Theoretical investigation of a closed liquid CO_2 energy storage system

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Introduction

In order to overcome the disadvantages of uncertainty, randomness and intermittency brought by wind and solar energy, different energy storage systems were proposed. Liquid air energy storage is an important technology in solving the grid connection problem of large-scale renewable energy. However, the production of liquid air needs a cryogenic liquefaction technology, which has a high facility cost and cold loss. Therefore a closed hybrid wind-solar-liquid CO_2 energy storage (WS-LCES) system was proposed. In the WS-LCES system, wind power was used to liquefy CO_2 and the CO_2 was stored in liquid phase with different pressures and temperatures at both energy storage and release stages. Also, the solar power was stored to increase the cycle efficiency. The system has a large storage capacity and no geographic constraints.

Objectives

- Develop a novel hybrid wind-solar-liquid CO_2 energy storage (WS-LCES) system for grid-scale utilization to avoid the disadvantages of current technology.
- Store unstable wind and solar power simultaneously for a stable output of electric energy and hot water.

Conclusions

- A novel grid-scale closed WS-LCES system without geographic constraints was proposed.
- The ESE, η_{ex} and EPV can reach 104.5%, 58.64% and 19.31 kWh/m³ under the design conditions, respectively.
- 10490 kW electric power and 521 t/h hot water (60 ℃) can be achieved within one energy storage cycle.
- The increase of compressor adiabatic efficiency and turbine inlet temperature both have beneficial effects.

Thermodynamic model

The WS-LCES system is mainly composed of four units:

- Wind power storage unit
- Solar heat storage unit
- Turbo-generation unit
- CO_2 reliquefaction unit

Energy storage process:

- ✓ Produce high pressure CO_2 and transfer compression heat into hot water.
- ✓ High pressure CO_2 is liquefied and stored.
- ✓ Low temperature thermal oil is heated by the solar thermal collector.

Energy release process:

- ✓ Liquid CO_2 is pumped to a high pressure and preheated by thermal oil .
- ✓ Gaseous CO_2 expands to generate power and releases waste heat to hot water.
- ✓ Low pressure CO_2 was condensed again and stored.

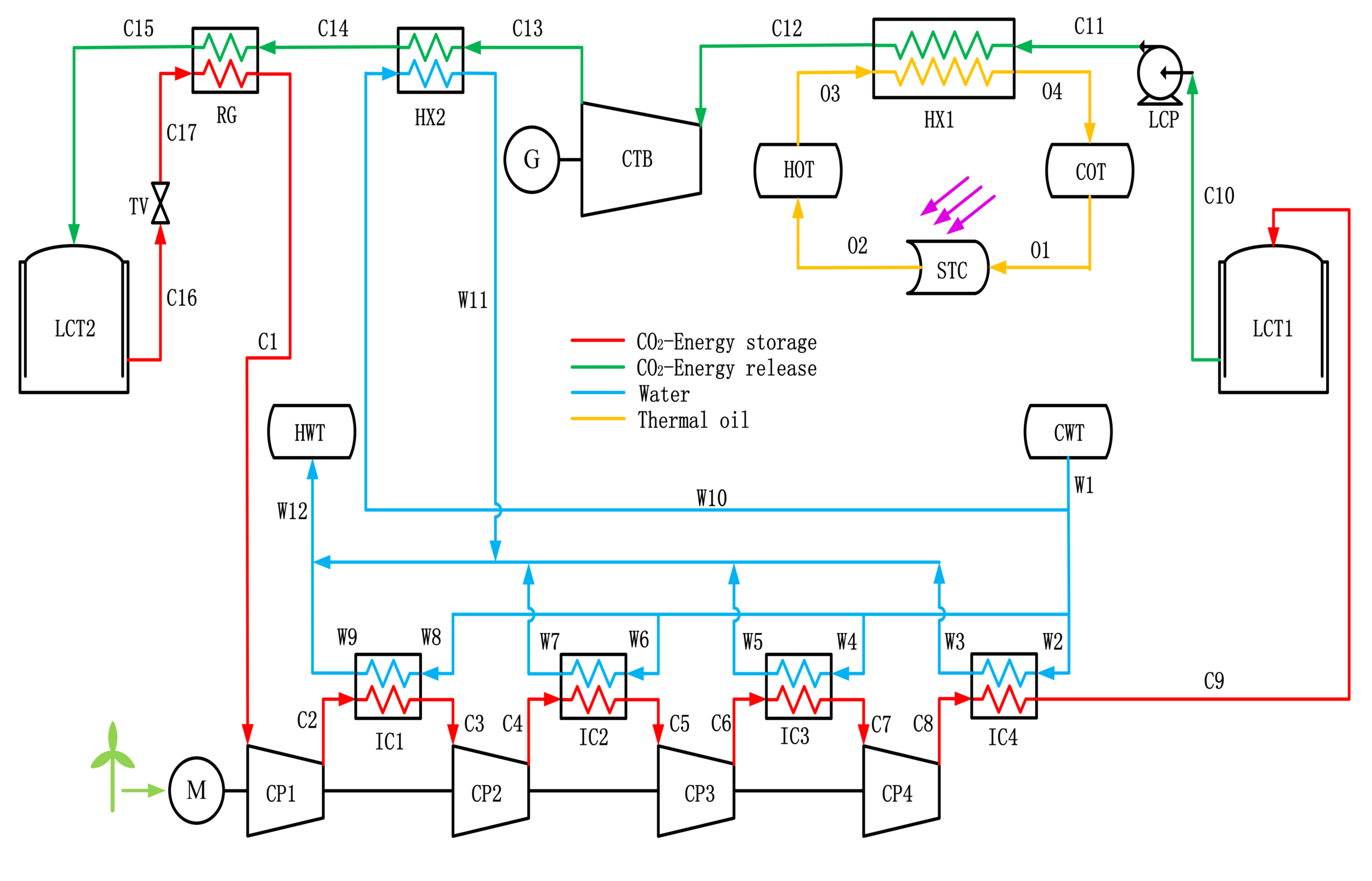

Figure 1. Schematic diagram of the proposed WS-LCES system

Simulation Results

Simulation results of the proposed WS-LCES system

Term	Unit	Value
Power of CP1-CP4	kW	9370
Power of LCP	kW	695
Power of CTB	kW	10490
Net output power	kW	9790
Heat absorption of STC	kW	22300
Mass flow of CO_2	kg/h	196300
Mass flow of hot water (60℃)	t/h	521
ESE	%	104.5
η_{ex}	%	58.64
EPV	kWh/m³	19.31

- Therminol 66 was chosen for solar energy storage medium.
- The isentropic efficiency of the turbine and pump were set as 85% and 80%, respectively.
- 60 ℃ is the recommended temperature for hot water supply in China.
- The outlet pressure of CO_2 after expansion is 8 bar.
- The η_{ex} of WS-LCES is higher than that of existing literature.

Parametric analysis

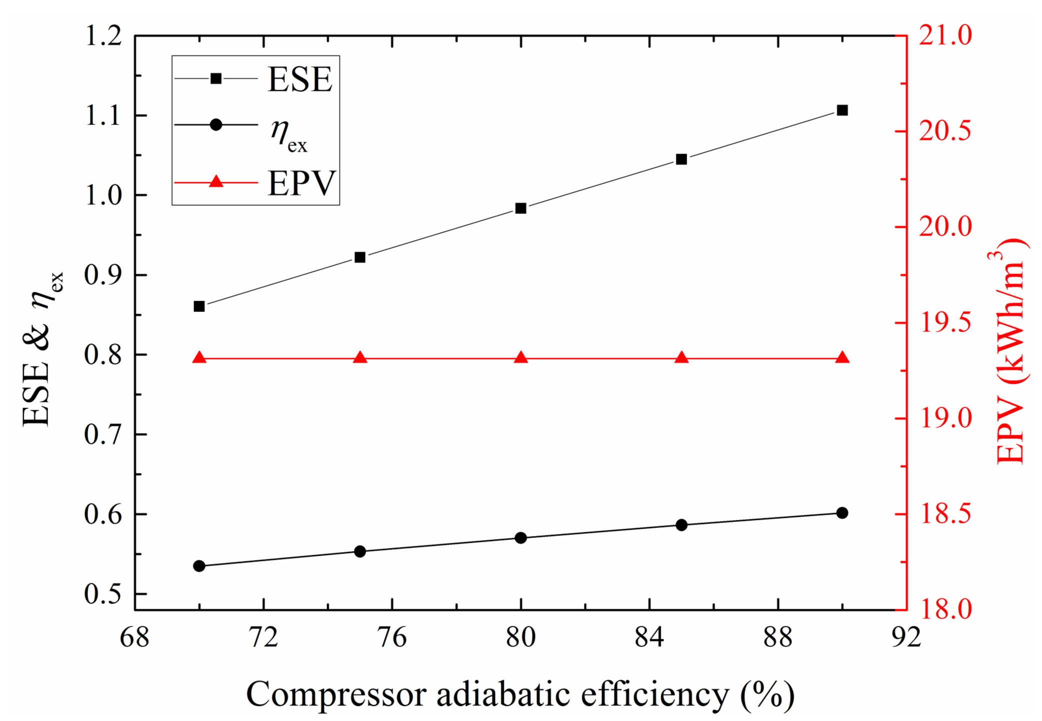

Figure 2. Effect of compressor adiabatic efficiency

- ESE and η_{ex} both increase with the increasing compressor adiabatic efficiency, for a lower power consumption of compressor was needed under a higher adiabatic efficiency.
- Although a high adiabatic efficiency is beneficial, it is constrained by available technology.

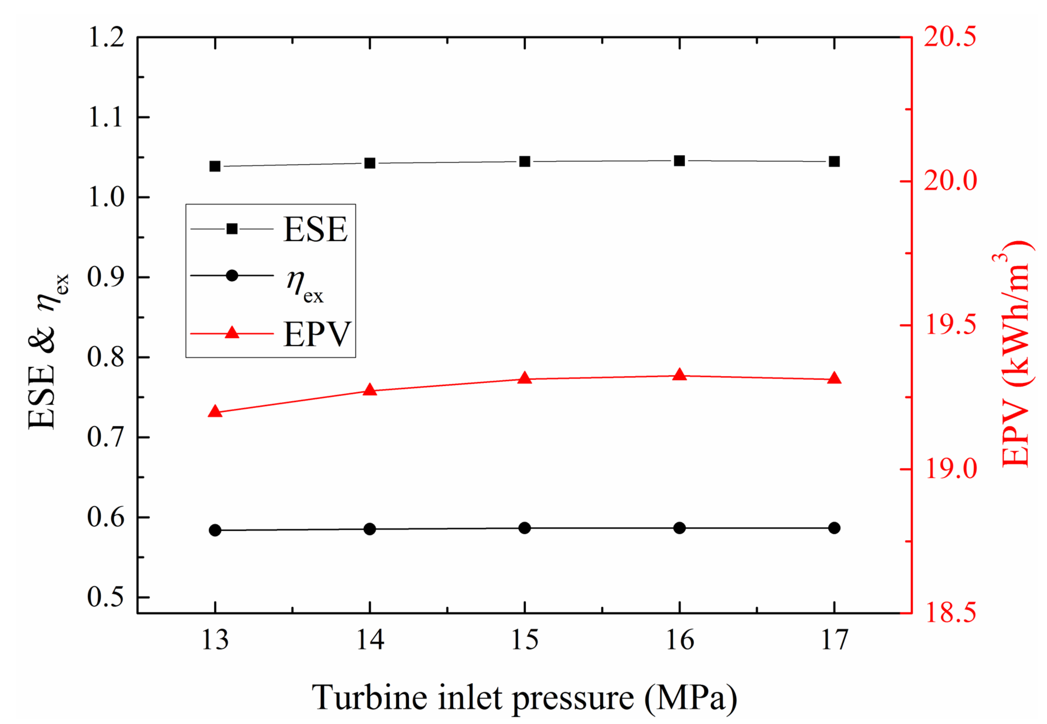

Figure 3. Effect of CO_2 turbine inlet pressure

- As the power of CO_2 turbine and liquid CO_2 pump both increase with the increasing turbine inlet pressure, all the three indexes have little change.
- However, the equipment cost increases significantly with the increasing pressure. Thus the optimum turbine inlet pressure should not be too high.

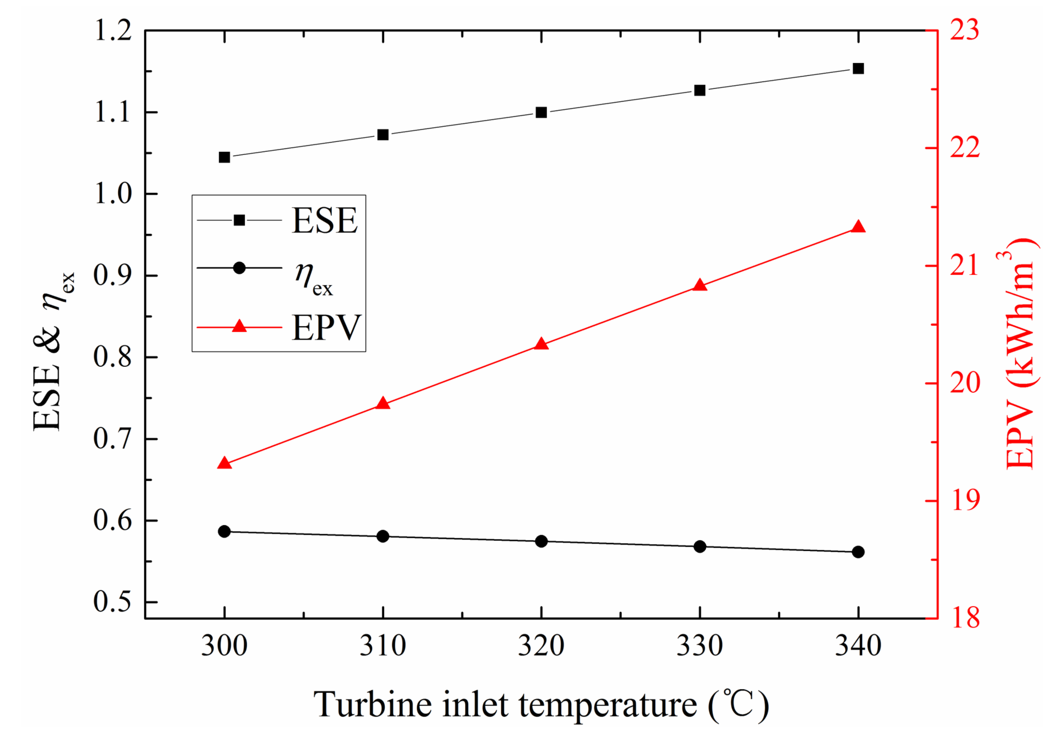

Figure 4. Effect of CO_2 turbine inlet temperature

- Both the ESE and EPV increase with the CO_2 turbine inlet temperature as a result of a larger output power of CO_2 turbine. But a greater heat absorption of solar thermal collector leads to the decrease of η_{ex}.
- The optimum CO_2 turbine inlet temperature is chosen by the tradeoff between the ESE and η_{ex}.