Preliminary economic analysis of Nuclear integrated Liquid Air Energy Storage System

Jung Hwan Park, Jeong Ik Lee

Dept. Nuclear & Quantum Eng., KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea

Introduction

- With increase portion of Renewable Energy Sources (RESs), the intermittency of RES causes issues regarding the stability of electric grid.
- Nuclear Power Plant (NPP) can be sensitive to these RES induced fluctuations because frequent use of control rod may cause xenon oscillation and accelerate component degradation.
- As a solution to this problem, nuclear integrated Liquid Air Energy Storage System (LAES) is proposed.
- LAES is one of the large-scale energy storage systems which storing energy by liquefying air. When electricity is oversupplied, air is compressed and liquefied. When additional electricity is needed, liquid air is evaporated and expanded to generate electricity.
- The integration is established by Steam Turbine-Driven-Compressor (STDC). The power of NPP is controlled by bypassing steam before Low Pressure Turbine (LPT) and the bypassed steam is used to operate STDC for transferring energy to LAES.

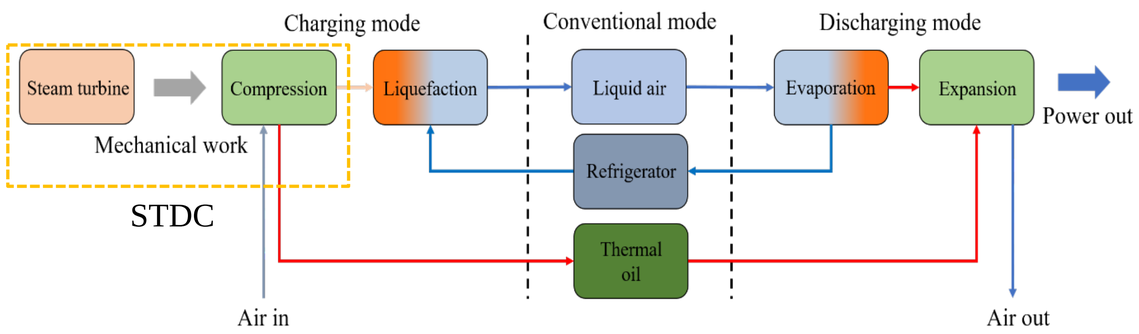

Fig. 1. Diagram of mechanically integrated LAES system with NPP

- Reported round-trip efficiency of integrated LAES is 53% and energy density is 125kWh/m^3.
- However, technical evaluations alone are not enough to further realize integration of LAES. In order to increase feasibility of integration, economic analysis is essential.
- Levelized Cost of Electricity (LCOE) is a typical economic value which measures the average net present cost of electricity generation for a power plant over its lifetime. By calculating LCOE, it can be evaluated that how economically LAES stores energy.
- The purpose of this study is preliminary economic analysis of proposed system by calculating LCOE with various economic parameters.

Methodology

- Definition of LCOE

$$LCOE_{typ} = \frac{\sum_{t=1}^{n} I_t + M_t + F_t}{\sum_{t=1}^{n} E_t} \qquad LCOE_{int} = \frac{\sum_{t=1}^{n} I_t + C_{opp} + M_t + O_t}{\sum_{t=1}^{n} E_t}$$

where I_t is capital cost, M_t is operation and maintenance cost, F_t is electricity cost, E_t is generated energy, C_{STDC} is cost of STDC, and O_t is opportunity cost of NPP.

- LCOE is calculated as the ratio between all the discounted costs over the lifetime by a discounted sum of the actual energy amount delivered.
- The LCOE of integrated LAES contains cost of STDC and opportunity cost of NPP. Since additional steam turbine is needed for mechanical integration, the cost of STDC should be included. The electricity cost should be replaced with the opportunity cost of NPP, since the net power of NPP is decreased during charging process.

- Cost categories of LCOE

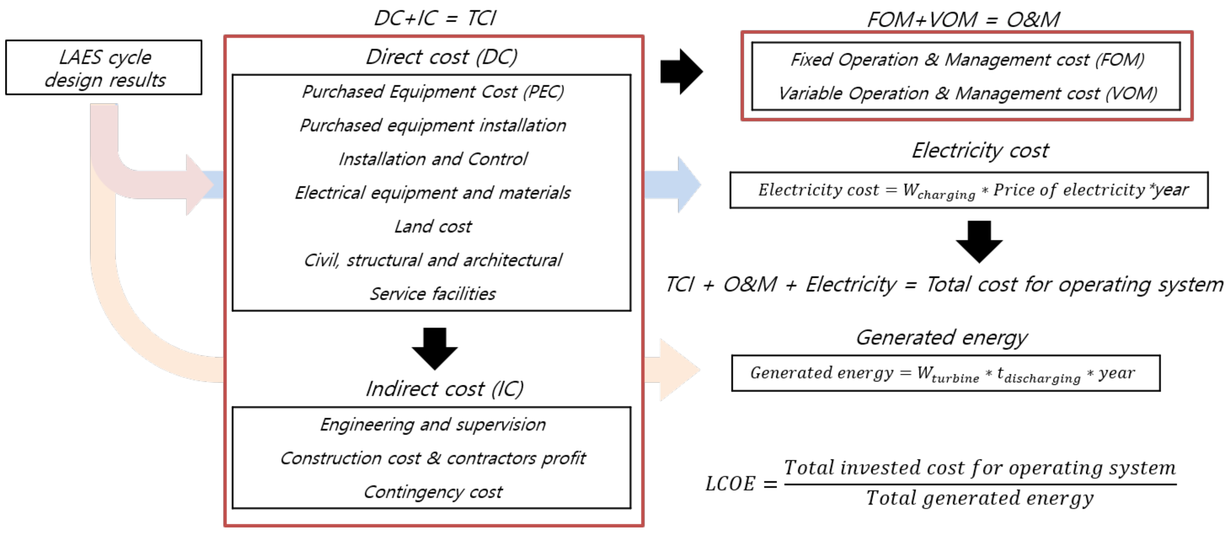

Fig. 2. Cost categories of LCOE

- LCOE is calculated with various sub-items: Total Capital Investment (TCI), O&M, and electricity price.
- To calculate equipment cost, previous economic research is referred and the cost is listed at Table 2. When calculating PEC, six-tenth law is applied.
- Rest of sub-items including DC, IC, and O&M are calculated by the ratio of its base and the ratio is listed at Table 2.

Table. 1 Referred PEC data

Account	Reference cost	Reference capacity
Steam turbine	10M$	15MW
Motor	0.75M$	15MW
Air compressor	10.95M$	23MW
Air turbine	99.39M$	193MW
Thermal oil	$6.1/kg	N/A
Methanol	$400/ton	N/A
Propane	$0.23/kg	N/A
Cold box	3.79M$	33MW$_t$
Air-oil HX	0.44M$	15.3MW$_t$
Evaporator	1.60M$	31.9MW$_t$
Oil tank	$423/m^3	2185m^3
Liquid air tank	$1548/m^3	3458m^3
Propane tank	$1326/m^3	5643m^3
Methanol tank	$572/m^3	1452m^3
Cryo-pump	0.4	0.84MW
Cryo-turbine	0.4	0.84MW
Air-recuperator	0.44	15.3MW$_t$

Table. 2 Cost assumption of LCOE

Account	Unit	Value	Base
Purchased equipment Installation	%	20	PEC
Piping	%	10	PEC
Instrumentation & control	%	7	PEC
Electrical equipment and materials	%	10	PEC
Land cost	%	10	PEC
Civil, structural and Architectural	%	30	PEC
Service facilities	%	30	PEC
Engineering and Supervision	%	9.8	DC
Construction cost & contractors profit	%	1.19	DC
Contingency cost	%	15.0	DC
Fixed O&M	%	1.29	FCI
Variable O&M	%	9.0	FOM

Results

- For calculating LCOE, the capacity of nuclear integrated LAES is referred from previous research. In order to conduct sensitivity analysis, the economic parameters are listed at Table 3.

Table 3. Specification of nuclear integrated LAES

Parameter	Value
Charging power	300MW
Charging time	8 hours
Discharging time	10 hours
Storage capacity	2.4GWh/day
Operating year	30 year
Discount rate	1~3%
Nuclear price	₩50~70/kWh
Number of cycles	100~365

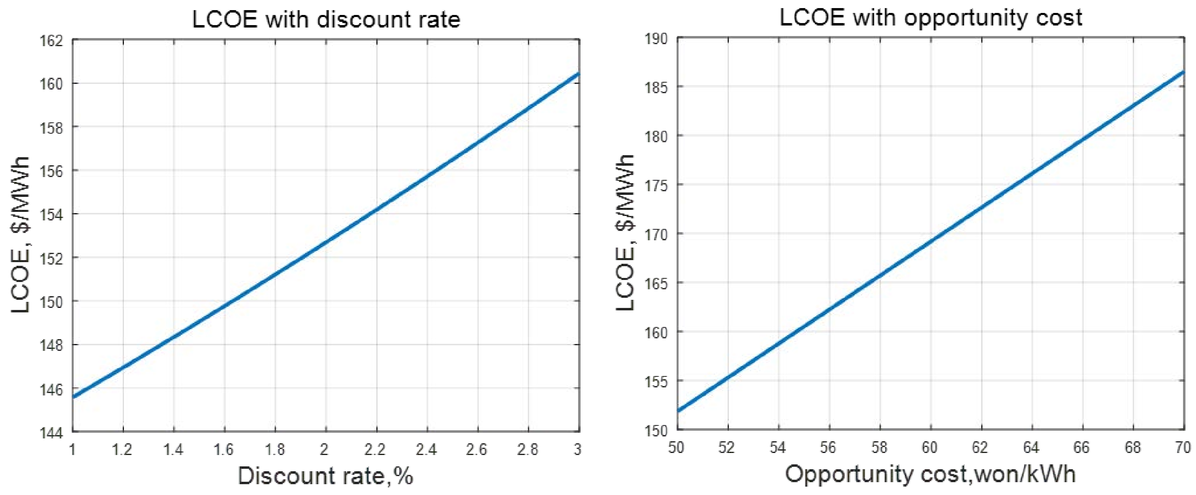

Fig. 3. LCOE with discount rate (left) and opportunity cost of NPP (right)

- Fig. 3 shows the sensitivity of LCOE with discount rate and opportunity cost of NPP.
- The discount rate converts the future value into Net Present Value (NPV). It means that high discount rate makes NPV low. Therefore, high discount rate causes high LCOE.
- Also, as the opportunity cost increases, LCOE linearly increases. This is because the LCOE includes opportunity cost rather than electricity price.

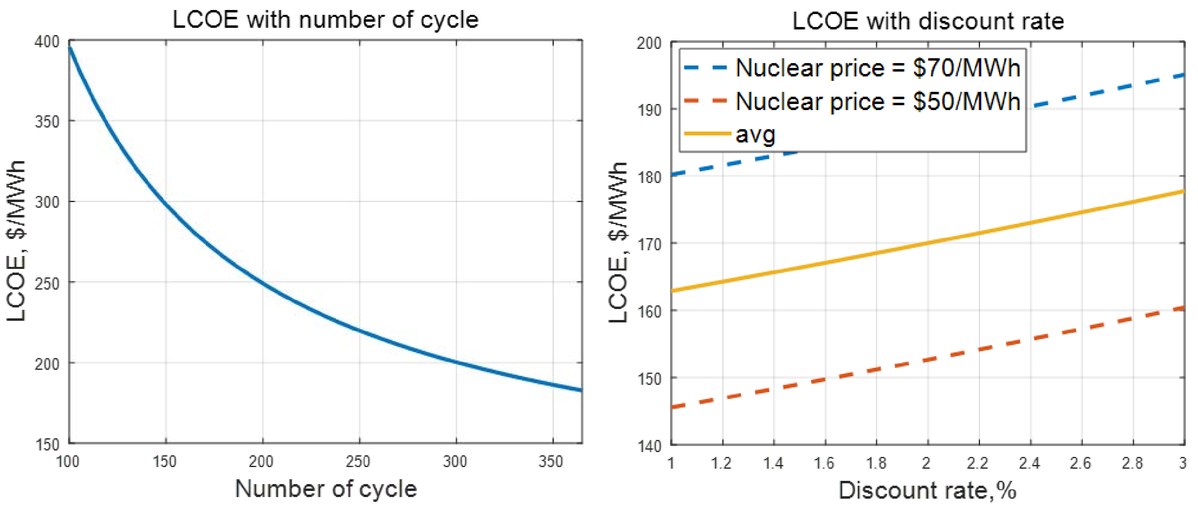

Fig. 4. LCOE with number of cycle at 1.5% discount rate (left) and the range of LCOE for one cycle per day operation (right)

- Fig. 4 shows the sensitivity of LCOE with number of cycles and the calculated range of LCOE for one cycle per day operation.
- As the number of cycles increases, LCOE steeply decreases. This is because the generated electricity increases exponentially while the invested cost is the same.
- From the sensitivity analysis, the range of LCOE is presented in the right side of Fig. 4. .
- Fig. 4 shows the range of LCOE with discount rate and nuclear price for a year while assuming charging and discharging processes occur daily. The range of LCOE is between $145/MWh and $190/MWh varying with discount rate and nuclear price.

Table 4. Calculated LCOE of nuclear integrated LAES

Parameter	Value
Charging power	300MW
Charging time	8 hours
Charging capacity	2.4GWh/day
Range of LCOE	$145/MWh~$190/MWh
Average LCOE	$167.5/MWh

Conclusion

- A preliminary economic analysis of nuclear integrated LAES is conducted in this study.
- To evaluate LCOE, the definition of LCOE for integrated system is newly proposed and various economic parameters are presented including TCI, DC, IC, and O&M.
- As a result of the sensitivity analysis, LCOE increases when discount rate increases which leads to reducing NPV and elevating opportunity cost.
- The range of LCOE with number of cycles per year is also presented.
- From the sensitivity analysis, the range of LCOE is located between $145/MWh and $195/MWh.
- However, this study contains many assumptions. Therefore, in the future, detailed economic indicators will be used to obtain LCOE with better accuracy.
- Furthermore, in order to demonstrate economic feasibility, a comparison with standalone LAES will be performed.

Acknowledgement

▣ This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government (Ministry of Science and ICT) (NRF-2019M2D2A1A02059823).