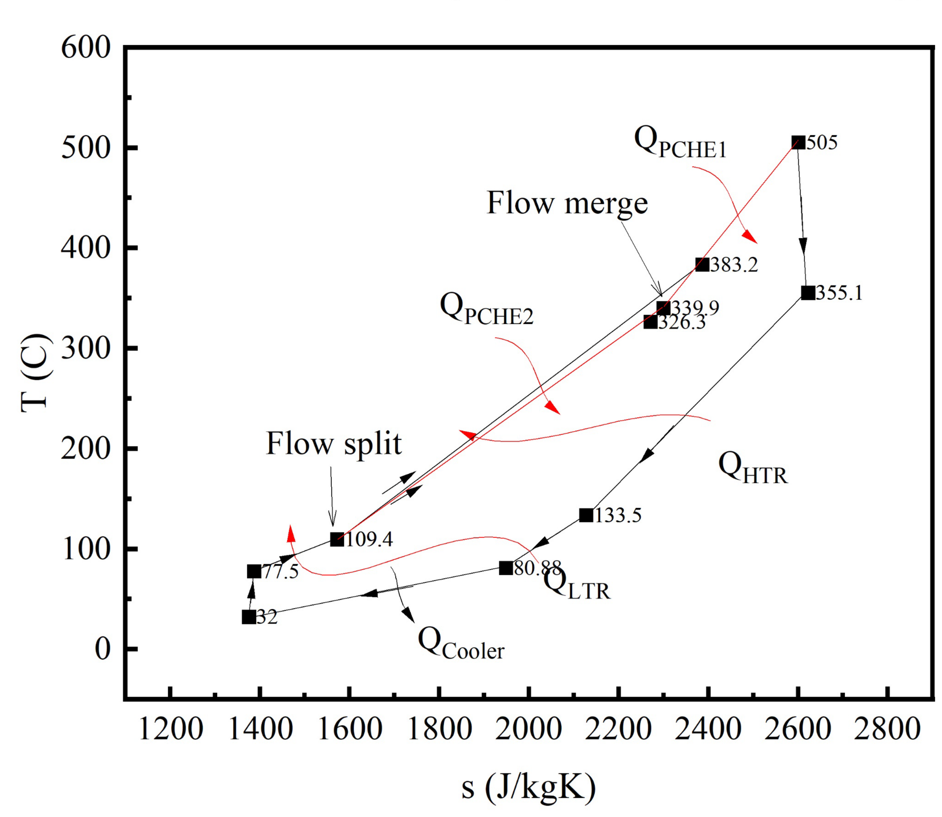

Fig. T-s diagram of Partial heating cycle for thermal energy storage system.

Table : Design constraints for supercritical CO_2 brayton cycles

Compressor inlet condition	32℃, 7.6 MPa
Maximum pressure	30 MPa
Heat exchanger effectiveness	< 95%
Compressor efficiency	88%
Turbine efficiency	92%

- The heat storage capacity of the thermal energy storage system is 1 GWht and the rated output is 100 MWth

- The compressor inlet condition was assumed to be cooled to the critical point of 32℃ and 7.6 MPa in the cooler.

- The maximum pressure was set to 30 MPa or less.

- The effectiveness of the heat exchanger is more than 95%, the cost of the heat exchanger increases rapidly, so it was limited to less than 95%.

- Compressor and turbine efficiencies were assumed to be 88% and 92%, respectively, as typical efficiencies of commercial products.

- In thermal equilibrium, the effect of pressure change in other equipment other than the turbine and compressor was neglected.

Development of Dynamic Model

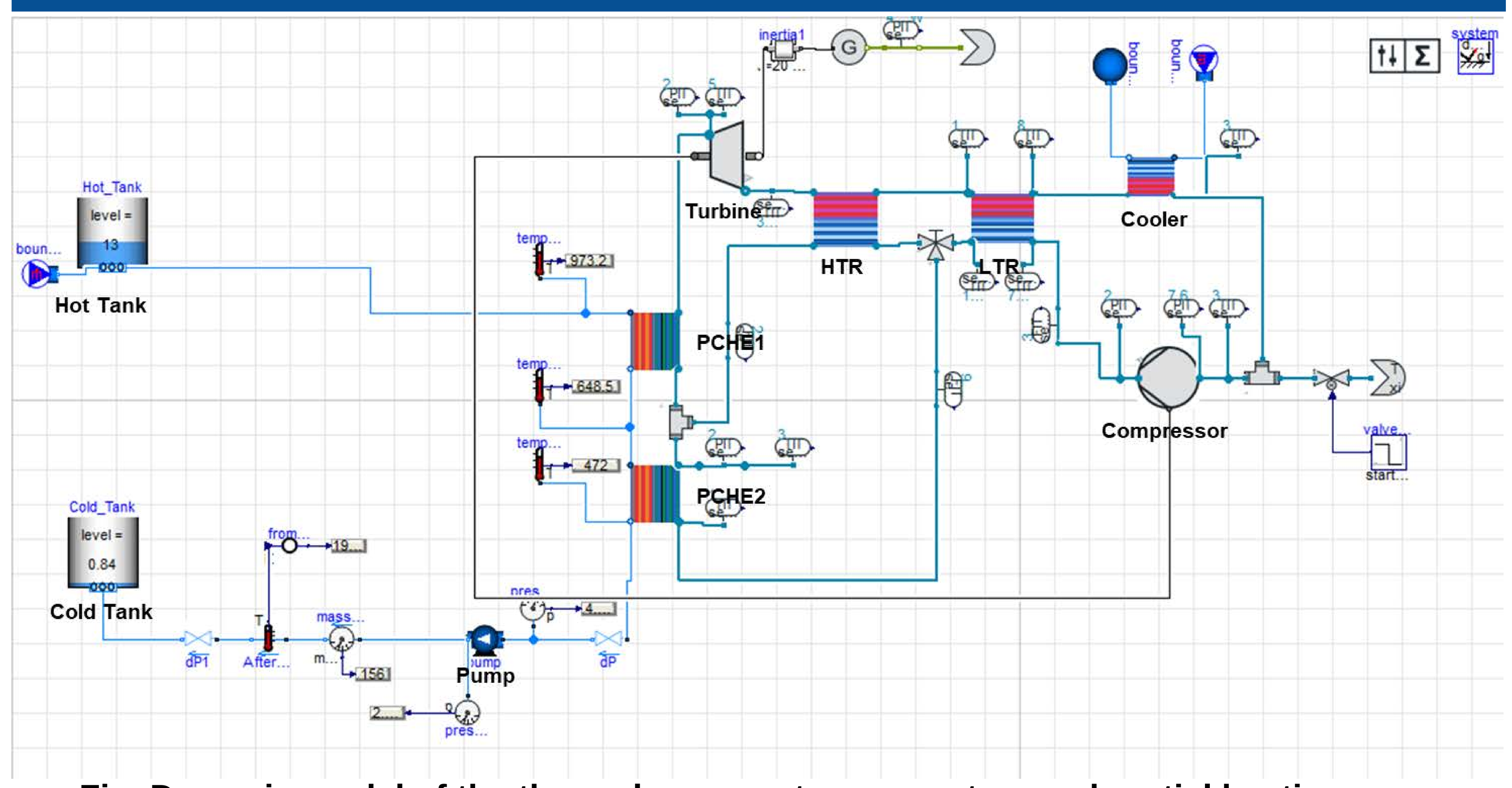

Fig. Dynamic model of the thermal energy storage system and partial heating sCO2 brayton cycle

- Using Dymola software, a dynamic model of the thermal energy storage and utilization system was built.

- For carbon dioxide properties and turbo machinery, the model provided by ClaRaPlus Library v1.3.0 was used

- For sodium properties, the properties provided by SolarTherm Library v0.2, which are basically provided by Modelica, were used

- The heat exchangers of PCHE, recuperator, and cooler were manually modeled by connecting pipes and heat transfer walls

- It was confirmed that the maximum error of temperature and pressure coincided very well with the heat balance within 4°C and 1.55 MPa, respectively

- The heat transfer rate of PCHE1 and PCHE2 was good agreement with the heat balance in the error of 1%. The heat transfer rate of PCHE1 and PCHE2 was 63.88 MW and 36.2 MW

Plant Control Strategy

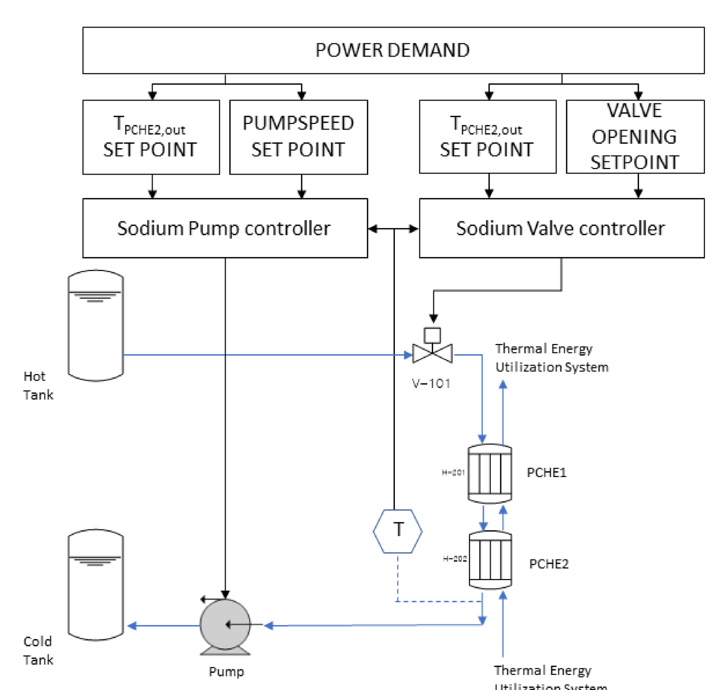

Fig. Control system for TES system

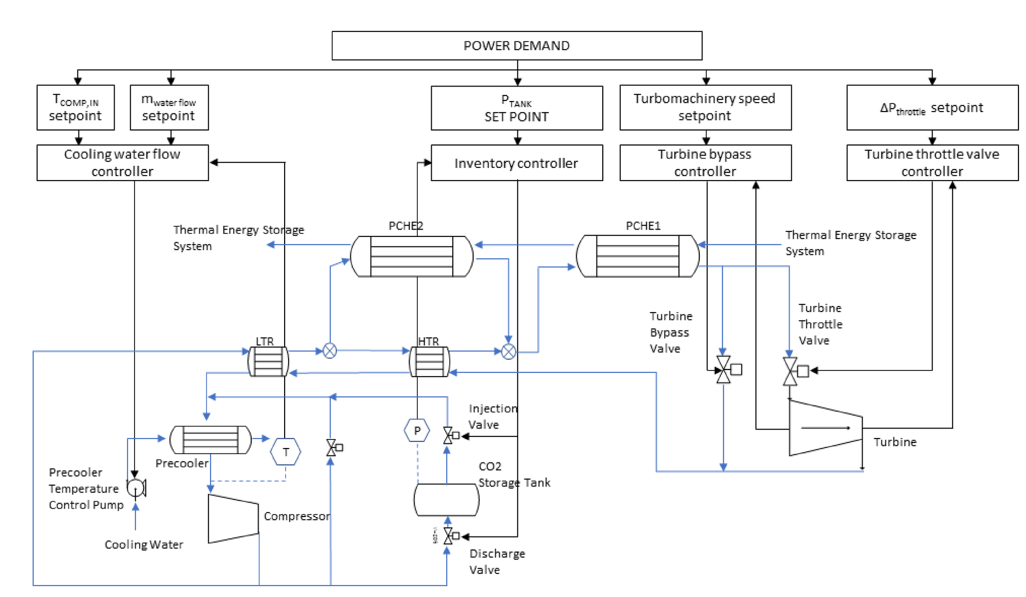

Fig. Control system for power generation system

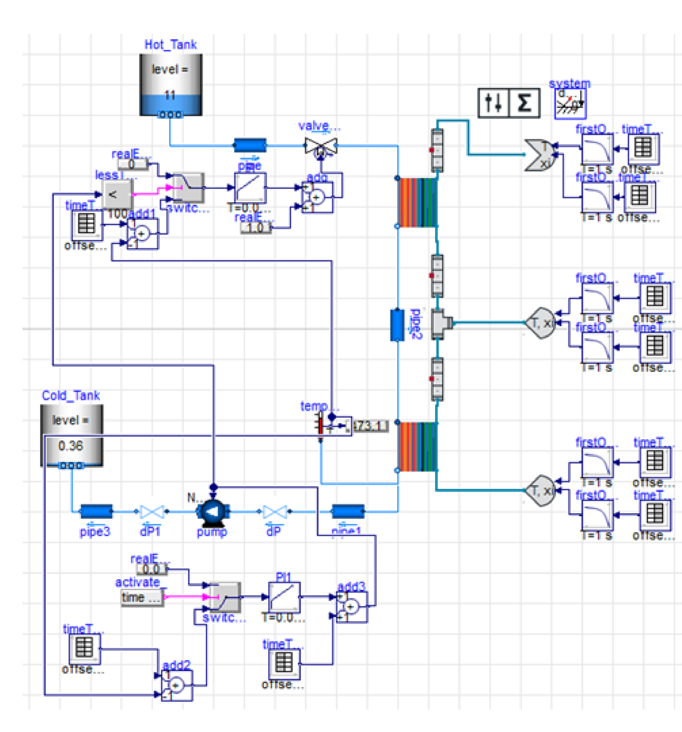

Fig. Controller modeling using Modelica for TES

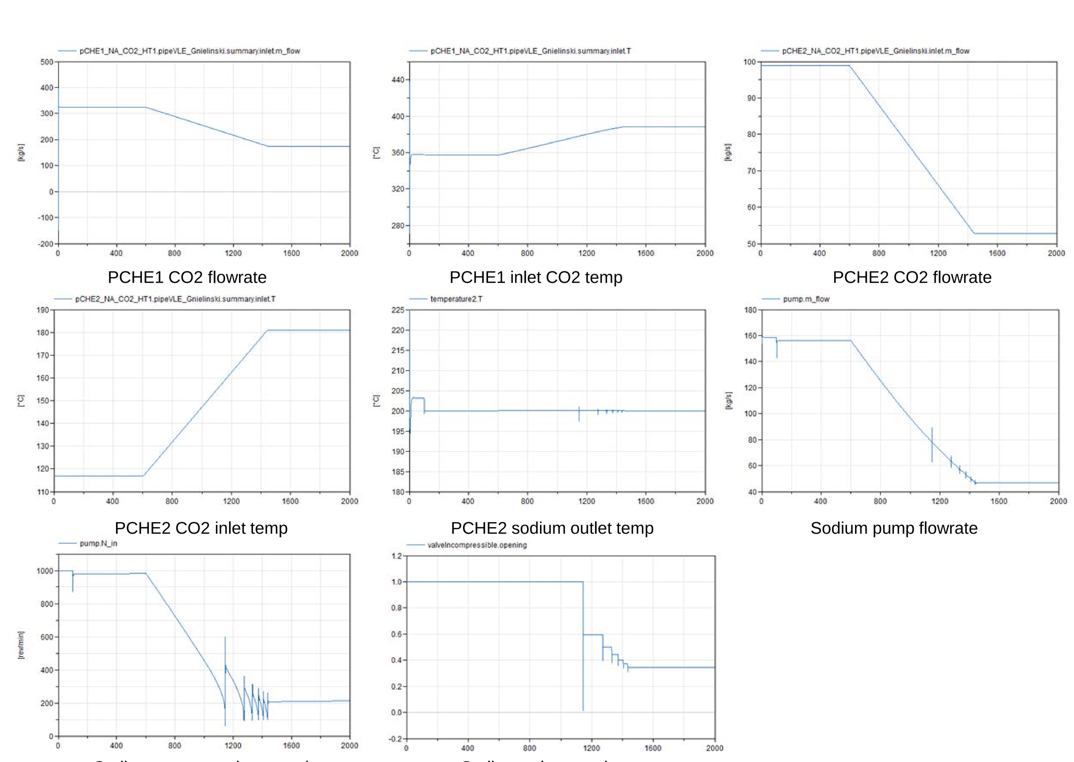

Fig. Process variable changes of ramp load change from 100% to 30%

Conclusions

· **The efficiency of the cascade cycle and the partial heating cycle was compared to find an option of a supercritical CO2 brayton cycle suitable for application to a large temperature range of a thermal energy storage system**

· **The efficiency of the partial heating cycle was 40.4%, which shows higher than the efficiency of the cascade cycle, 33.7%.**

· **The developed model confirmed its accuracy by comparing with the heat balance, and it was confirmed that the maximum error of temperature and pressure of the thermal energy utilization system was well matched within 4℃ and 1.55 MPa, respectively. The heat transfer from the thermal energy storage system was also well matched with a maximum error of 1%.**

· **The control performance evaluation was performed for the ramp load change, and it was confirmed that the change in the process variable satisfies all the control performance requirements. (The ramp load change within 30% - 100% range: 5%/min (settling time 60 s), The step load change when power grid fluctuates in the range of ±10%: 10%/10sec (settling time 20 s))**