Off-design Performance Analysis of Compressed CO_2 Energy Storage System Integrated to a Conventional PWR

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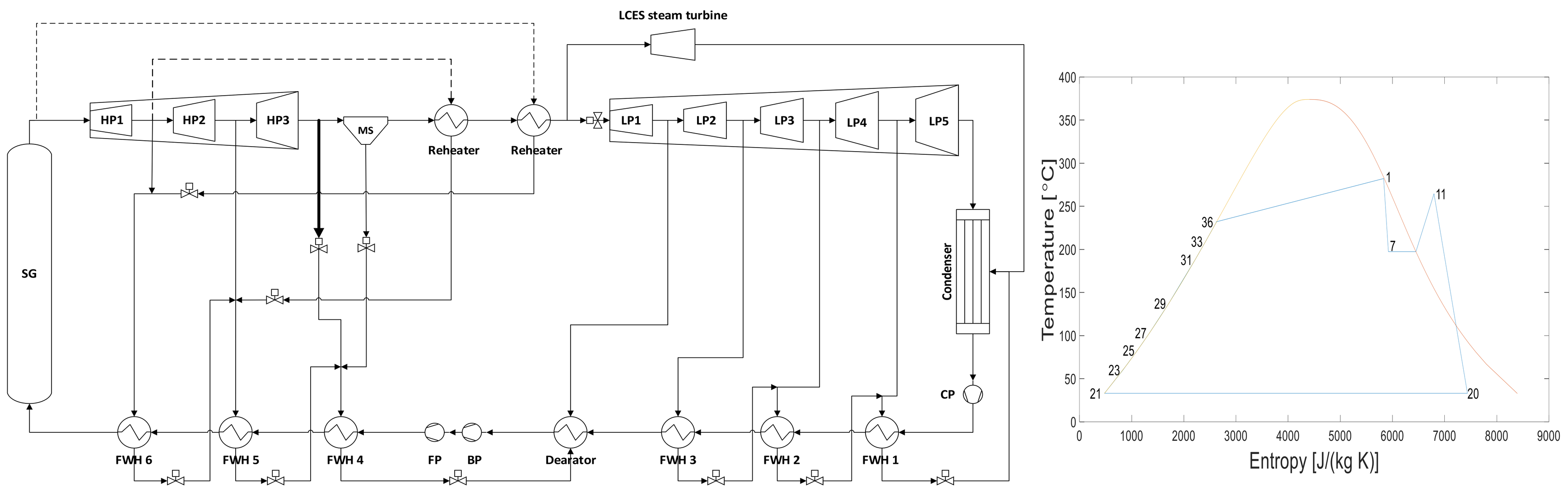
Introduction

- ✓ Recently, the energy production from renewable energy (RE) sources is increasing globally and domestically to reduce greenhouse gas (GHG) emission and prevent climate change, but renewable energy has unexpectable intermittency during power generation. This issue can be alleviated by load-following operation of a nuclear power plant (NPP).
- ✓ It is not economical to control power output of the reactor in an NPP and can have a problem in nuclear fuel integrity. Energy Storage System (ESS) attached to the power cycle can solve this issue.
- ✓ Among the various ESSs, compressed CO_2 energy storage (CCES) is promising ESS due to high round-trip efficiency (RTE) and simple layout.
- ✓ CCES integrated to a conventional PWR was studied and analyzed thermodynamically previously. From this reference, its maximum RTE was estimated to be around 62%.

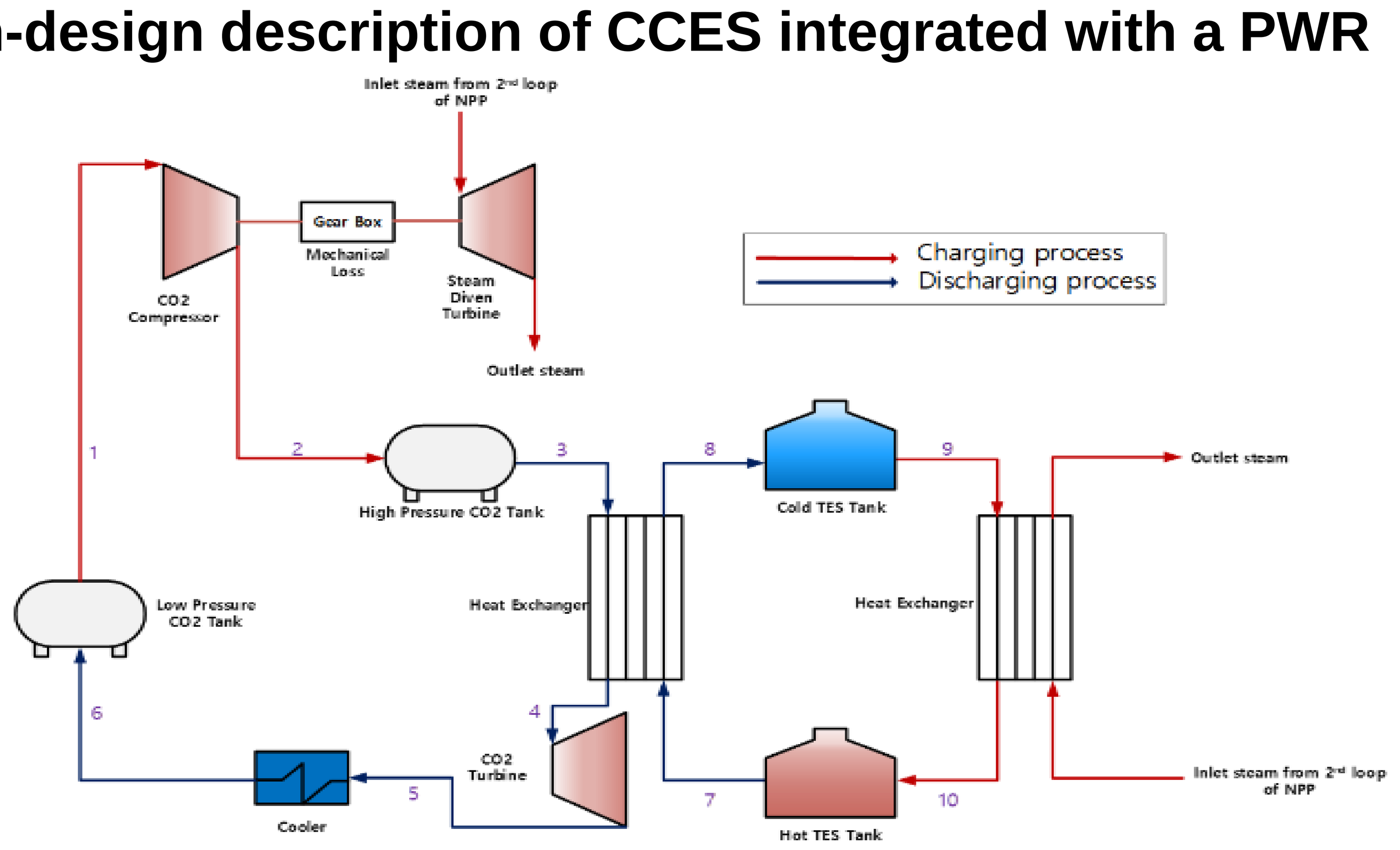


- Layout (Left) and T-s diagram (Right) of Steam Cycle integrated with LCES

- ✓ However, it doesn't always produce constant work since each time the required power is not same. Thus, it needs to analyze dynamic simulation when it produces different work from on-design.
- ✓ The off-design performance analysis in discharging operation mode should be performed as a preliminary study before dynamic simulation. Hence, the control method should be applied not to affect next charging process.
- ✓ Thus, in this paper, **the off-design performance analysis of a CCES integrated to a conventional PWR in discharging operation mode are studied.**

Off-design modeling

✓ On-design description of CCES integrated with a PWR



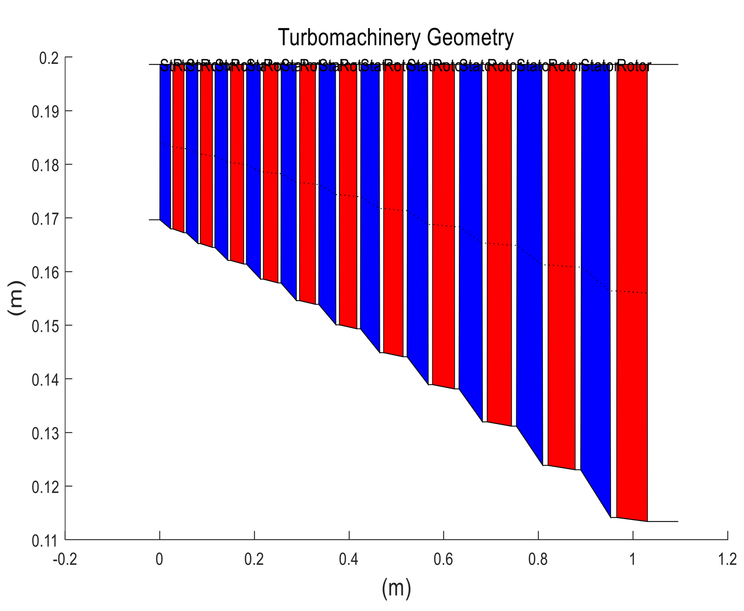
- Layout of CCES integrated to PWR steam cycle

✓ CCES off-design modeling in discharging operation

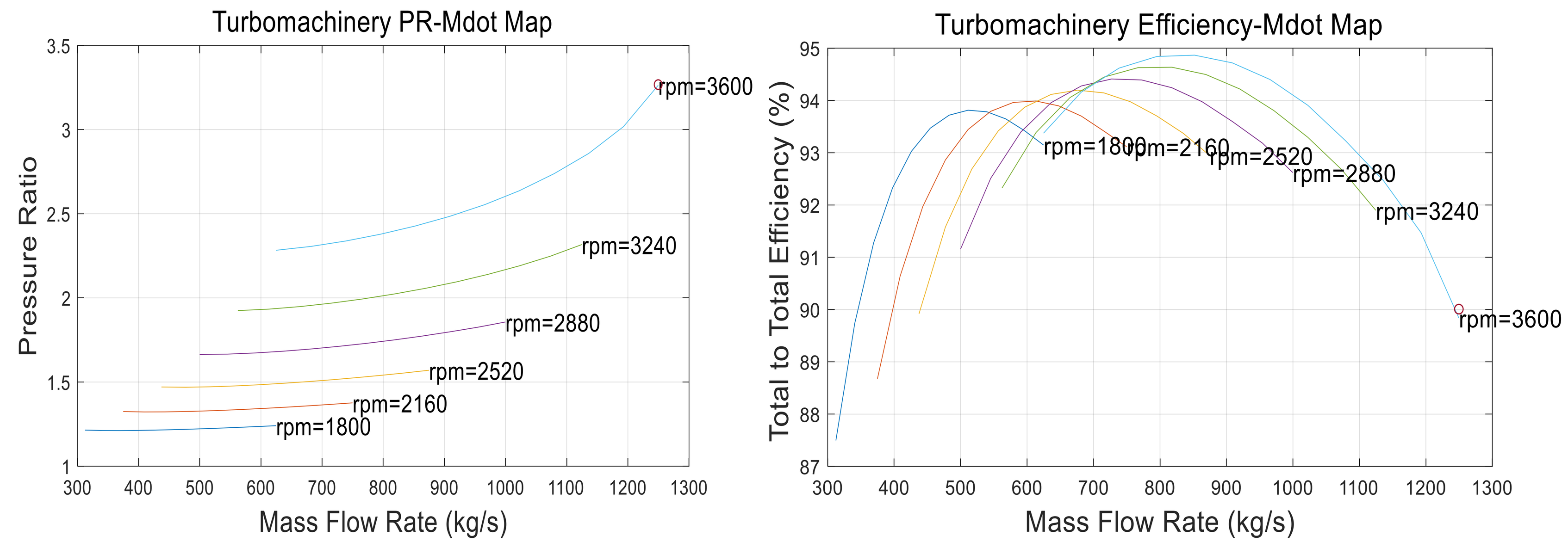
In this paper, the turbine work produced is evaluated when the mass flow rate of the working fluid is different from the on-design CO_2 mass flow rate during the discharge process. Therefore, its analysis requires **the conceptual design of heat exchangers and turbine and control strategy**.

✓ Conceptual design of Turbine

	Turbine	Unit
Type	Axial	
RPM	3600	
Number of stages	11	
Efficiency	90.01	%



- Turbine geometry of KAIST-TMS (Left) and TMD (Right)



- Turbine pressure ratio map(Left) and efficiency map(Right)

✓ Heat exchanger design

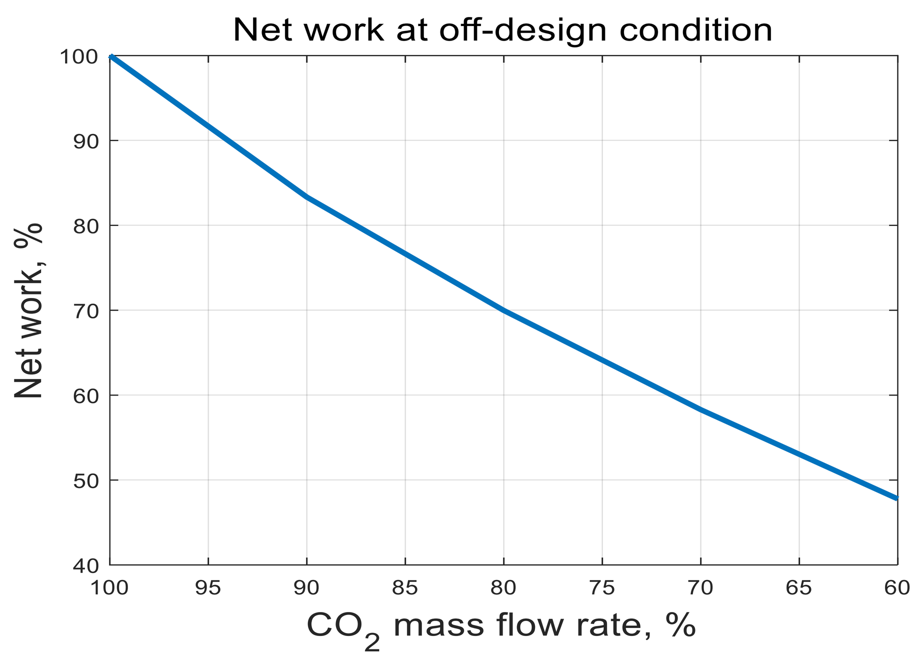
KAIST-HXD results	Heater	Cooler
Type	PCHE	PCHE
Length [m]	6.41	1.7
Number of hot channels	240000	100000
Number of cold channels	240000	100000
Diameter of hot channels [mm]	7.5	4.5
Diameter of cold channels [mm]	2.92	15
Fluid of hot channels	HITEC salt	CO_2
Fluid of cold channels	CO_2	Water

✓ Control strategy

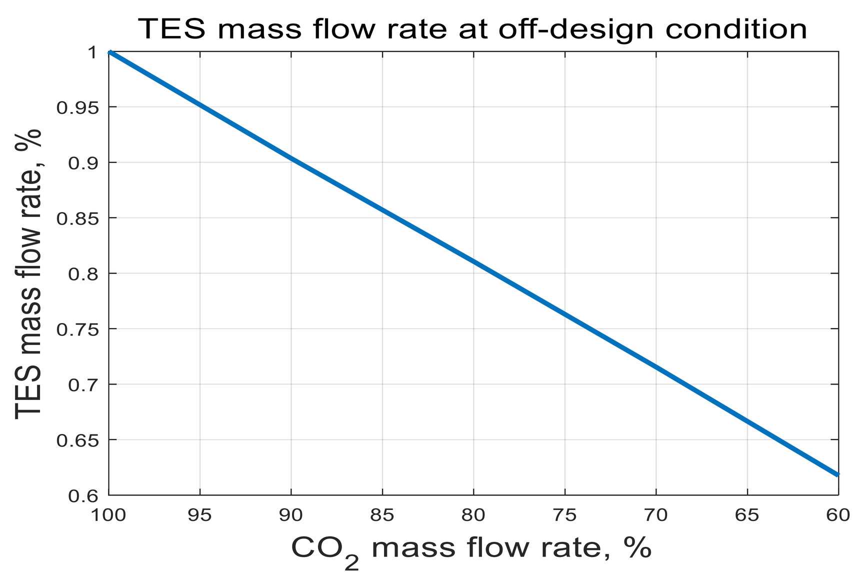
During partial load operation, it is expected that the CO_2 after the discharging process will be different from the design point. It is required to **control the temperature and pressure** of CO_2 before LP tank inlet to match the design point.

(1) Controlled to the pressure by installing a **throttle valve** between the turbine and the cooler to match the design pressure.
(2) In order to maintain the **temperature** constant, the **mass flow rate of water**, the coolant of the cooler, is adjusted to control the temperature.
(3) In addition, to keep constant TES cold tank condition, the **mass flow rate of HITEC salt** is adjusted to control the **HITEC temperature**.

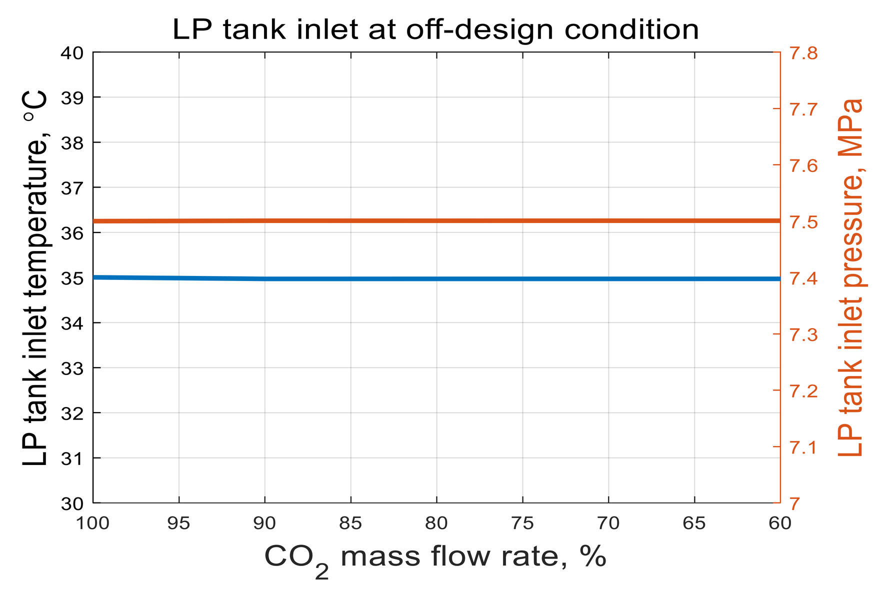
Results



- CO_2 mass flow rate vs Net work ratio



- CO_2 mass flow rate vs TES mass flow rate ratio



- CO_2 mass flow rate vs LP tank inlet T & P

Summary and Future works

- ✓ It is shown that as the CO_2 mass flow rate decreases, the produced turbine work decreases more. Thus, **the improved strategy of part load operation is required**.
- ✓ By control strategy using throttling valve and control of water mass flow rate, **LP tank inlet maintain constant form the design point**.
- ✓ However, a **control method** that can **improve performance** during partial load operation is **required** such as constant volumetric flow rate method.
- ✓ Further investigation will commence soon regarding **dynamic simulation of CCES by adding better control strategy** as well.