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A Sensitivity study of Thermo-electric energy storage system based on TES

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1. Introduction

The national greenhouse gas reduction target of 37% compared to business as usual (BAU) by 2030 encourages new energy technologies to emerge. The penetration of renewable energy will increase, and its intermittency has to be countered with the energy storage system. Recent study shows that among many ESSs, a mechanical ESS for large grid scale energy storage can be connected with the operating nuclear power plant to restore stability of the grid.

Within the mechanical ESS, Thermo-Electric Energy Storage (TEES) based on ice storage and CO_2 as a working medium is a system that stores electrical energy as heat, and has drawn attention for its high energy density. The fact that electricity can be stored as heat and that it has a high-power density increases the possibility of early commercialization. The model in ice storage is designed to exchange enthalpy and the volume of ice storage is assumed to be 0.5 times the sum between hot and cold tanks. In this paper, a TEES (thermo-electric energy storage) system is investigated and the sensitivity of systems' performance to the assumed component parameters are presented.

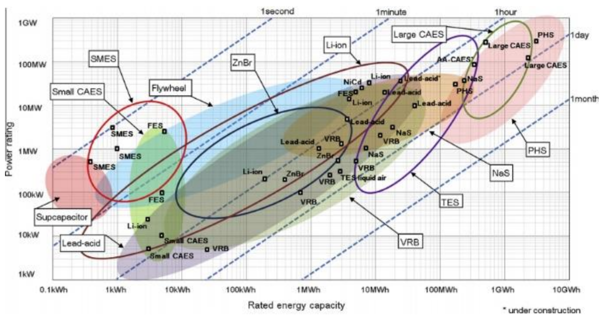

Fig 1. Comparison of power rating and rated energy capacity with discharge time duration at power rating. [1]

2. Methods and Results

2.1 Heat exchanger modeling

The TEES system has a charging cycle and a discharging cycle. Each cycle is a closed Brayton cycle. The charging cycle and the discharging cycle are connected with a thermal energy storage (TES), in which the heat of the charging cycle is stored in the TES and then received by the discharging cycle later on. TEES is a composed of compressor(C), turbine (T), hot storage tank (HT), cold storage tank (CT), heat exchanger (HX) and ice storage.

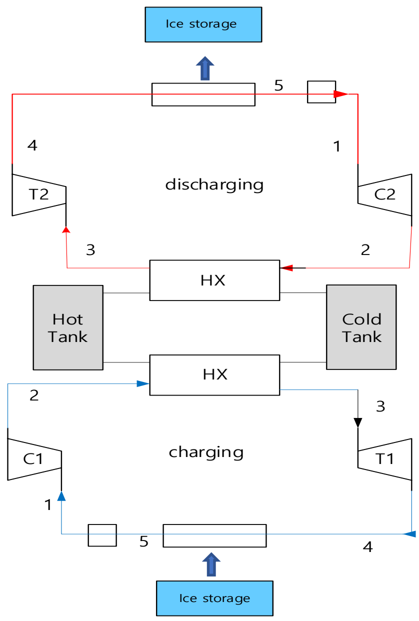

Fig. 2. Heat exchanger model, discharging and charging

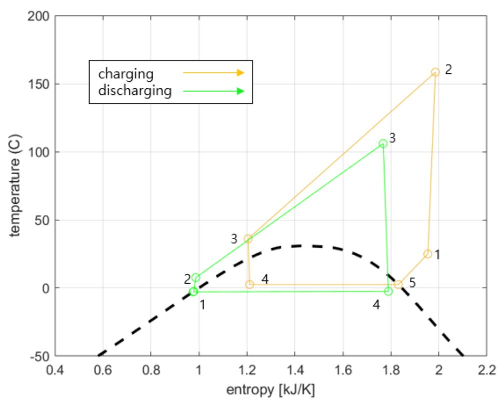

Fig.2. TEES charging and discharging cycle model with T-S diagram

2.2Performance of TEES

Performance can be expressed by round-trip efficiency (RTE) and power density

2.2.1 Round-trip efficiency of TEES system

The round-trip efficiency of the TEES system can be defined as the ratio of electric output power during discharging mode to electric input power during charging mode. In the charging mode, the actual compressor and turbine powers for the working fluid are determined using an isentropic efficiency defined as

$$\text{RTE} = \frac{W_{discharging}}{W_{charging}} = \frac{W_{T2}-W_{C2}}{W_{C1}-W_{T1}} \quad (1)$$

2.2.2 Power density of the TEES system

Then, the power density of the TEES system can be defined as the ratio of turbine work during the charging and discharging modes to volume of hot tank, cold tank, and ice storage. Determining the turbine work and volume using an isentropic density is as follows

$$\text{Power density} = \frac{W_{turbine1}+W_{turbine2}}{V_{hot\ tank}+V_{cold\ tank}+V_{ice\ storage}} \quad (2)$$

2.3 Thermodynamic modeling of TEES

Assumptions used for the modeling are as follows.

1) There is no pressure drop in the pipelines.
2) Turbines and compressor have constant isentropic efficiencies, respectively.
3) There are no changes in potential and kinetic energies.
4) Same pressure drop 1% in all heat exchanger
5) The total volume of ice storages is equal to half the volume of hot tank and cold tank.

2.3.1 Heat exchanger

Generally, the effectiveness, ε is defined :

$$\varepsilon = \frac{Q}{Q_{max}} \quad (3)$$

In counterflow heat exchanger, one of the fluids would experience the maximum possible temperature difference,

$$T_{hot,inlet} = T_{cold,inlet} \quad (4)$$

Therefore, Q_{max} is determined to have the minimum heat capacity between cold flow and hot flow to get larger temperature difference.

$$Q_{max} = C_{min}\,(T_{hot,inlet} - T_{cold,inlet}) \quad (5)$$

The heat exchanger in TEES system have constant pressure drop rate 1% and determined the heat in TES as equation.

Pressure drops occur in the heat exchanger. This is the same percentage, 1% for all heat exchangers.

MATLAB was used to check the power density and RTE of TEES system with ideal condition and Table 1.

Table 1. Design parameters of TEES

Parameters	Value	Unit
Effectiveness of HX	0.95	
Maximum of pressure	16	MPa
Minimum of pressure	3.7	MPa
Isentropic efficiency of turbine	0.9	
Isentropic efficiency of compressor	0.85	
Pressure drop in HX	1	%
Mass flow rate ratio (CO_2 : $Tank\ fluid$)	1 : 2	

Table 2. Variable of parameters of TEES

Parameters	Value	Unit
Temperature of cold tank	303	K
Isentropic efficiency of turbine	0.9	
Isentropic efficiency of compressor	0.85	

2.4 Sensitivity of TEES

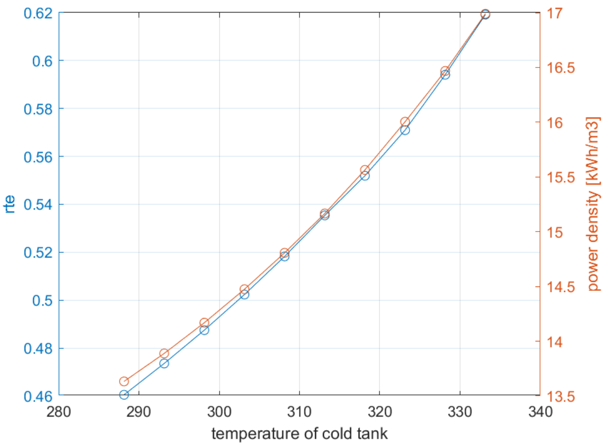

Fig 3. Sensitivity of cold tank temperature – power density and RTE

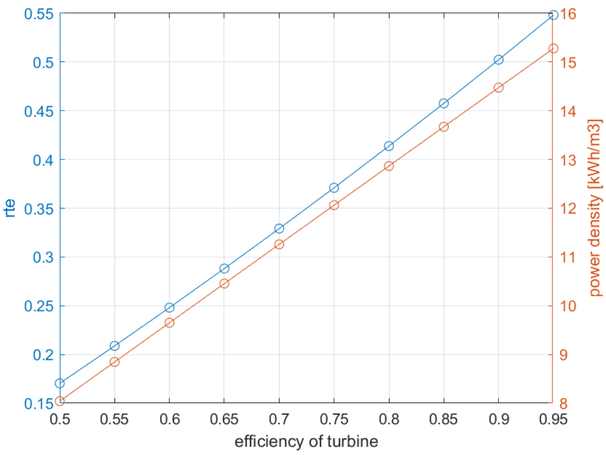

Fig 4. Sensitivity of turbine efficiency – power density and RTE

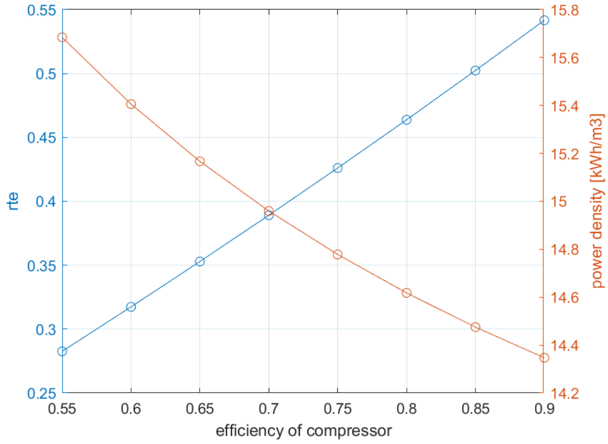

Fig 5. Sensitivity of compressor efficiency – power density and RTE

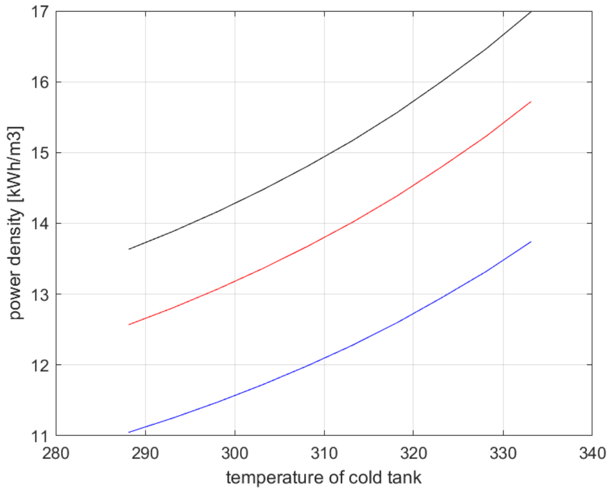

Fig 6. Sensitivity of cold tank temperature – power density
[Tank fluid: therminol VP-1 (black), therminol LT (blue), therminol 59 (red)]

The higher the temperature of the cold tank, the higher the RTE and power density.
Increased turbomachinery efficiency leads to increased power density with RTE, and increased compressor efficiency leads to increased RTE but decreased power density.
Increasing the efficiency of the compressor reduces the temperature of the compressor outlet, thus reducing the difference in enthalpy.
Therefore, when compressor efficiency is 0.85, turbine efficiency is 0.9 and temperature of cold tank is 303K, RTE is 0.50 and power density is 14.47kWh/ m^3 is checked for the proposed TEES system.

3. Conclusions and Future works

To study the fundamental aspect of TEES (thermo-electric energy storage) system, the authors have modelled heat exchangers and stored heat to confirm the high-power density of TEES. The temperature of the cold tank and the efficiencies of turbine and compressor are increased to understand how component efficiency determines the system's efficiency. In the near future, the optimal temperature between heat exchanger and ice storage will be obtained to find a more suitable working fluid.

Acknowledgement

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