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Analysis of changes in LAES round trip efficiency according to the number of turbines and compressors

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1. Introduction

The significant increase of variable renewable energy sources is expected to cause stability issue of electric grid due to the intermittency of variable renewable energy. The challenge of intermittency is making energy storage system more important. Among the grid-scale energy storage systems, a Liquid Air Energy Storage System (LAES) is becoming increasingly popular due to its high energy density, long expected service life time, less operation and maintenance cost, and reduced geographical constraint.

LAES is a technology that stores energy in the form of liquid air. Fig. 1 illustrates the charging and discharging process of LAES. During off-peak times, air is compressed by air compressor and liquefied by cold energy storage system. When additional electricity is needed, liquid air is evaporated and expanded in air turbine to produce electricity. Since the energy is stored in liquid form, the volume of thermal fluid can be greatly reduced and the energy density is significantly increased. So far, there have been many studies on thermodynamic and economic analyses of LAES [1]. LAES has five common stages: compression, liquefaction, storing, evaporation, and expansion, as shown in Fig. 1.

In this study the effect of multiple turbines and compressor on the round trip efficiency of LAES will be thermodynamically studied.

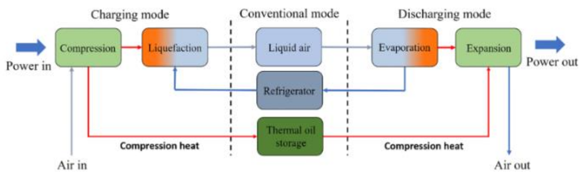

Fig. 1. LAES flow diagram

2. Methods

2.1 system description

Fig. 2 shows a schematic diagram of the proposed nuclear integrated Liquid Air Energy Storage System (LAES) which is composed of nuclear steam cycle and LAES cycle. The system comprises three main regions: Nuclear steam cycle, LAES charging cycle, and LAES discharging cycle.

When electricity is inexpensive or power is excessively supplied to grid, several air compressors are operated to compress purified air. The compressed air reaches high temperature because the air is compressed to nearly 180 bar. A thermal storage system was adopted to recover this compressed heat. After the air is compressed, the air is further cooled down to about −196 ℃ by heat exchangers, and cold exergy is stored in cold storage fluids. After liquefaction process, air is stored in the insulated liquid air tank. During the discharging mode, the cycle operates opposite to the charging mode. Liquid air is evaporated by pumping up to 120 bar and storing the cold exergy in the cold storage fluids. After the air evaporates, it is heated by stored thermal energy and expanded to ambient pressure by several air turbine stages. During the expansion phase, external heat sources such as LNG (liquefied natural gas) and waste heat and compressed heat stored in the heat oil tank can be used [2,3].

2.2 Round-Trip efficiency

The round-trip efficiency is defined as the ratio of the energy recovered from the energy storage device and the energy put into the device. So LAES round-trip efficiency can be defined as the power output in the discharging cycle divided by the power input in the charging cycle. This represents the apparent efficiency of the system [4]. Therefore, the higher the Round-trip efficiency is, the lower the loss in the energy storage.

$$\eta_{RTE} = \frac{W_{discharging}}{W_{charging}} \quad (1)$$

where η_{RTE} is round trip efficiency, $W_{discharging}$ is discharging work, and $W_{charging}$ is charging work.

Table 1 represents the design parameters for the system.

Table 1: Design parameters

Parameters	Value
Turbine efficiency	90%
Compressor efficiency	85%
Cryo-turbine efficiency	80%
Cryo-pump efficiency	80%
Pinch temperature	5K
Hot side pressure-drop	3% of inlet pressure
Cold side pressure-drop	3% of inlet pressure
Mass flow ratio of propane	1.019
Mass flow ratio of methanol	0.437
STDC work	118.8MW
Mechanical loss	2%
Ambient temperature	298.15K
Ambient pressure	101kPa
Propane temperature	93K ~ 214K
Methanol temperature	214K ~ 288K

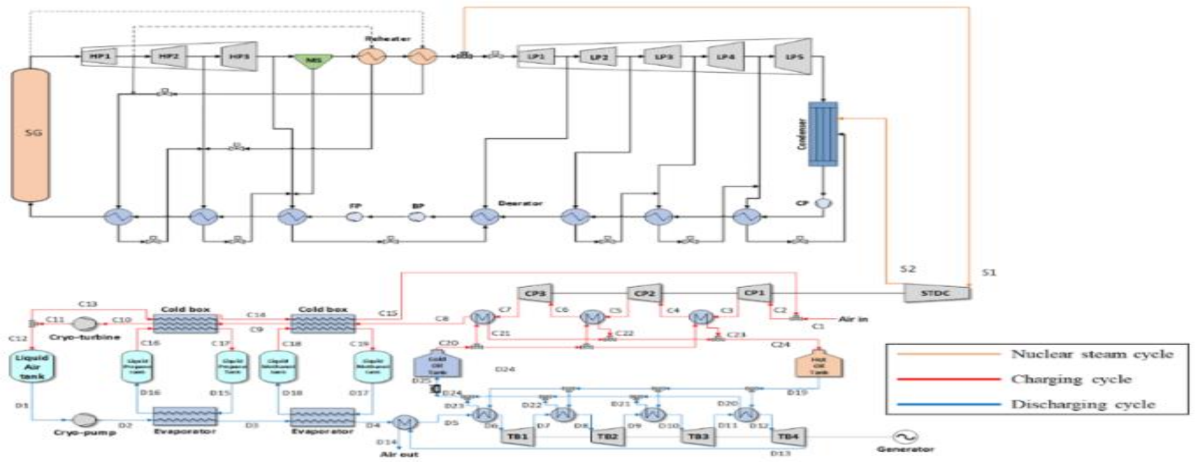

Fig. 2. Schematic diagram of nuclear integrated LAES

3. Results

Table 2: Round trip efficiency (%)

	3 Turbine	4 Turbine	5 Turbine
2 Compressor	56.5	55.7	54.3
3 Compressor	51.6	53.9	53.8
4 Compressor	48.7	50.9	52.1

The thermodynamic performance of nuclear integrated LAES is evaluated in the MATLAB environment. The number of turbines and compressors are varied and the performance of the suggested system was evaluated. This is to observe how the round trip efficiency changes with respect to the number of turbomachinery in the system which can contribute to the optimization of the thermodynamic process in the future.

As shown in Table-2, when the three turbines and two compressors are used, the round trip efficiency becomes the largest. In general, when the number of turbines is one to two more than the number of compressors, higher round trip efficiency is obtained. It is noteworthy that as the number of turbines and compressors increases, in other words the compression and expansion process approaches isothermal conditions, the round trip efficiency decreases. This is because the efficiency of the turbine and compressor is not 100% and increased pressure drop in heat exchangers due to additional reheating and intercooling. These combined effects reduce the round trip efficiency.

4. Conclusions

A liquid air storage system uses excess power to compress and liquefy air to store electricity, and to vaporize and expand liquid air when additional power is required to produce electricity. However, due to the intermittency of variable renewable energy sources, flexible operation of nuclear power plants is inevitable to assist electric grid stabilization. For this reason, an alternative to operate a large-capacity energy storage system in connection with the power generation system of a nuclear power plant was recently proposed. The influence of turbine and compressor number on the proposed system's round trip efficiency is analyzed in this study. In terms of round trip efficiency, the highest efficiency is shown when two compressors and three turbines are used.

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