The concept design of the new cycle layout of the nuclear-solar hybrid system

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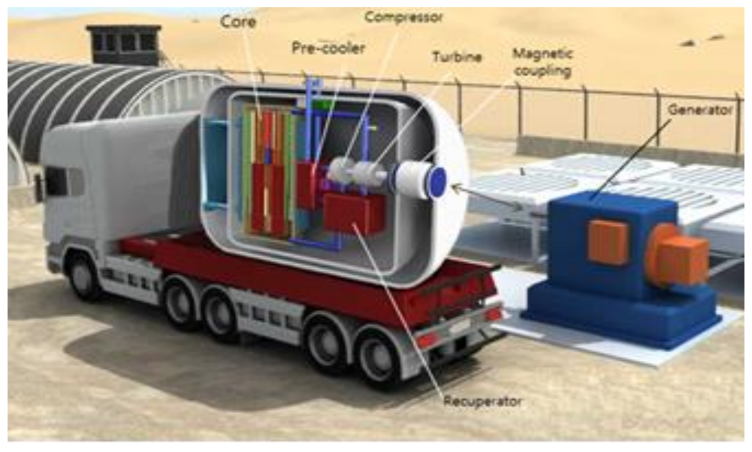
Introduction

■ In previous study, the KAIST research team developed the concept of a nuclear-solar hybrid system that combines nuclear power, TES (Thermal Energy Storage), and CSP (Concentrated Solar Power).

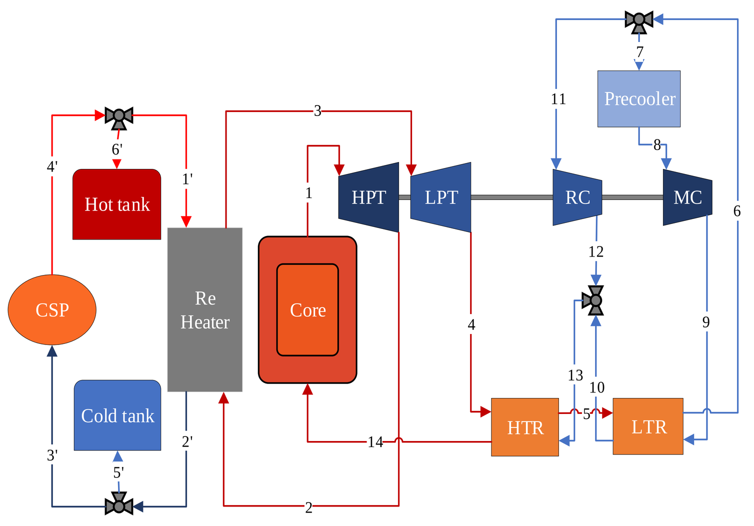
■ The hybrid systems have the advantage to compensate for each other's shortcomings: maintain high capacity factor during load-following (Nuclear), large solar field area (CSP).

■ KAIST-MMR using sCO_2 power cycle was used for the nuclear power of the hybrid system.

■ KAIST-MMR is composed of a single module that combines the power system and the reactor core, so it can be transported by truck or ship.



△ Concept diagram of the KAIST MMR



△ Recompression with reheating cycle layout of the previous hybrid system

■ MMR is a CO_2-cooled reactor and the working fluid of the CSP and TES is a molten salt, recompression with reheating cycle layout is used.

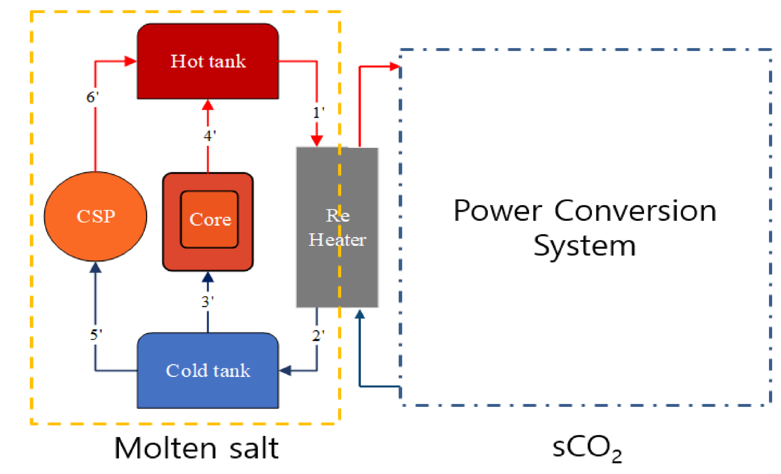
■ However, the temperature difference between the TES inlet and outlet is smaller than that of the TES used in the operating CSP.

▽ The temperature difference between the hot and cold TES of the various operating CSP

	Hybrid system	Gemasolar plant	Dunhuang plant
$T_{TES,Hot}$ (°C)	585	565	565
$T_{TES,Cold}$ (°C)	530	290	290
ΔT_{TES} (°C)	55	275	275

■ The new cycle layout is proposed using a molten salt cooled reactor that has the same output as MMR.

■ It has the advantage of increasing the temperature difference of TES and can improve the flexibility of the output through one integrated heat source.



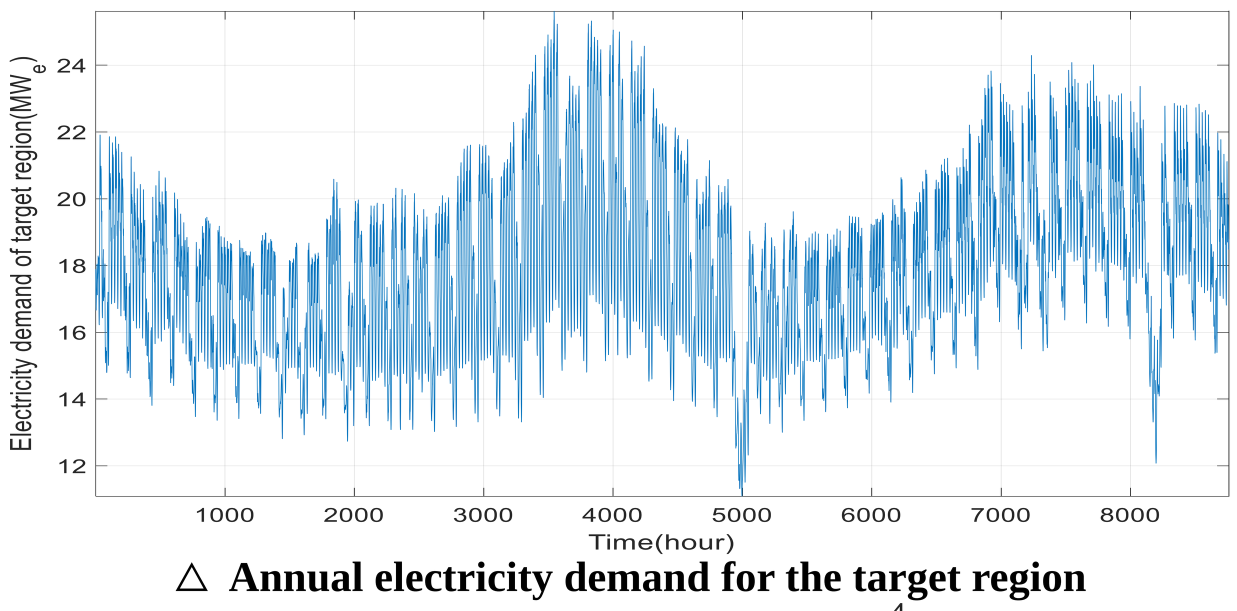
△ New cycle layout for the hybrid system

■ Therefore, in this study, the new cycle layout is optimized and the cycle component design is performed.

Methods

1. Site selection

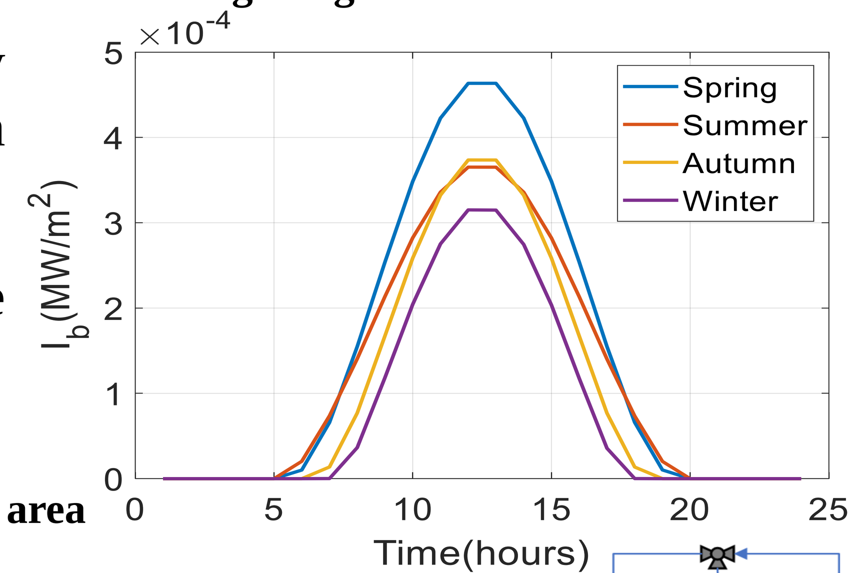
■ The same heat output and target region were set to fairly compare the previous hybrid system and the new system



△ Annual electricity demand for the target region

■ In previous hyrbrid system, the electricity demand and DNI was selected using the South Korea's data

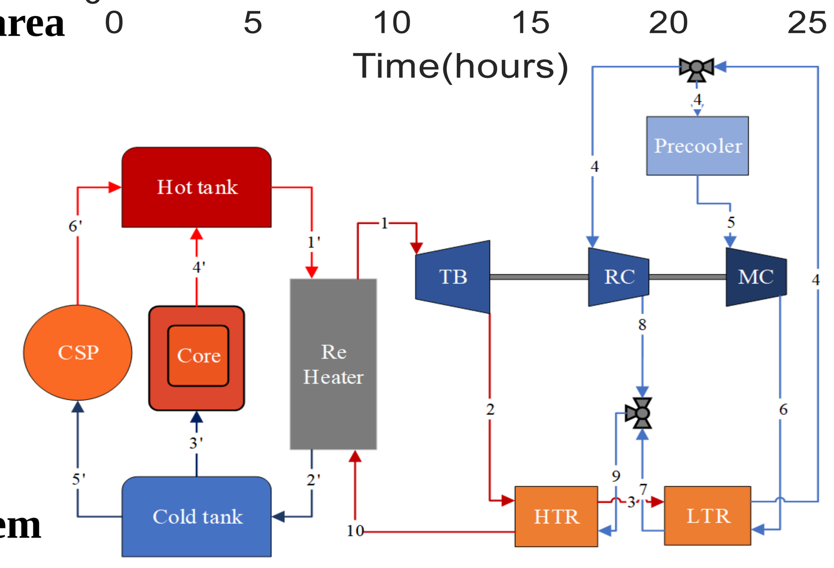
■ The electricity demand and DNI used the same thing as the previous hybrid system.



▷ The seasonal average DNI of the target area

2. Cycle optimization

■ According to Ahn's work, the recompression cycle has the highest cycle efficiency at 400-600°C among the various layout.

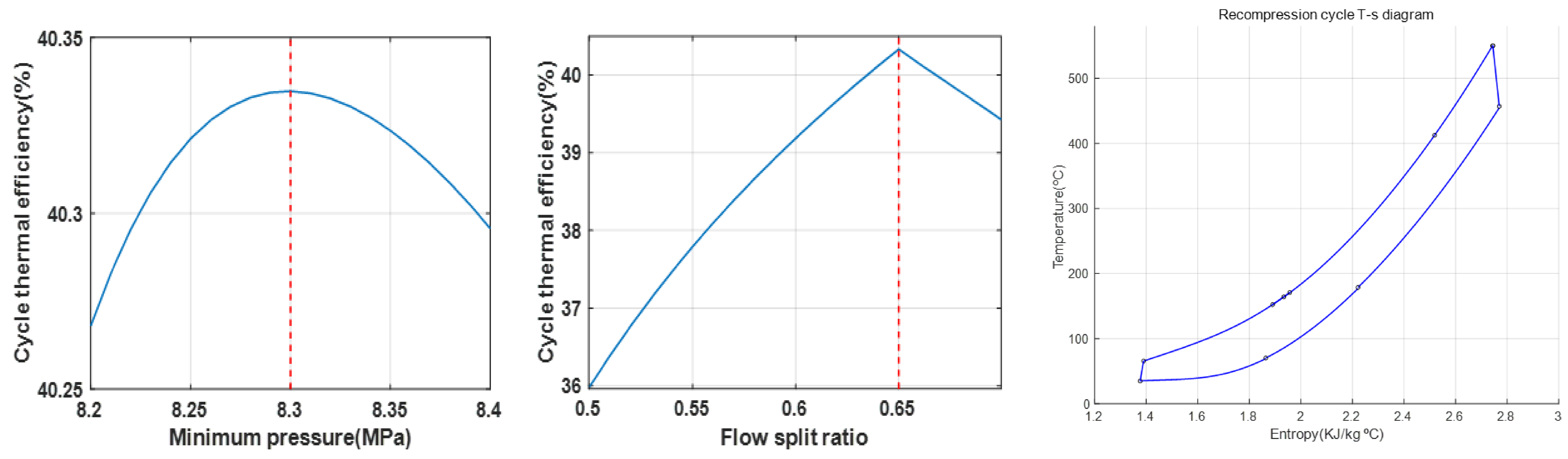


▷ Recompression cycle layout for the hybrid system

■ For a fair comparison, the cycle design values were set the same as in the previous system except for the re-heater CO_2 outlet temperature as shown in the below table.

▽ Cycle design fixed value and optimization variables

Cycle design fixed value			
Max Pres.	20Mpa	MMR heat	36.2MWth
Min Temp.	35°C	CSP heat	27.15MWth
MMR outlet Temp.	550°C	Turbine eff.	85%
Re-heater outlet Temp.	550°C	Compressor eff.	80%
HTR, LTR effectiveness	0.95	Component pressure drop (Kpa)	100-150
Optimization variables			
Pressure ratio		Flow split ratio	



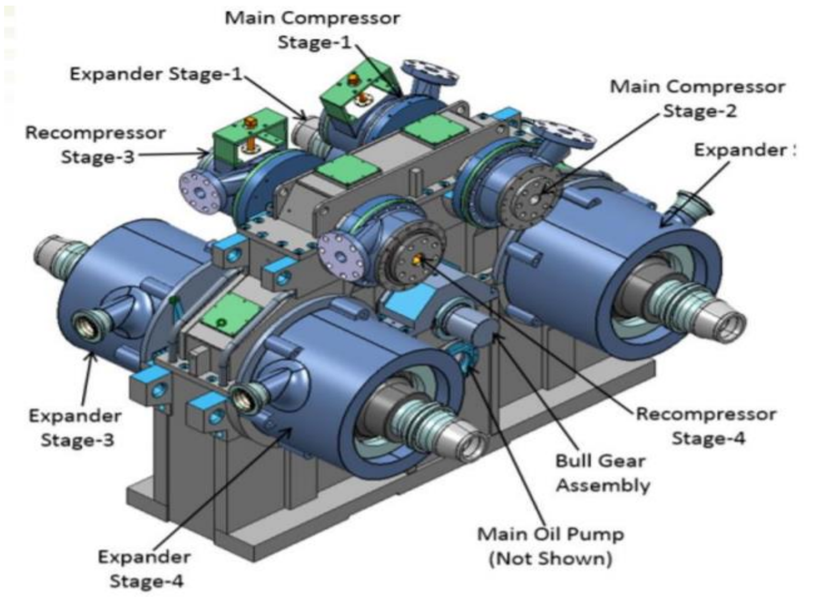
△ Optimization results and T-s diagram of the hybrid system

■ As a result of the optimization, it was confirmed that the highest efficiency was 40.2% at Pressure Ratio (PR) = 2.26 and Flow split ratio (FSR) =0.65.

3. Cycle Component design

■ It is assumed that the turbomachinery of the hybrid system uses an integral gear approach.

■ If the turbomachinery is designed at different rpm, it can be connected to one shaft by being bitten by the central bull-gear shaft.



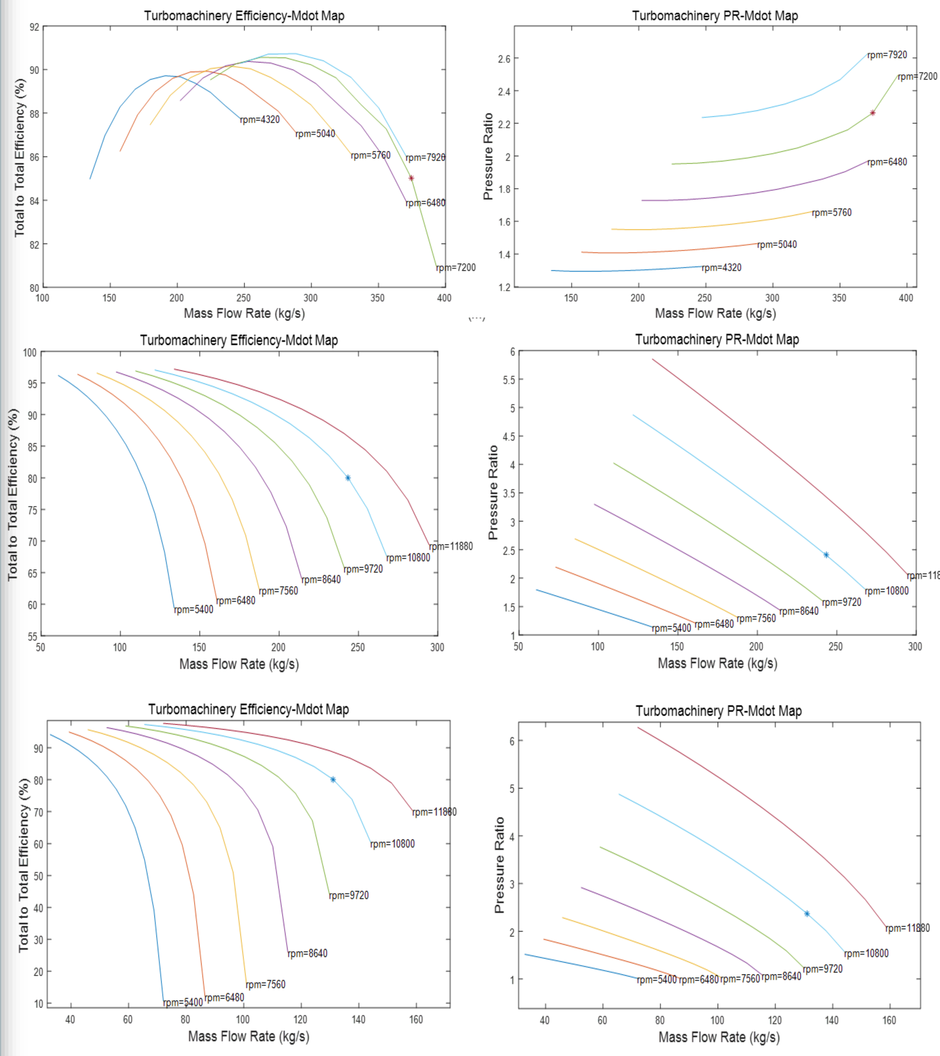
△ The example of the integrally geared expander compressor

■ KAIST-TMD code is used to estimate the turbomachinery off-design performance map for the hybrid system by using corrected mass flow rate and rpm.

■ Heat exchangers were designed through the KAIST-HXD code which was developed in MATLAB environment and can perform PCHE design for the sCO_2 power system.

Result

■ The cycle components were designed using the KAIST-TMD and KAIST-HXD code as follows.



△ Performance map (Turbine, Main comp., Re-comp.)

▽ Design result of the turbomachinery

	Turbine	Main comp.	Re-comp.
RPM	7200	10800	10800
Stage	4	6	10
Work (MW)	38.3	5.5	7.3
Pressure ratio	2.26	2.4	2.37
Efficiency (%)	85	80	80
T_{in} (°C)	550	35	70.3
P_{in}(Mpa)	19.7	8.3	8.4
P_{out}(Mpa)	8.7	20.0	19.9
Mass flow rate(kg/s)	374.4	243.4	131.1

▽ Design result of the heat exchangers

Parameters	HTR	LTR	Pre-cooler	Re-heater
PCHE Type	Zigzag	Zigzag	Zigzag	Straight
Heat load [MW]	120.0	52.9	38.3	63.3
Hot Avg. Re #	35000	46000	74400	1000
Cold Avg. Re #	54000	23000	3930	16000
ΔP_{hot} [kPa]	150	150	100	80
ΔP_{cold} [kPa]	100	100	100	100
Length [m]	2.15	3.74	0.97	4.63
Volume [m³]	6.34	11.92	1.13	17.26

Conclusions

■ The cycle layout of the new hybrid system was optimized and the cycle components were designed using the in-house code.

■ The difference in TES temperature was increased by about 90°C compared to the previous hybrid system.

■ As a future study, the off-design performance of the new hybrid system will be calculated.