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Discharge Transient Simulation of Compressed CO_2 Energy Storage

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1. Introduction

Nowadays, the demand for variable renewable energy source is rising to reduce carbon emission. However, the variable renewable energy sources such as solar power and wind power have inherently intermittency problem. In contrast, a large-scale power plant typically operates at constant power. Most of the nuclear power plants have operated at constant power, but the load following capability is becoming more and more important to match the intermittency in variable renewable energy sources.

Instead of changing the reactor power, the previous works suggest to use various energy storage systems with the nuclear power plant. Especially, thermodynamic energy storage options can operate in a large-scale, and can be retrofitted to a nuclear power plant as shown in Fig 1. [1, 2, 3].

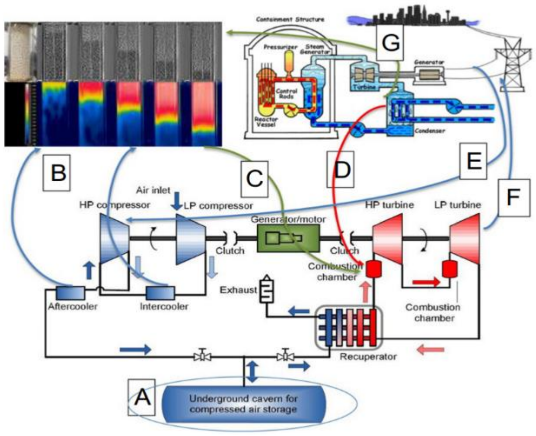

Fig. 1. Integration of energy storage system to nuclear power plant [3]

Among various storage options, compressed CO_2 energy storage (CCES) is gaining popularity due to its large capacity and fast response while achieving competitive round-trip efficiency. However, most of the previous studies mainly focused on the system design of CCES. Since CCES is not likely to operate at steady state, a dynamic simulation is conducted for the discharge process of CCES with GAMMA+ code in this paper [4].

2. Methods and Results

In short, the charging process (compression process to high pressure tank) occurs to store energy when electricity supply surpasses the power demand, and the discharge process (expansion process to low pressure tank) occurs when the power demand is more than the supply. Therefore, the simplest form of CCES consists of compressor, turbine, high and low pressure tanks for charging and discharging processes. Additionally, it is possible to add thermal energy storage (TES) for improved energy density and round trip efficiency as shown in Fig 2.

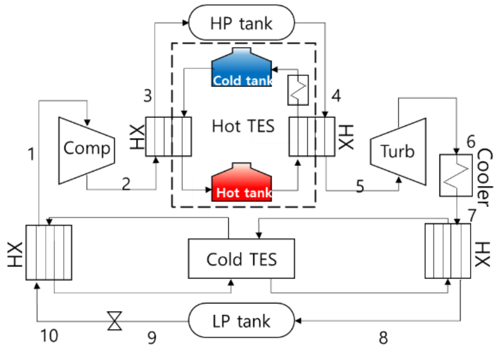

Fig. 2. System layout of designed CCES

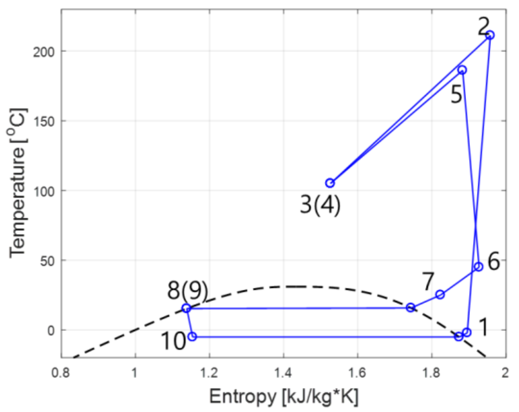

Fig. 3. T-S diagram for designed CCES

Table. 1. Summary of design point thermodynamic variables

	T [℃]	P[MPa]		T [℃]	P[MPa]
1	-2.18	3	6	44.9	5.22
2	211.1	30	7	25	5.17
3	105	29.7	8	15.25	5.11
4	105	29.7	9	15.25	5.11
5	186.1	29.4	10	-5.18	3.03

The proposed CCES is equipped with Hot TES and cold TES utilizing phase change material for heat transfer (state 7-8, 10-1). The T-S diagram and thermodynamic variables are presented in Fig. 3 and Table 1. The mass flow rate is 126.7kg/s and the round trip efficiency is 53.3% at the designed point. In this research, discharging process (state 4-8) were simulated with GAMMA+ code. Particularly, the effect of high pressure tank volume was investigated. For the simulation, turbine rotational speed and turbine inlet temperature were fixed at constant values.

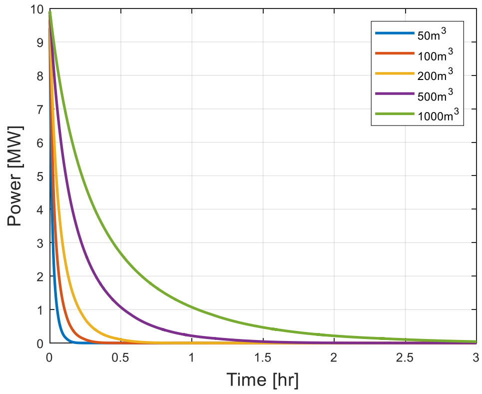

Fig. 4. Discharging power with respect to high pressure tank volume

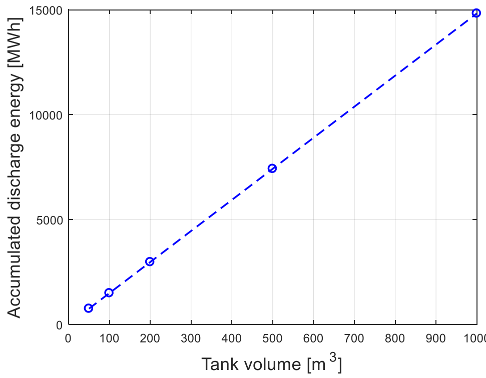

Fig. 5. Accumulated discharging energy with respect to high pressure tank volume

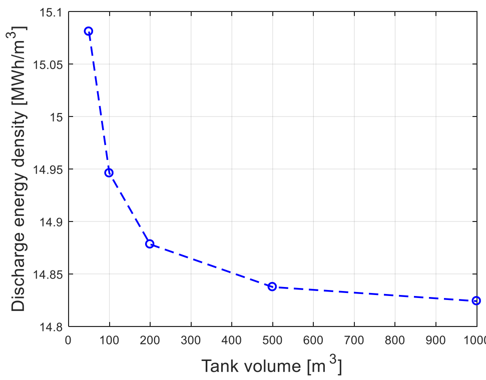

Fig. 6. Discharging energy density with respect to high pressure tank volume

It is natural that a large volume of pressure tank can store a large volume of CO_2, so it can produce more energy over a long period of time. This is confirmed in Fig. 4. Regardless of the tank volume, all cases started with power of 10MW, but the power reduction profiles become different as time passes. It is straightforward that the power reduction will be slower if the tank volume is larger.

The total energy generated over the discharging process is presented in Fig 5. The accumulated discharge energy increases linearly with respect to the tank volume. Discharge energy density can be derived when the accumulated energy is divided by the tank volume. Fig. 6 shows that there is only minor variation in terms of energy density.

3. Summary and Conclusions

A thermodynamic energy storage system has a potential to be applied to a large-scale power plant such as nuclear power plant to improve the load following capability. As one of the potential candidates for such system, Compressed CO_2 Energy storage (CCES) is being researched. However, most of the previous research works focused on the optimum design while assuming steady state operation throughout charging and discharging.

In this study, the dynamic characteristics of CCES under off-design operation is investigated, since CCES can never operate at steady-state. The dynamic simulation of CCES was conducted for discharging process first for various high pressure tank volumes. The results show that the total discharge energy is linearly proportional to the tank volume, with slight difference in energy densities.

ACKNOWLEDGEMENTS

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