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Performance Analysis of Thermal Energy Storage System For Nuclear Power Plant Application

Seunghwan Oh, Jeong Ik Lee*
Department of Nuclear & Quantum Engineering, KAIST
**Corresponding author: jeongiklee@kaist.ac.kr*

Introduction

- A low-carbon power generation technology is important to mitigate climate crisis.

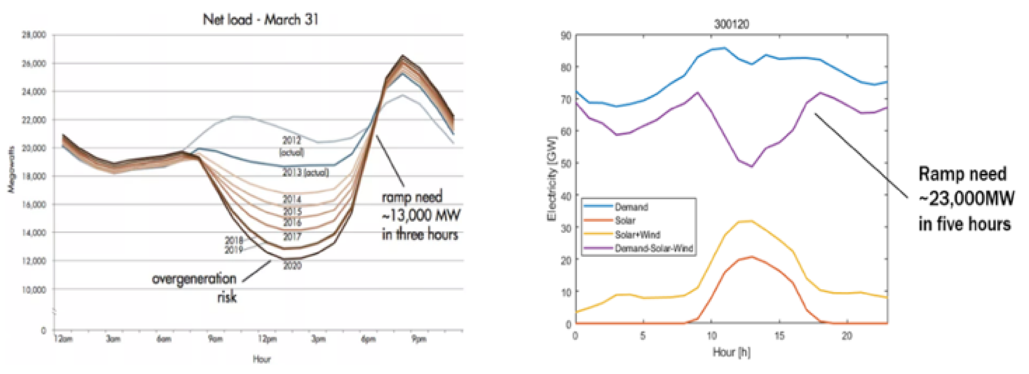

Fig. 1. Duck curve (Left) California, CAISO (Right) South Korea

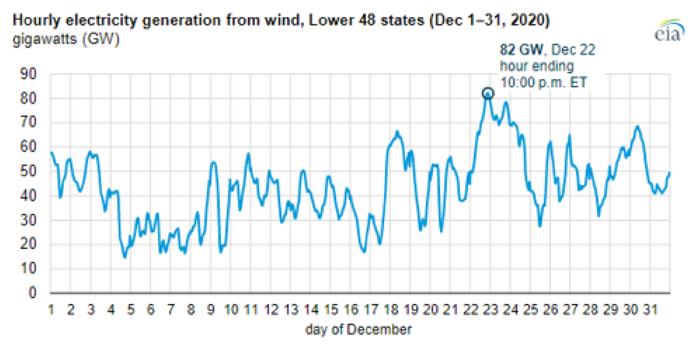

Fig. 2. Hourly electricity generation from wind

- Energy storage system (ESS) can stabilize grid system and make it more efficient.
- Recently, thermal energy storage system (TES) has been studied for nuclear power plant (NPP) application.
- The TES temperature is determined by the operating temperature of the NPP.
- It is important to select a suitable heat transfer fluid (HTF).
- Therefore, TES performance is analyzed for NPP application using round-trip efficiency (RTE) and energy density.

TES integrated NPP

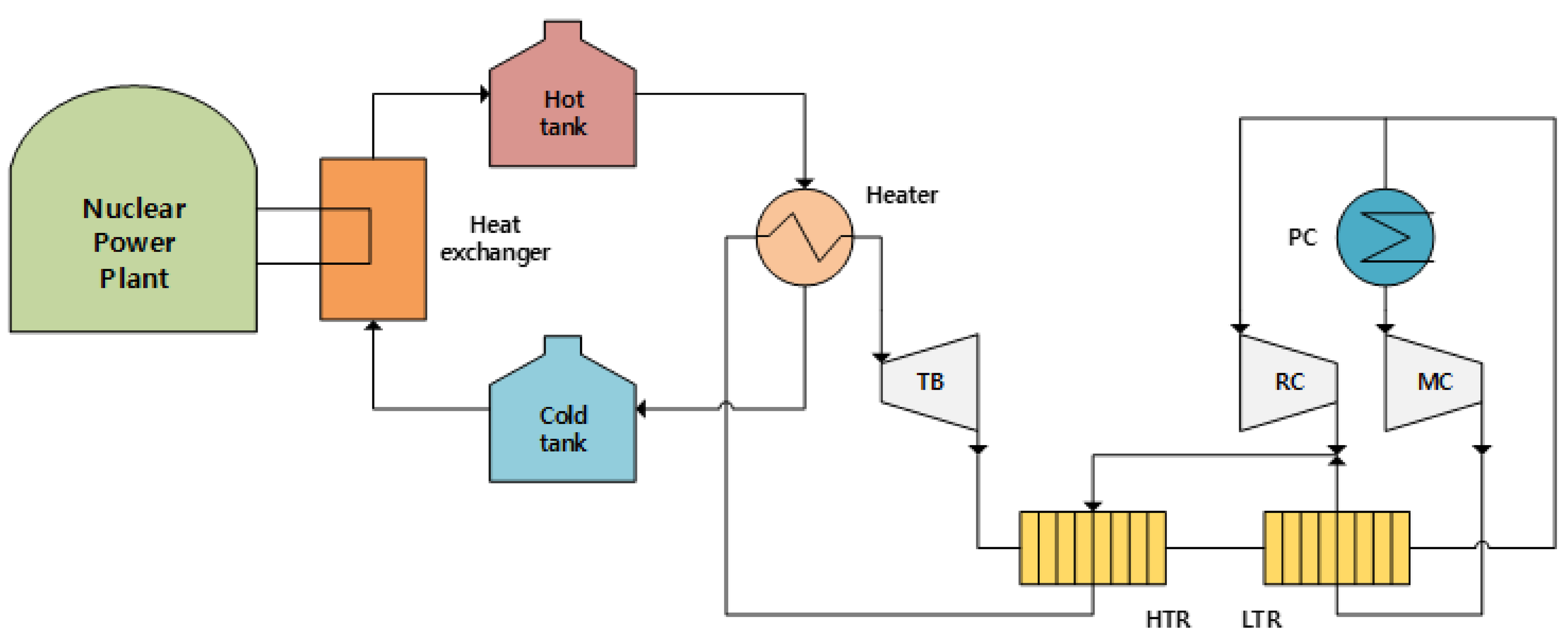

Fig. 3. TES integrated NPP

- During charging mode, thermal energy of NPP transfer to TES.
- HTF is heated through heat exchanger and stored in the hot tank.
- When additional power is required (discharging mode), thermal energy is converted to electric energy using TES dedicated power cycle.

❖ Heat transfer fluid (HTF)

- The main HTF used in power plant industry are HITEC salt and solar salt.
- However, both of these salt mixtures become thermally and chemically unstable at temperatures above 600 °C.
- Thus, liquid sodium was recommended as HTF at higher temperature.

Table I. Properties of HTFs

HITEC salt	
Operating temperature [°C]	142 ~ 538
Density $[kg/m^3]$	$\rho = 2293.6 - 0.7497T$
Heat capacity $[J/(kg\ K)]$	$C_p = 5806 - 10.833T + 7.2413 \times 10^{-3}T^2$
Solar salt	
Operating temperature [°C]	223 ~ 550
Density $[kg/m^3]$	$\rho = 2263.628 - 0.636T$
Heat capacity $[J/(kg\ K)]$	$C_p = 1396.044 + 0.172T$

Liquid sodium	
Operating temperature [°C]	97.7 ~ 873
Density $[kg/m^3]$	$\rho = 219 + 275.32 \times \left(1 - \frac{T}{2503.7}\right) + 511.58 \times \left(1 - \frac{T}{2503.7}\right)^{0.5}$
Heat capacity $[J/(kg\ K)]$	$C_p = (1.6582 - 8.4790 \times 10^{-4}T + 4.4541 \times 10^{-7}T^2 - 2992.6T^{-2}) \times 10^3$

❖ S-CO_2 power cycle

- The S-CO_2 power cycle has higher efficiency than that of the steam Rankine cycle for the same turbine inlet temperature.
- Since it operates above the critical point, the pressure ratio is small and the turbine outlet temperature is high.
- The S-CO_2 power cycle requires a large amount of recuperation process to increase the efficiency.
- The S-CO_2 recompression cycle has high cycle efficiency and is mainly used to avoid the pinch point problem in recuperators.

Table II. S-CO_2 recompression cycle conditions

Parameters	Value
Turbine efficiency [%]	90
Compressor efficiency [%]	80
Heat exchanger effectiveness [%]	90
Heat exchanger pressure drop [%]	1
Main compressor outlet pressure [MPa]	25
Main compressor inlet temperature [°C]	35
Net work [MW]	10
Turbine inlet temperature [°C]	Variable
Main Compressor inlet pressure [MPa]	Variable
Split ratio	Variable

$$\eta_{RTE} = \frac{W_{w/\,TES}}{W_{w/o\,TES}}$$

Eq. 1. RTE general definition

- Since the power cycle of NPP is not known, only the performance of the TES dedicated power cycle is analyzed.

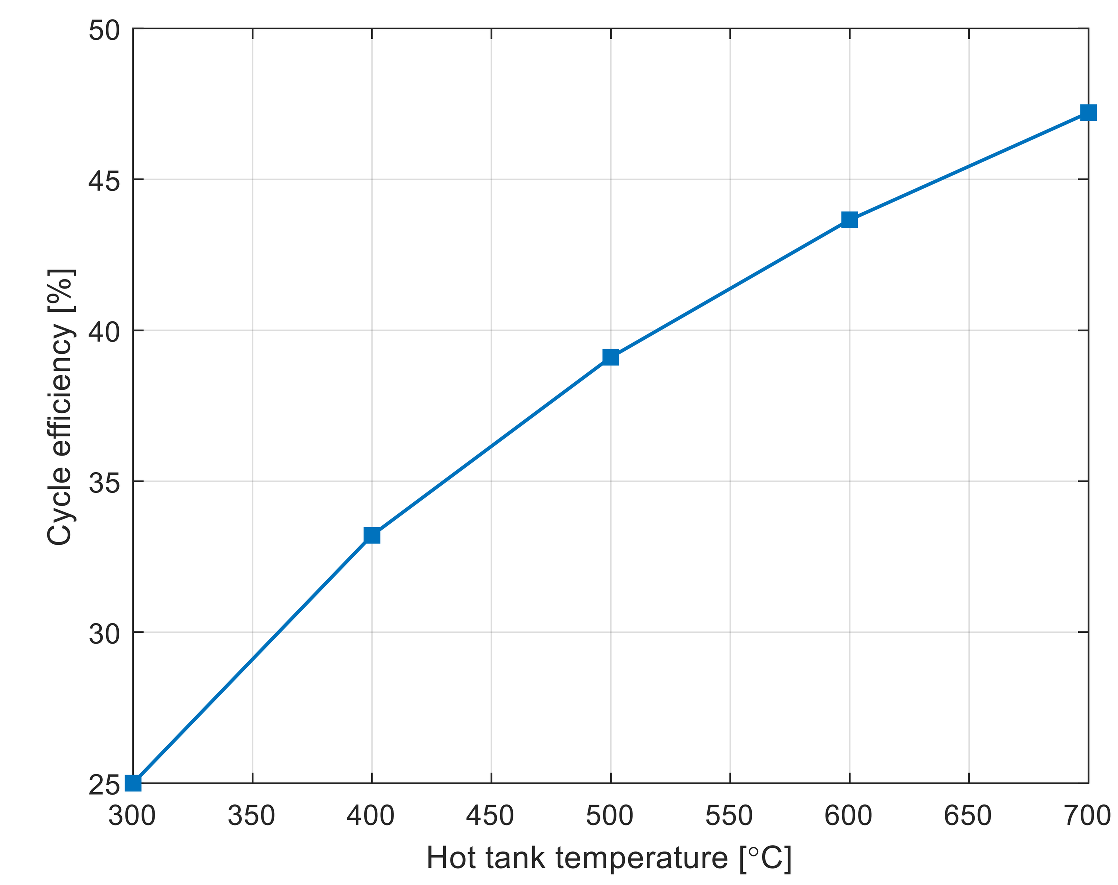

Fig. 4. TES dedicated power cycle efficiency

- Energy density is defined as the amount of energy that can be produced per volume.

$$\omega = \frac{\dot{w}_{out} t_{disch}}{\frac{\dot{m}_{disch} t_{disch}}{\rho_{hot}} + \frac{\dot{m}_{ch} t_{ch}}{\rho_{cold}}}$$

Eq. 2. Energy density definition with two tank TES

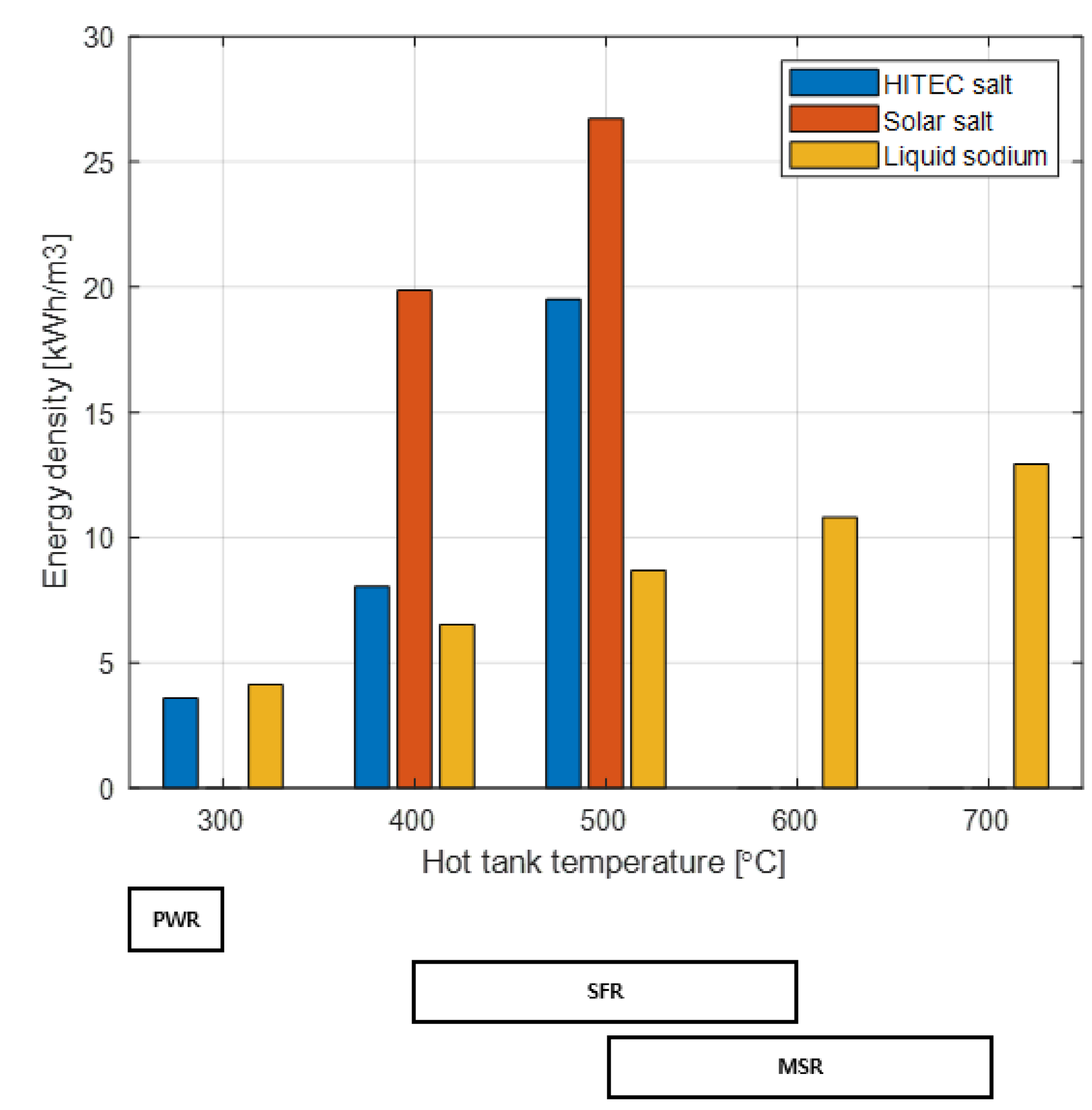

Fig. 5. TES energy density

Conclusions

- One of the solutions to the intermittency problem of renewable energy is flexible operation of conventional power plants.
- Overall, the energy density of TES is quite comparable to the other mechanical energy storage system (CAES, LAES).
- It is found that using TES is better for Gen-IV type reactors rather than coupling with conventional NPP (PWR).