Economic analysis of Liquid Air Energy Storage System with Small Modular Reactor

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Introduction

- ✓ Small Modular Reactor (SMR) is an attractive option for energy supply where a huge power plant cannot be installed Small power output for SMR will be appropriate for a small grid. Moreover, regional constraint such as river or oceans to supply huge amount of coolant to build a nuclear power plant is removed in SMR
- ✓ Due to increasing interest on SMR, the research on innovative SMR itself is underway but also, the research on an integrated system with SMR to increase its efficiency of maximize benefit is actively progressing. SMRs coupled with wind energy, energy storage, and hydrogen production via high-temperature steam electrolysis are good examples.
- ✓ The inlet temperature of the steam generator was checked to ensure that there was no problem with the secondary side of the SMR when the steam inside the SMR was branched. The Levelized Cost of Electricity (LCOE) is calculated up to 50% steam split for an SMR.
- ✓ An economic analysis on the Liquid Air Energy System (LAES) combined with SMR is presented to show the feasibility of the mechanically integrated ESS with SMRs. As an example, a standalone LAES and SMR integrated LAES are compared in terms of LCOE. The size of the integrated SMR is 486MWth and the steam after high pressure turbine will be split to steam turbine driven compressor in the LAES

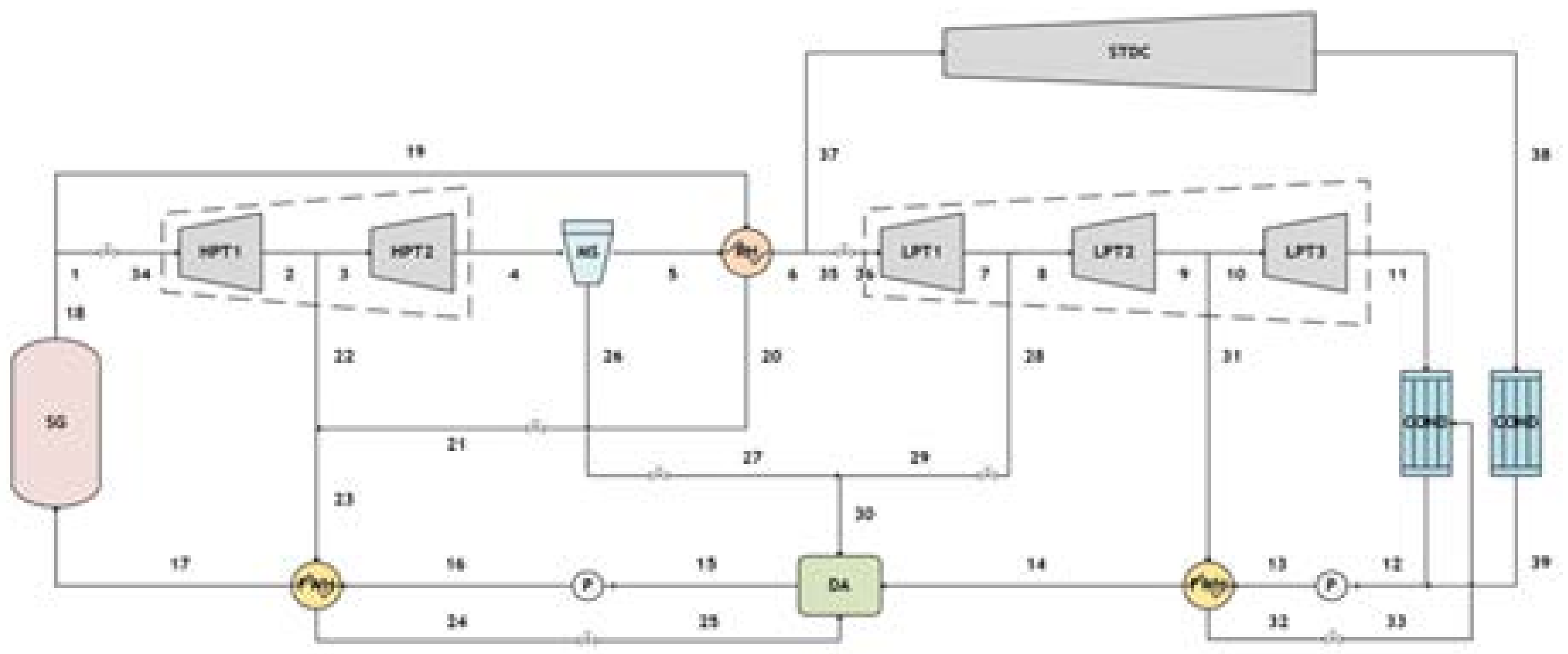


Figure 1. Layout of Secondary Cycle for Small Modular Reactor

Methodology

✓ LCOE Calculation

The LCOE is essentially the total lifecycle cost for a system divided by the lifetime energy production. In the case of LAES standalone system, the calculation of LCOE follows equation below

$$\mathbf{LCOE_{standalone}} = \frac{\sum_{t=1}^{n} \frac{(I_t + M_t + F_t)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t: *capitical investment*
M_t: *operation and maintenance cost*
F_t: *electricity cost*
E_t: *generated energy*
r: *discount rate*

The LCOE of LAES integrated with SMR should consider the cost of steam driven compressor and the opportunity cost of SMR. It means that as split flow of steam in the SMR cycle operate compressor, there is output decrease in the SMR cycle. It should be reflected in the LCOE of LAES cycle. It will be equation below.

$$\mathbf{LCOE_{integrated}} = \frac{\sum_{t=1}^{n} \frac{(I_t + M_t + F_t + C_{STDC} + O_t)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

C_{STDC}: *cost of to steam turbine driven compressor*
O_t: *opportunity cost of SMR*

✓ LCOE for Large Reactor and SMR

	Supported Case		Merchant Case	
Reactor Type	Large Reactor	SMR	Large Reactor	SMR
LCOE($/MWh)	55.0	59.1	96.1	96.3

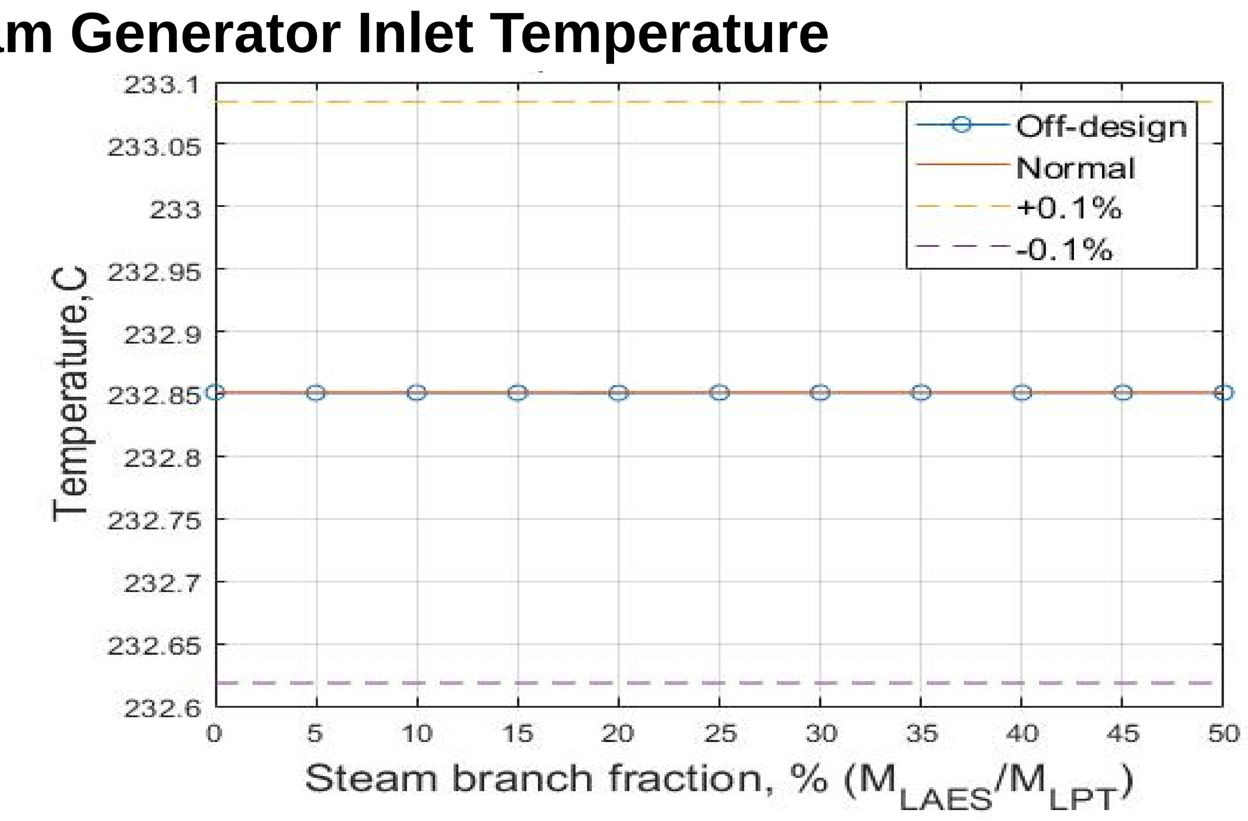
The opportunity cost of SMR follows the merchant case summarized in the table upward. Also the parameter for LCOE calculation are shown in the table below.

✓ Economic Parameter

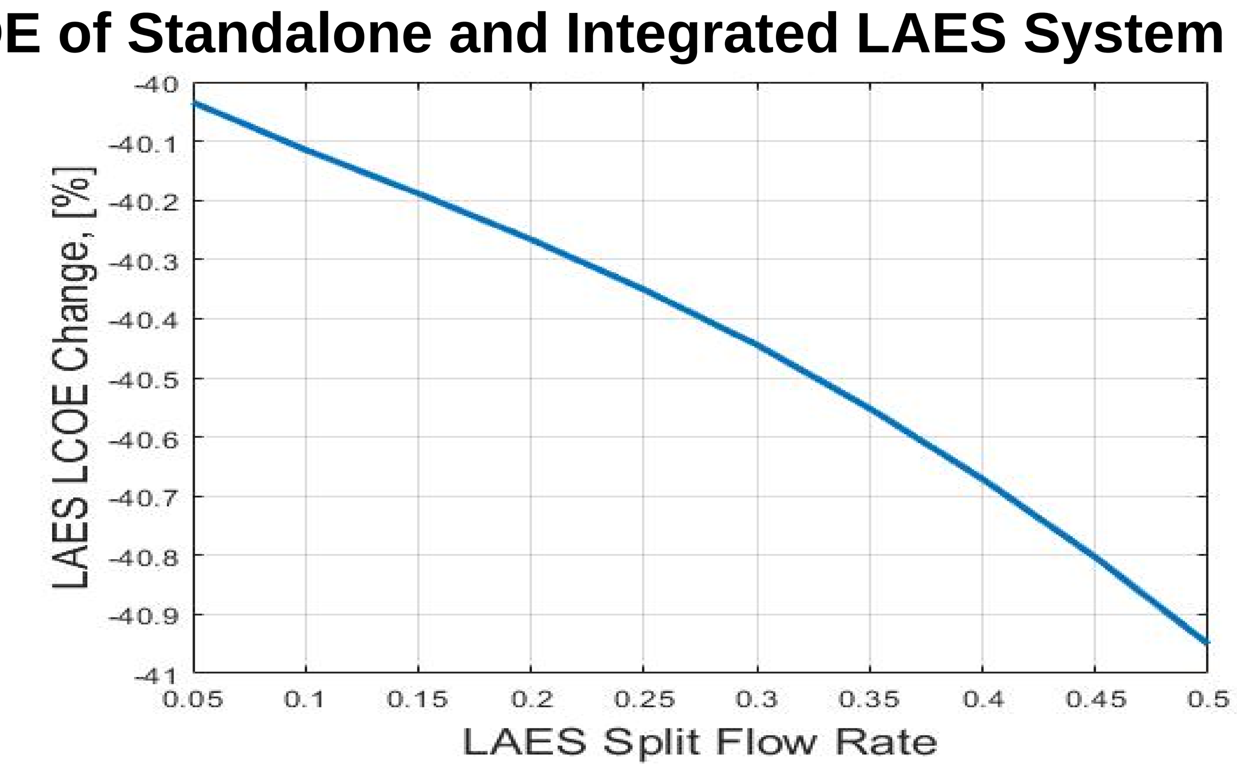
Parameter	Value
Operating year	60 year
Discount rate	1.2%
Construction year	2 year
Electricity price	120$/MWh
Charging time of LAES	10 hours
Discharging time of LAES	10 hours
Number of cycles in year	365

Results

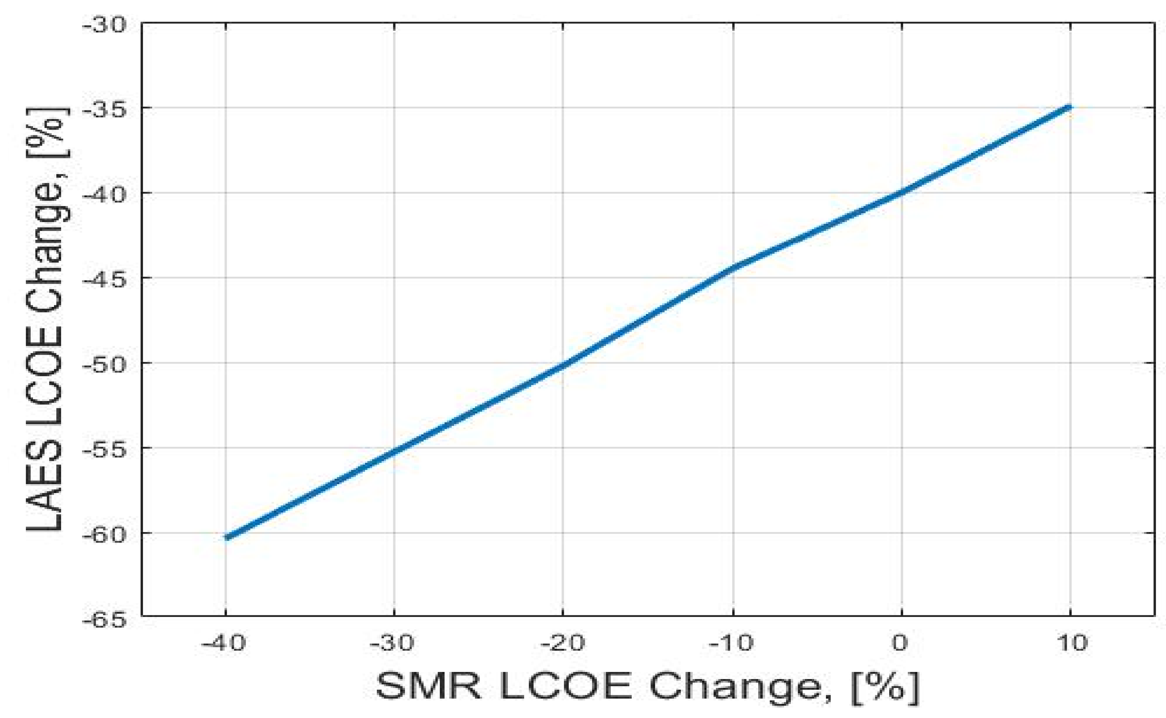
✓ Steam Generator Inlet Temperature



✓ LCOE of Standalone and Integrated LAES System



✓ Integrated System LCOE trend following change of SMR LCOE



(1) There is no substantial temperature change in the SMR steam generator inlet temperature due to steam bypassing to LAES.
(2) Although there is nearly 1% of difference in LCOE for the minimum split rate (0.05) and the maximum split rate (0.50). This will make SMR more flexible and economical while preserving economic performance.
(3) 40% decreased SMR LCOE case can reduce LAES LCOE by 60% compared to the standalone LAES system. This trend shows that further technical advancement and economical improvement in SMR can make LAES system more favorable.

Summary

1) When SMR and LAES systems were linked, there was **no considerable change** in **SMR's steam generator inlet temperature**.
2) There was **no significant change** in **the LCOE of NPP-LAES-linked system** according to the **steam split fraction**. NPP-LAES-integrated systems could operate **flexibly under various situations**.
3) The sensitivity of LCOE of the integrated system to the SMR's LCOE is shown that the **integrated system's LCOE decreases** with the **LCOE** of **SMR decrease**.