Potential of applying liquid air energy storage to large-scale nuclear power plants for the APR1400 application

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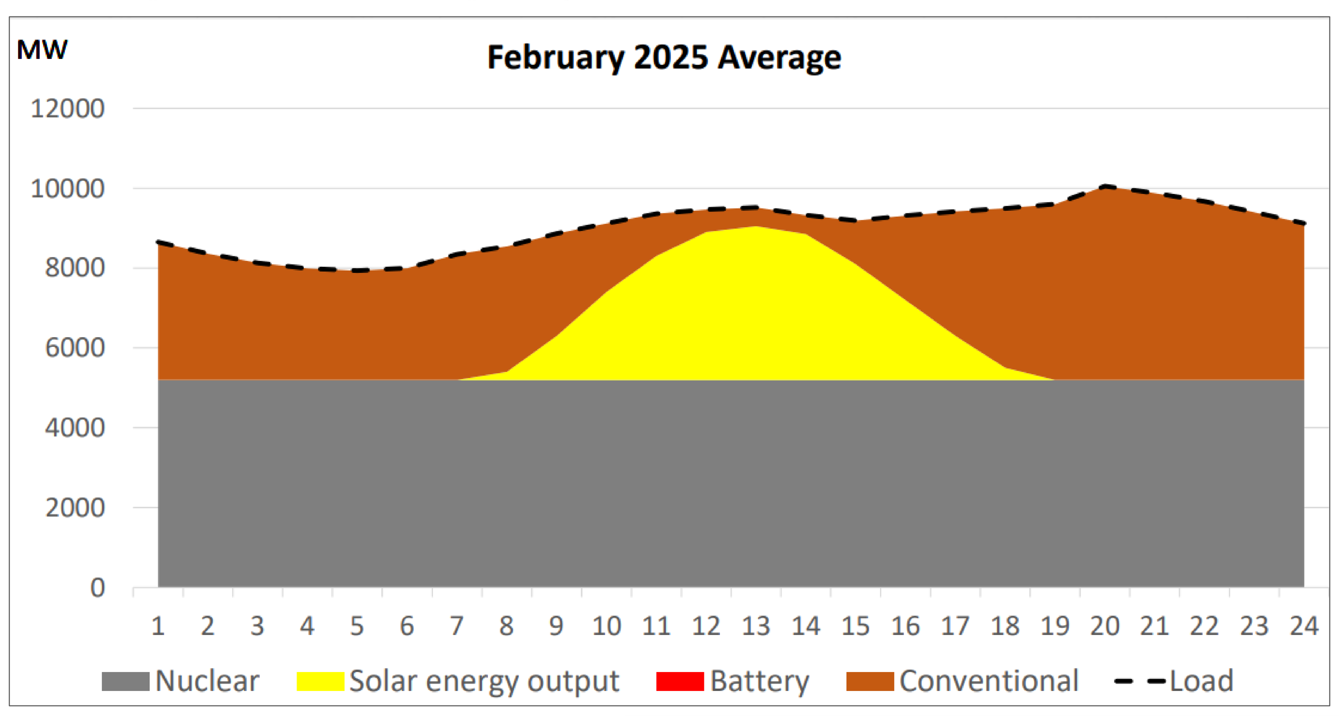
Background

▣ Due to the integration of renewables, grid dynamics will fluctuate more and require increased energy storage systems (ESS).

▣ As the need for base-load power lessens, nuclear power plants may need to load-follow or incorporate hybrid solutions using grid-scale ESS.

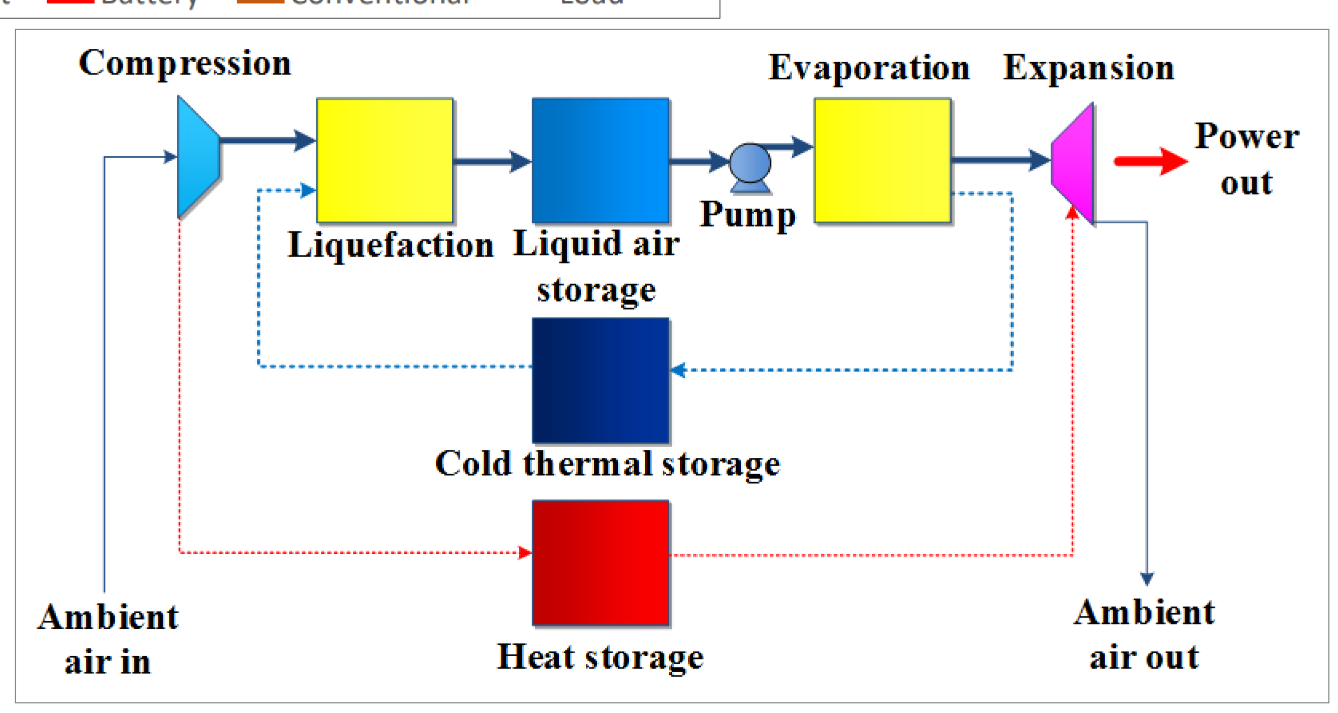
▣ The potential of adopting a concept of liquid air energy storage (LAES) is examined, especially in the context of the existing APR1400 system in the Middle East.

▣ LAES utilizes liquid air as a storage medium – it generates liquid air during the air liquefaction cycle and provides heat for turbine expansion during the discharge cycle.



← Fig. Winter 2025 scenario daily demand and production profile for Abu Dhabi, UAE [1]

Fig. Schematic of LAES with storage options [2] →



LAES Cycle Analysis

▣ The LAES cycle is modeled thermodynamically using NIST REFPROP referring to Morgan et al. [4].

▣ Charging cycle (blue): isothermal compressor (1-2), isenthalpic Joule-Thomson valve (3-4)

▣ Discharging cycle (red): isothermal turbine (2-1), pump work (4′-3)

▣ The theoretical round trip efficiency is calculated using $\chi = y\frac{(W_t - W_p)}{W_c}$.

▣ LAES can combine with APR1400 in two ways: using coolant outlet temperature at 43°C (option 1) or steam bypass valve to store heat at 285°C (option 2). Option 1 becomes advantageous in the Middle Eastern climate.

▣ Round trip efficiency increases as pressure ratio increases, and option 1 brings up to 2% improved performance for ESS and for option 2, 12%.

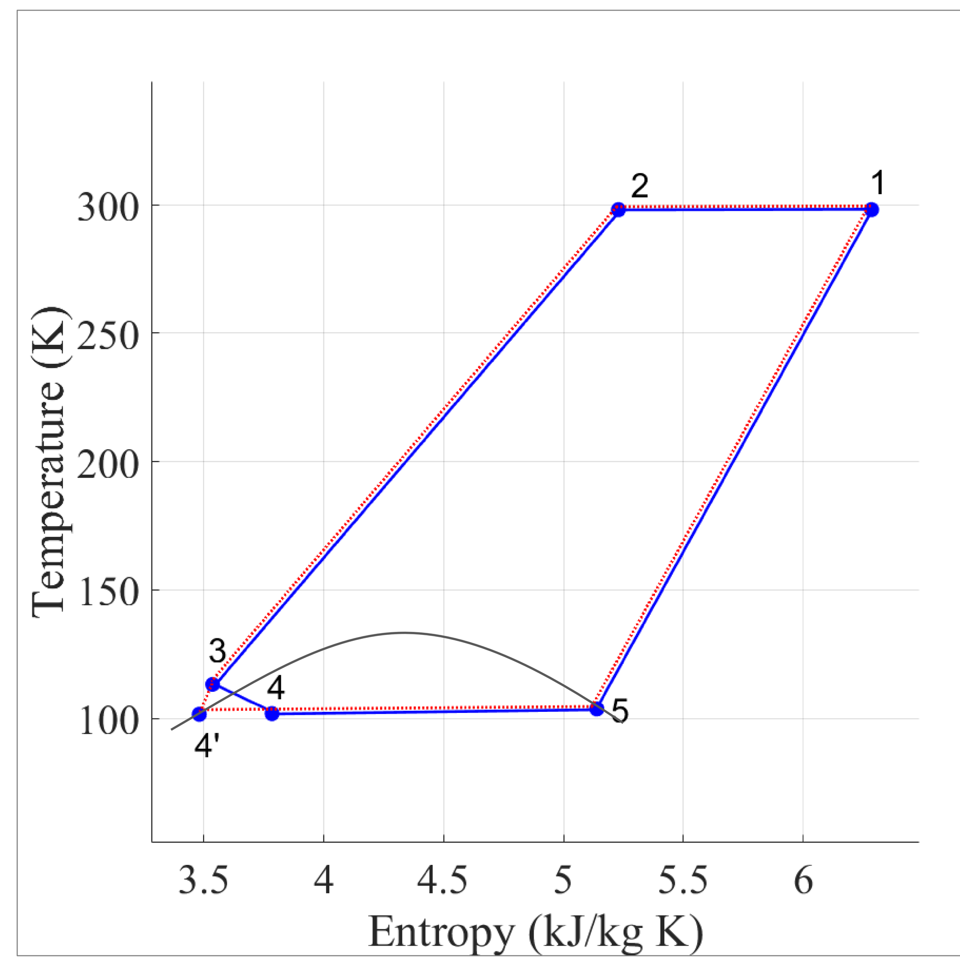


Fig. T-s diagram of the LAES cycle marked in blue (CCW charging cycle) and red (CW discharging cycle)

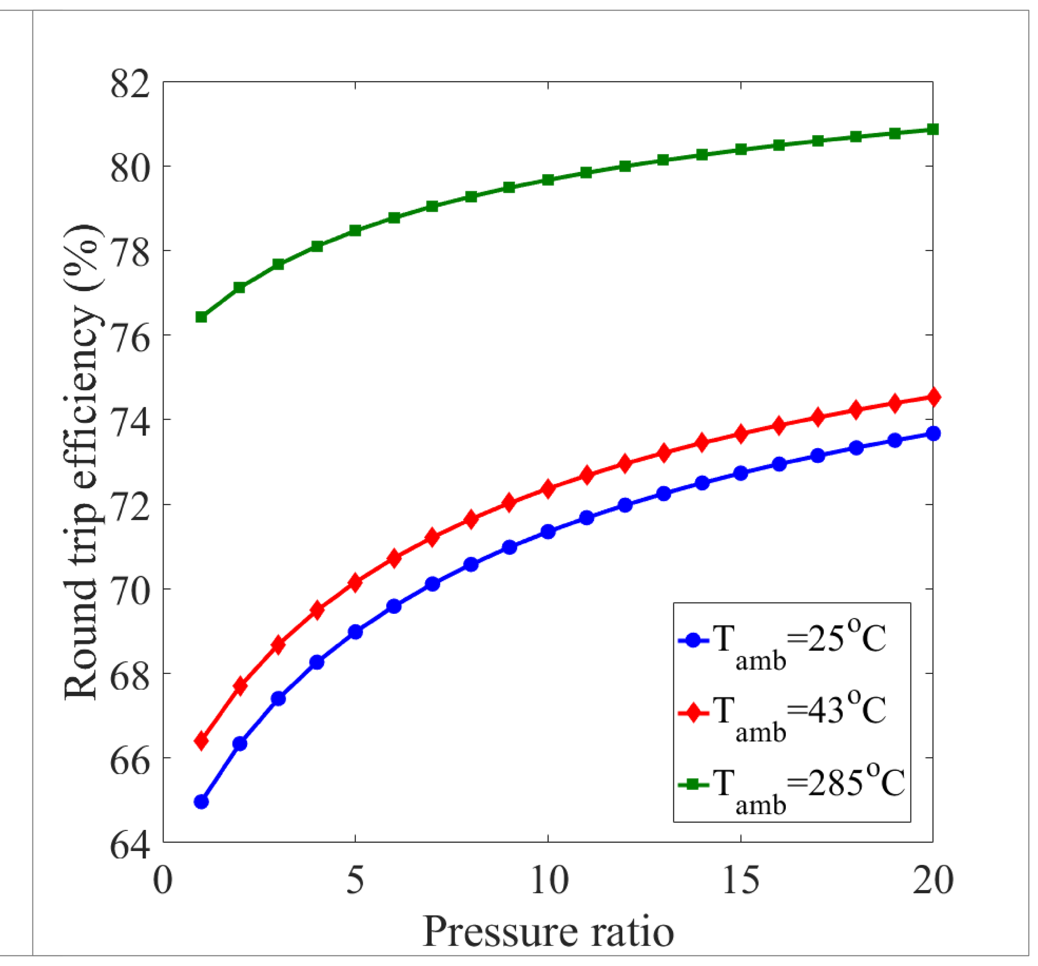


Fig. Graph of round trip efficiency vs. pressure ratio with respect to three different ambient temperature options

Advantages of Liquid Air Energy Storage (LAES)

▣ Does not suffer from **geological restrictions** which other large-scale energy storage systems such as pumped hydropower storage (PHS) and compressed air energy storage (CAES) have

▣ Energy density for LAES is **4-6 times** higher, and its specific energy is **3-7 times** higher than that of CAES

▣ Minimal daily self-discharge (0.05% by volume per day)

▣ Round-trip efficiency (%): 55-80+ (LAES), 70-80 (PHS), 40-70 (CAES)

▣ Planned for construction of Highview Power Storage GigaPlant with capacity of 200MW/1.2GWh

*Reference: Luo et al. (2015)

Conclusions

▣ Nuclear power plants may need to adapt to the grid integration of renewables, especially in regions with high solar penetration.

▣ LAES has the potential to outperform conventional grid-level ESS such as PHS and CAES, in terms of energy density, round trip efficiency, and geological restrictions.

▣ LAES can be further improved by combining with conventional large scale NPP such as APR1400, by increasing the ambient temperature using coolant outlet temperature or steam bypass valve.

▣ Due to safety issues and design constraints of the APR1400, realistic combinations should be further investigated.

References

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