Performance of an advanced liquid air energy storage system based on cold energy utilization at LNG receiving station

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Abstract

The integration of liquid air energy storage (LAES) with liquefied natural gas (LNG) cold energy utilization not only facilitates the efficient utilization of LNG cold energy but also enhances the energy efficiency of the LAES system. However, the desynchronization of the regasification process at the LNG receiving station and the cold energy utilization process results in an imbalance between the supply and demand of LNG cold energy, thereby limiting the scale and efficiency of cold energy utilization. In this study, we propose a system to stabilize the utilization of LNG cold energy. The system employs the intermediate storage unit to preserve the cold energy from the LNG, which is subsequently channeled to the LAES. We conduct detailed calculations and discussions on the system using a developed composite thermodynamic model.

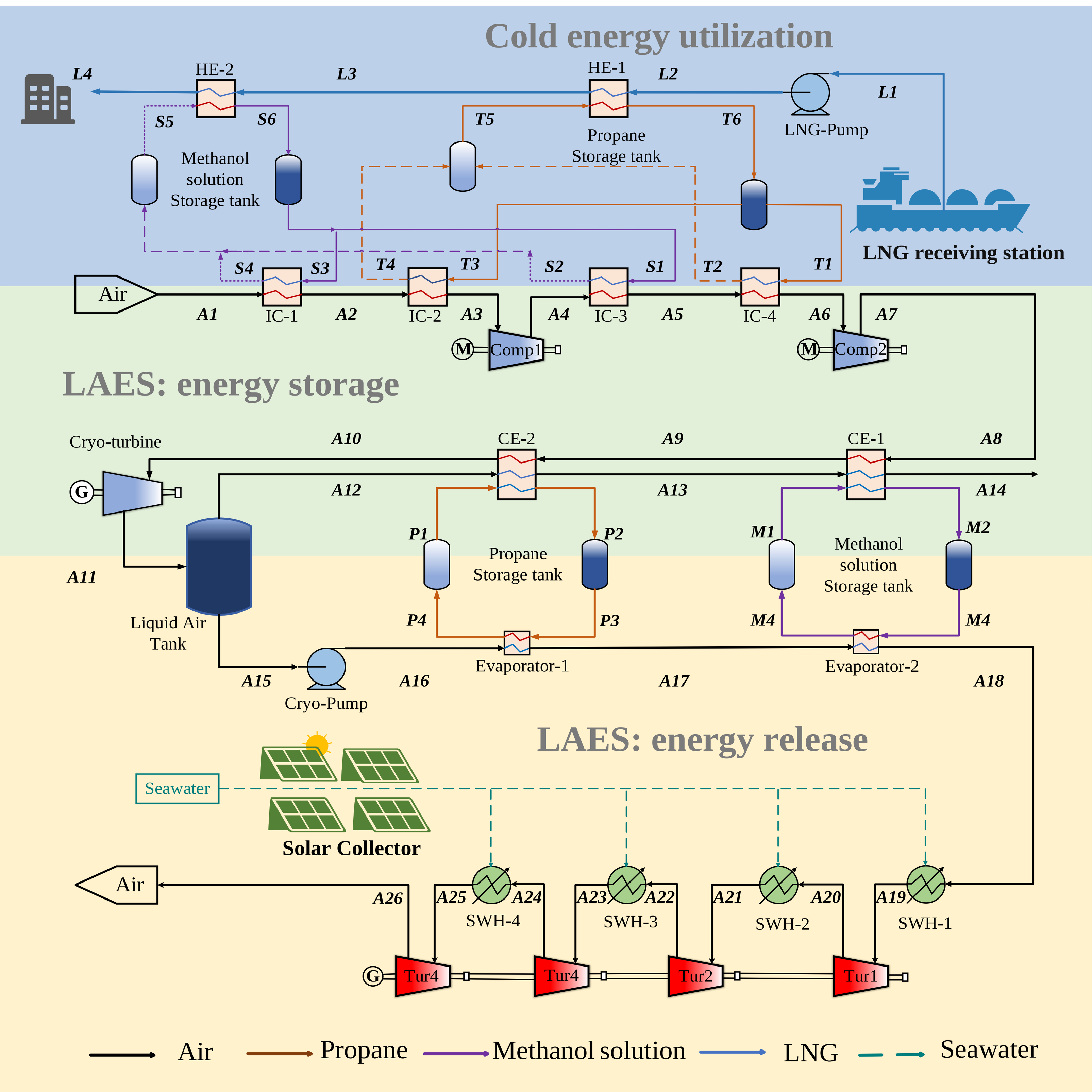


Fig 1. Conceptual design of the system.

LNG cold energy utilization unit

- A methanol solution is employed to store the low-grade cold energy of LNG.
- The propane is used for high-grade cold energy storage.
- Concurrently, an accumulator is utilized to integrate the cold energy, mitigate the fluctuation of the cold energy supply at the LNG receiving station, and stabilize the cold energy output to the downstream LAES system.

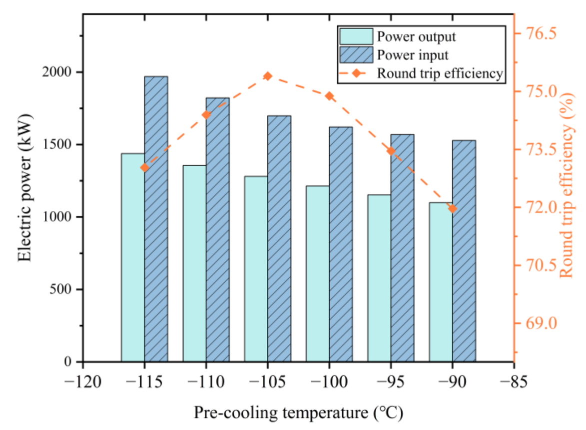
LAES energy storage unit

- During the storage phase, the air undergoes pre-cooling and stage-wise compression (A3-A4, A6-A7).
- The high-pressure air is cooled and liquefied by CE-1 and CE-2.
- The liquid high-pressure air is expanded to atmospheric pressure by a cryogenic turbine before being stored in the liquid air storage tank.

LAES energy release unit

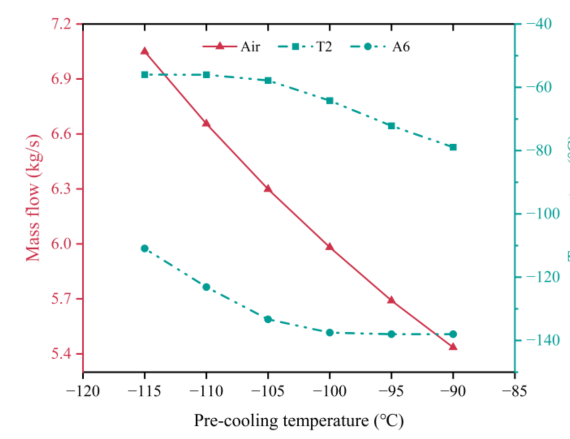
- The liquid air is pressurized by a cryogenic pump.
- The high-pressure liquid air is vaporized by an evaporator to recover the cold energy.
- The vaporized high-pressure air is heated by 80℃ hot water between stages and then enters the expander to perform work and output peak power.

Effect of air pre-cooling temperature



- Both the input and output electrical energy of the system gradually decrease.
- The round-trip efficiency of the system initially increases and subsequently decreases.
- At the pre-cooling temperature of -105°C, the round-trip efficiency attains its maximum value of 75.40%.

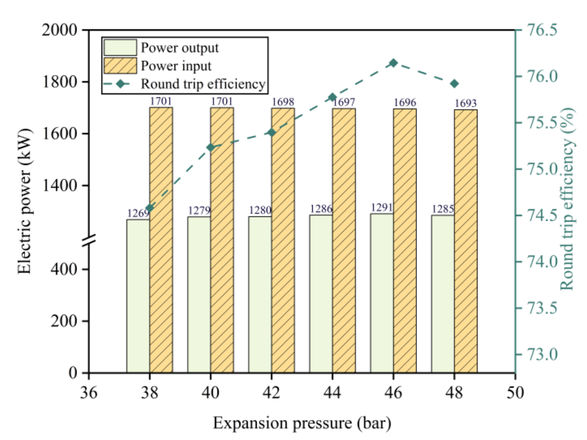
Fig 2. Influence of pre-cooling temperature on the LNG-LAES performance



- The cold fluid outlet temperature in IC-4 diminishes, leading to a reduction in cold energy utilization.
- The mass flow rate of air in the LAES system decreases.
- The air outlet temperature (A6) in IC-4 decreases and then stabilizes.

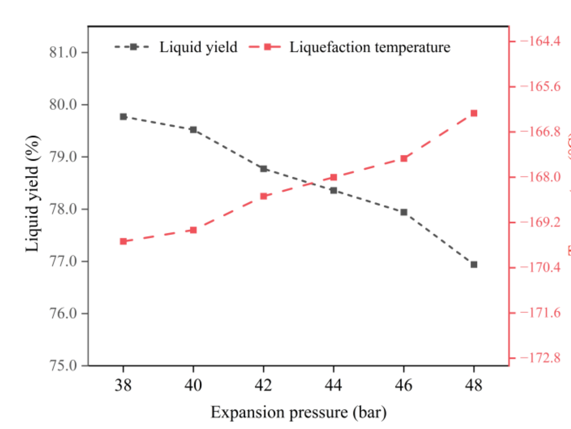
Fig 3. Influence of pre-cooling temperature on air flow and cold energy utilization.

Effect of air expansion pressure



- When the expansion pressure rises from 38 bar to 48 bar, the system's efficiency initially increases, reaching a peak of 76.15% at 46 bar, before subsequently decreasing.
- The system's input power steadily declines, while its output power first increases, peaking at 1291.14 kW at 46 bar, before decreasing.

Fig 4. Influence of expansion pressure on the LNG-LAES performance.



- The increase in expansion pressure results in a higher liquefaction temperature (T_{A10}) and a reduction in the amount of liquid air produced. .
- The low liquefaction rate reduces the total amount of working fluid, leading to a decrease in the output electrical energy.

Fig 5. Liquid yield and liquefaction temperature of the system at different expansion pressures.

Process Calculation

■ Assumptions

(1) The air is assumed to be pure and uncontaminated.

(2) The state parameters of all the fluids are based on the Peng-Robinson.

■ The round-trip efficiency of this system is defined as follows:

$$\eta_{RT} = \frac{8\times(\sum_{i=1}^{4} W_{Tur,i} - W_{Cryo-Pump} - W_{LNG-Pump})}{8\times(\sum_{j=1}^{2} W_{Comp,j} - W_{Cryo-Tur}) + 16\times W_{LNG-Pump}}$$

■ The liquid yield, Y, is defined as the ratio of liquid air flow to the liquid air storage tank:

$$Y = \frac{m_L}{m_c}$$

■ Basic parameters

- LNG mass flow: 1 kg/s
- LNG inlet pressure: 1.3 bar
- Charging time: 8 h
- Discharging time: 8 h
- Natural gas outlet pressure: 70.0 bar
- Natural gas outlet temperature: 15 ℃
- The adiabatic efficiency of compressor: 85%
- The adiabatic efficiency of pump: 75%
- The adiabatic efficiency of expander: 85%

Conclusion

- ☐ This study proposes a coupled system that integrates LNG cold energy using a two-stage cold storage device.
- ☐ This arrangement allows the LAES to indirectly utilize the cold energy and achieve operation cycle matching.
- ☐ It is observed that the system's round-trip efficiency initially increases and then decreases with the rise in air pre-cooling temperature and expansion pressure.
- ☐ At the air pre-cooling temperature of -105 °C and expansion pressure of 46 bar, the system achieves a maximum round-trip efficiency of 76.15% and an output of 1,291.14 kW.