Comparison Analysis of Thermal and Mechanical Integrated Liquid Air Energy Storage Systems with Pressurized Water Reactor

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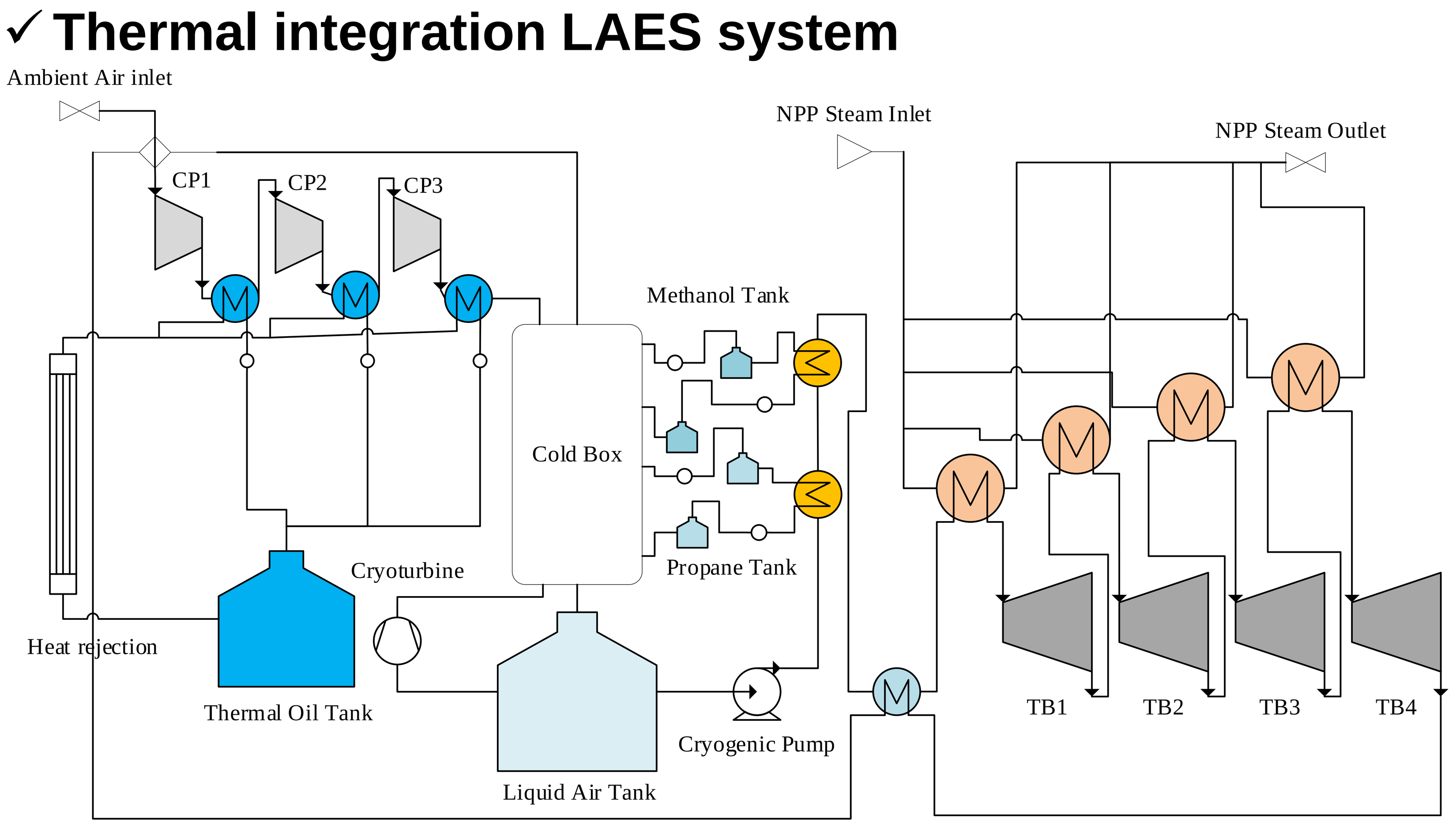
Introduction

- ✓ Renewable energy such as wind and solar power expected to hold large portion in renewable energy substantially depend on the environmental condition and time. To reduce this uncertainty in energy supply, an Energy Storage System (ESS) is necessary. Otherwise to use renewable energy efficiently, existing base-load should change following renewable energy source.
- ✓ In Korea, nuclear power has a high proportion of base load. Although the PWRs were originally designed to be able to do load-following operation, further development can improve its maneuverability while maintaining the safety margin and reducing the effluent release. The integration of Nuclear Power Plant (NPP) and ESS can be one of the candidate technologies.
- ✓ In this study, two types of different LAES-NPP integrated system is proposed. The first method is to integrate the NPP steam in the discharging cycle of LAES. This method is thermal integration of LAES with NPP. The second method is to operate the compressor in the LAES charging cycle with steam turbine which is operated by steam from NPP. This method is mechanical integration.
- ✓ The comparison of two methods will give insight to design that combines LAES and NPP. As two systems have different sensitivity to certain thermal parameters, it will help to choose and design a system that is more appropriate for a given constraint.

Thermodynamic modeling

✓ Thermal integration LAES system



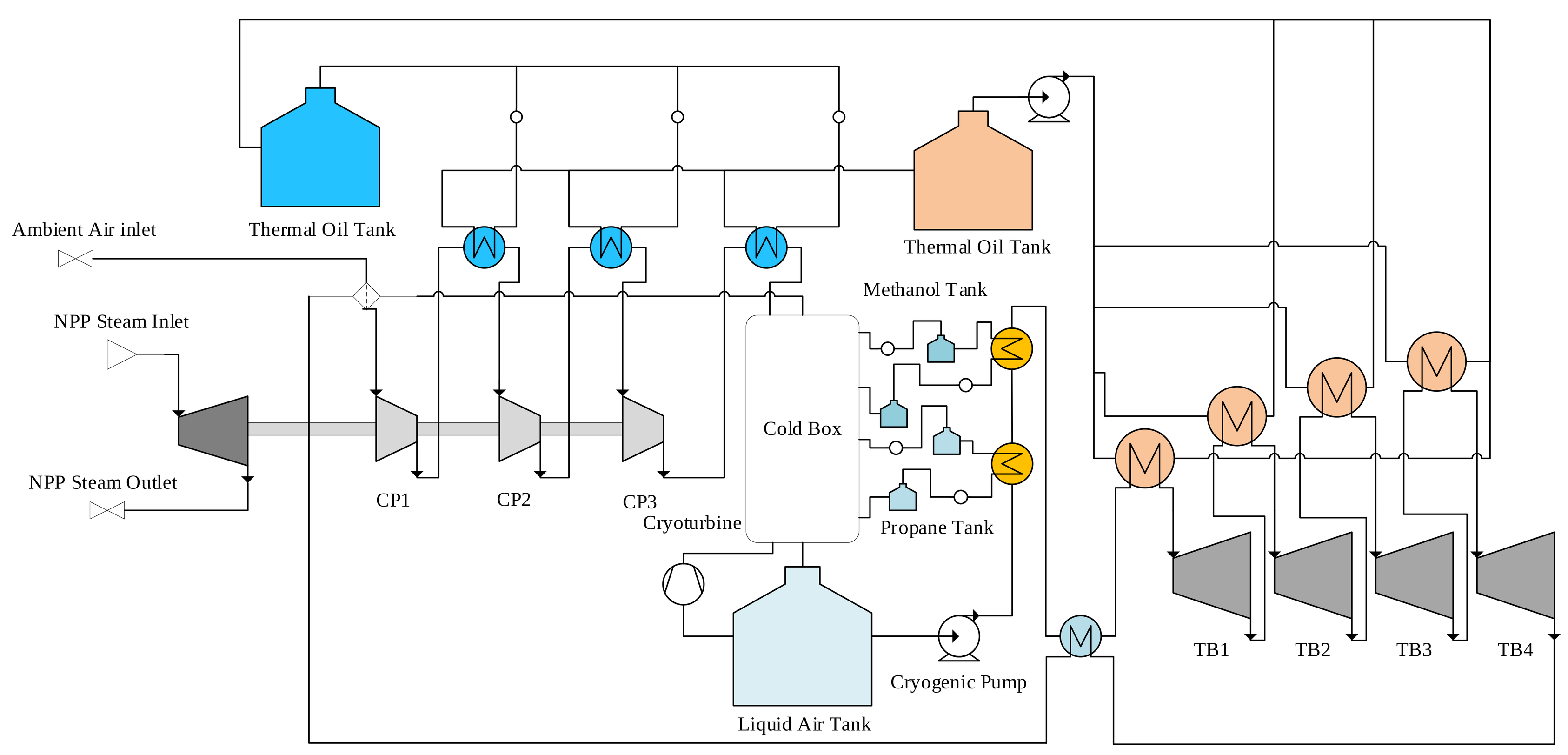
(1) As shown in the layout, the bypass steam from NPP reheat air before enter turbine in discharging cycle of LAES system.
(2) Since the mass flow rate of LPT inlet was changed from the nominal mass flow rate, off-design models for the LPT are applied in the below
(3) The total Round-Trip Efficiency (RTE) of LAES system is sum of energy production from LAES system and loss from NPP system, over total energy consumption to liquify air in LAES system.

$$\mathrm{RTE} = \frac{(P_{LAES,disc} - P_{loss,NPP}) \cdot (T_{disc})}{(P_{LAES,char}) \cdot (T_{char})}$$

$$\mathrm{P_{LAES,char} = P_{CP,char} + P_{pump,char} - P_{cryoTB,char}}$$

$$\mathrm{P_{LAES,disc} = P_{TB,disc} - P_{pump,disc}}$$

✓ Mechanical Integration LAES system



(1) As shown in the layout, the bypass steam from NPP enter turbine to operate turbine driven compressor in charging cycle of LAES system.
(2) Since the mass flow rate of LPT inlet was changed from the nominal mass flow rate, off-design models for the LPT are applied in the below
(3) The RTE of LAES system is sum of energy production from LAES system, over total energy consumption to liquify air in LAES system. As the energy loss from NPP is used for turbine driven compressor in the charging cycle, Its RTE has different definition to thermal integration system.

$$\mathrm{RTE} = \frac{(\mathrm{P_{LAES,disc}}) \cdot (\mathrm{T_{disc}})}{(\mathrm{P^{*}_{LAES,char}}) \cdot (\mathrm{T_{char}})}$$

$$\mathrm{P^{*}_{LAES,char} = P_{loss,NPP} + P_{pump,char} - P_{cryoTB,char}}$$

✓ Cycle condition

NPP parameter	value
steam inlet temperature	540(K)
steam inlet pressure	1443(kPa)
steam mass flowrate	298(kg/s)
Power loss from NPP	261(MW)

Results

✓ Thermal Integration

Energy consumption/generation	Value (MWh)
Charging	
Compressor	1167
Turbine	40
Pump	5
Total	1132
Discharging	
Turbine	633
Pump	18
NPP	261
Total	354
Round-trip efficiency	31 (%)

✓ Mechanical Integration

Energy consumption/generation	Value (MWh)
Charging	
NPP	1305
Turbine	40
Pump	5
Total	1270
Discharging	
Turbine	676
Pump	18
Total	658
Round-trip efficiency	52 (%)

✓ Thermal Condition of Turbines in Discharging Cycle

	Thermal Integration		Mechanical Integration	
	Pressure(kPa)	Temperature(K)	Pressure(kPa)	Temperature(K)
TB1_in	8643	479	8643	510
TB1_out	2870	362	2870	386
TB2_in	2842	477	2842	510
TB2_out	944	362	944	387
TB3_in	934	477	934	510
TB3_out	310	362	310	387
TB4_in	307	477	307	510
TB4_out	102	362	102	387

(1) The mechanical integration system has higher inlet temperature of turbine than the thermal integration system. This makes higher turbine output power in the mechanical integration system.
(2) As the steam from NPP should be separated after passing High pressure turbine in NPP, due to safety issues, It has lower temperature than using thermal oil in mechanical integration system.

Summary

- ✓ The two system were compared under **the same NPP condition**. The thermal integration system from the previous work is used. The calculation of **NPP side is improved by using off-design model** and **the isothermal compressors are replaced by normal compressor** for better representation of the system.
- ✓ The **thermal integration system has lower RTE** than the mechanical integration system. Its RTE is 31%, which is **21% lower** than the **mechanical integration**.
- ✓ The result is **limited to the given NPP constraint**. The NPP condition could be optimized for each method, and it will need to consider whether these conditions are satisfactory within the **limitations imposed on realistic system deployments** or not