Dynamic Modeling and Transient Analysis of a Molten Salt Heated Recompression Supercritical CO_2 Brayton cycle

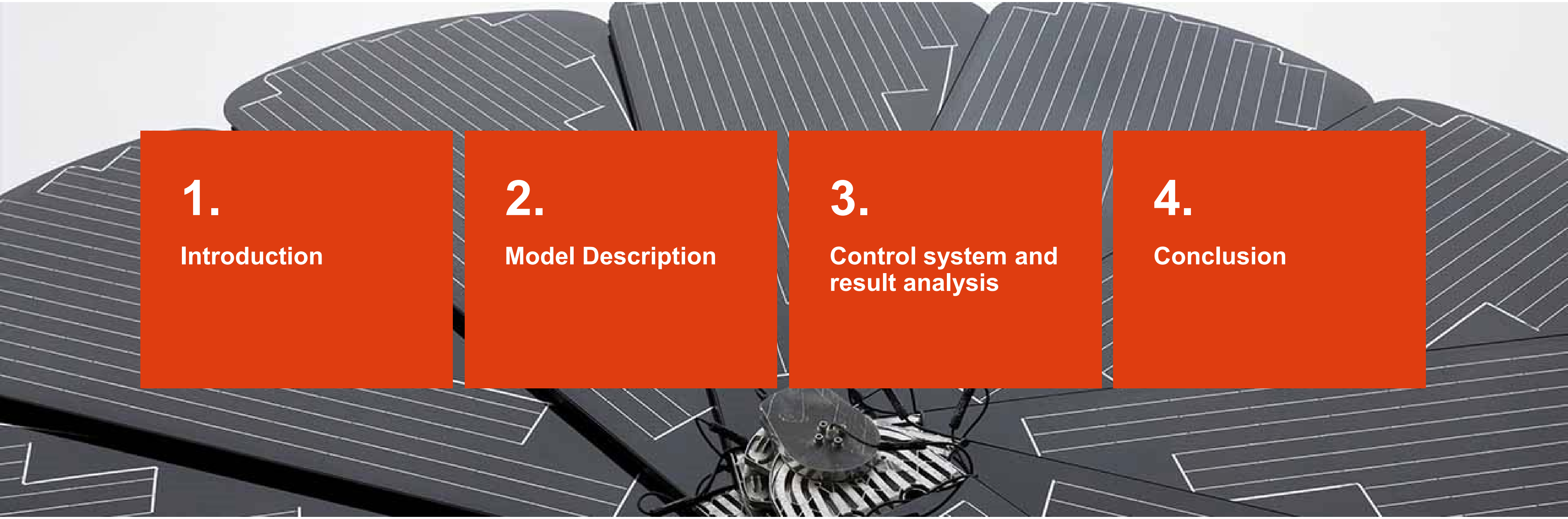
European sCO_2 Conference

ZHOU Pan, ZHANG Jinyi and LE MOULLEC Yann

EDF R&D China

2019/09/19

OUTLINE



1. Introduction

2. Model Description

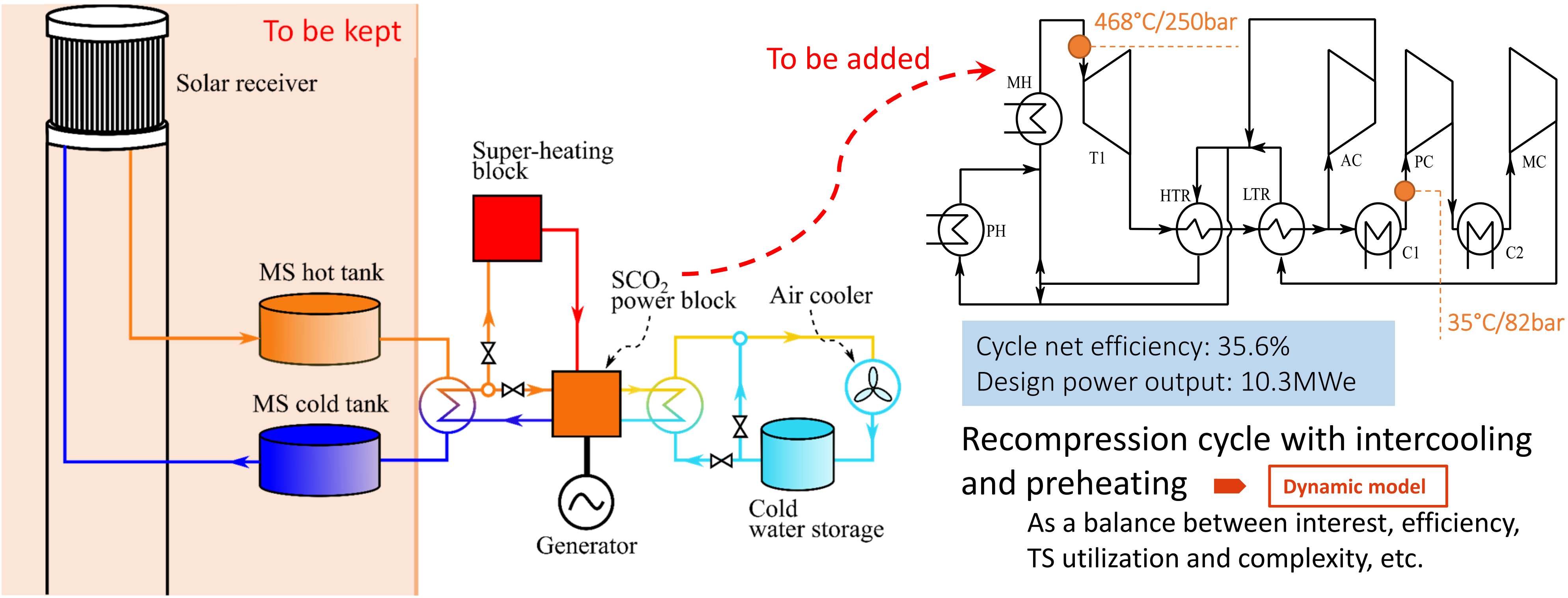
3. Control system and result analysis

4. Conclusion

Supercritical CO_2 Cycle + CSP

- **In China, 160 $/MWh, Year 2019 – Too expensive**
- SCO_2, together with high temperature (> 500 ℃) molten salt CSP solutions, could achieve higher efficiency than steam solutions.
- **Shouhang – EDF 10MWe sCO_2 demonstration project**
  1) Investigate the technical feasibility of SCO_2 cycle
  2) Industrial scale SCO_2 equipment, including turbine, compressor, recuperator, etc.
  3) Cycle control and operation

System design concept



Cycle net efficiency: 35.6%
Design power output: 10.3MWe

Recompression cycle with intercooling and preheating ➡ **Dynamic model**

As a balance between interest, efficiency, TS utilization and complexity, etc.

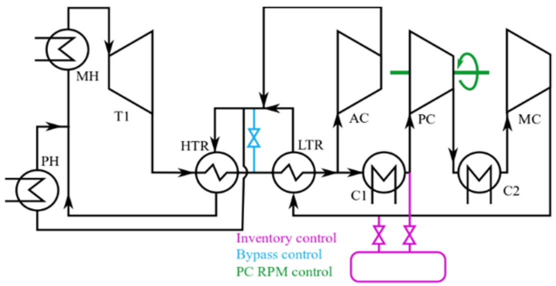
Tools used for development of dynamic model

Cycle design
toolbox

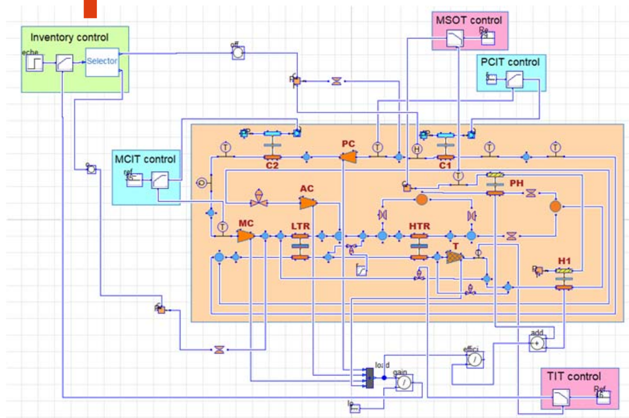
Predesign
toolbox

DYMOLA

MATLAB



Geometry of
equipment

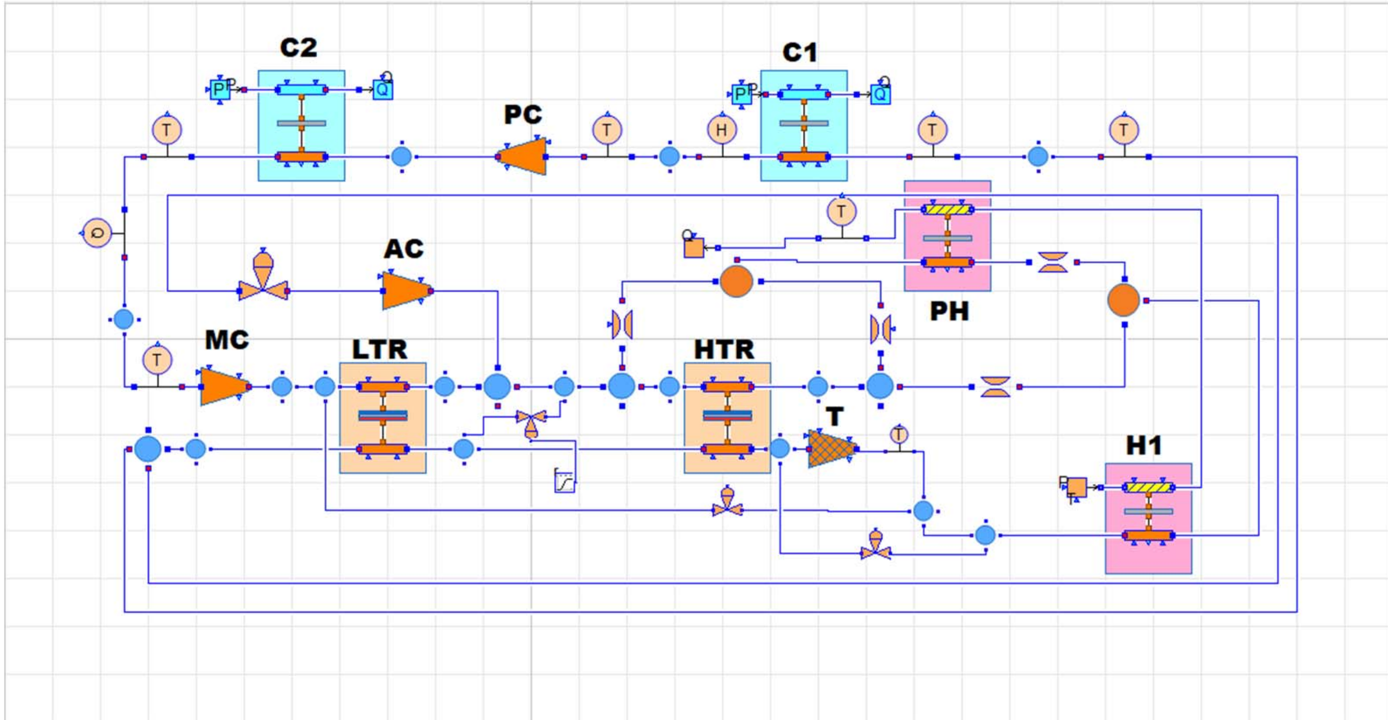


Cycle model

Water/CO_2 HX
Shell and tube heat exchangers

Thermodynamic properties
CO_2 prop. is calculated by dynamic call of REFPROP

Recuperators
Straight channel printed circle heat exchangers (PCHE)



Turbomachinery
Mass flow rate dependent compression ratio and isentropic efficiency

Auxiliary equipment
Simplified pipes, sensors and valves

Molten salt/CO_2 HX
Shell and tube heat exchangers

Turbo-machinery performance model

Energy balance → Pre-design → Off-design → Non-dimensionalize → DYMOLA

Energy balance
- Boundary conditions

Can be get by steady-state simulation

Turbo-machinery pre-design tools
- Geometry

Based on the mean-line design tool self-developed

Turbo-machinery off-design model
- Performance map (Q dependent)

Using off-design model to get the performance map

Non-dimensionalization
- post-processing

The final obtained curve will be imported in DYMOLA

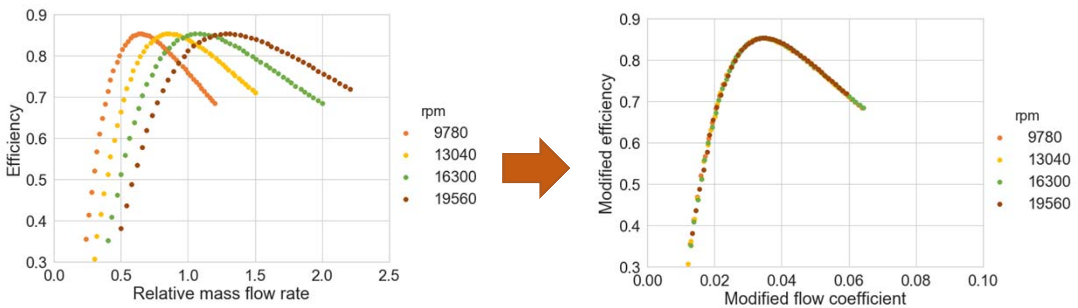
DYMOLA
- Simulation

Turbo-machinery is modelled based on the non-dimensionalized curve

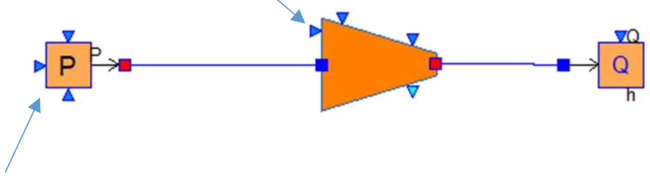
A realistic model which predicts performance (isentropic efficiency and compression ratio) depending on:

Inlet conditions
Mass flow rate
Rotation speed

For T, P known



Input rotation speed



Input fluid properties

Heat Exchanger Modeling

Energy balance

Energy balance
- ➢ Boundary conditions

Can be get by steady-state simulation.

Pre-design

Pre-design
- ➢ Geometry

Based on pre-design tools.

Modeling

Off-design model
- ➢ dymola Model

Off-design modeling in Dymola

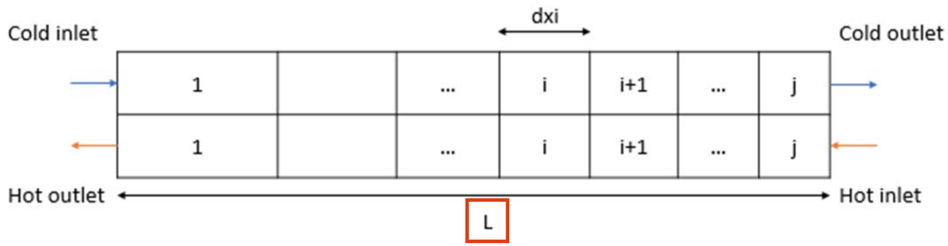
DYMOLA

DYMOLA
- ➢ Simulation

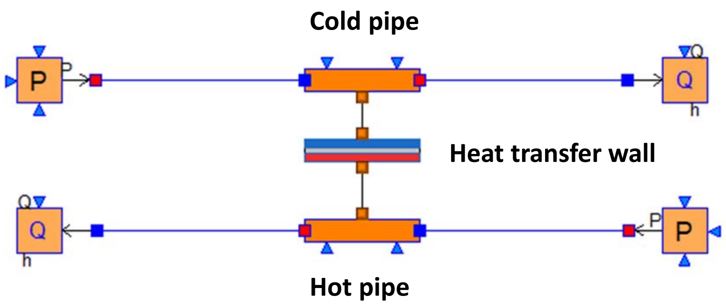
The implemented model will be simulated in Dymola.

A realistic model which predicts on-design and off-design performance of heat exchanger

Same heat exchanged for each section



- **Heat transfer calculation: Gnielinski's Correlation**
- **Pressure drop calculation: Chen's correlation**



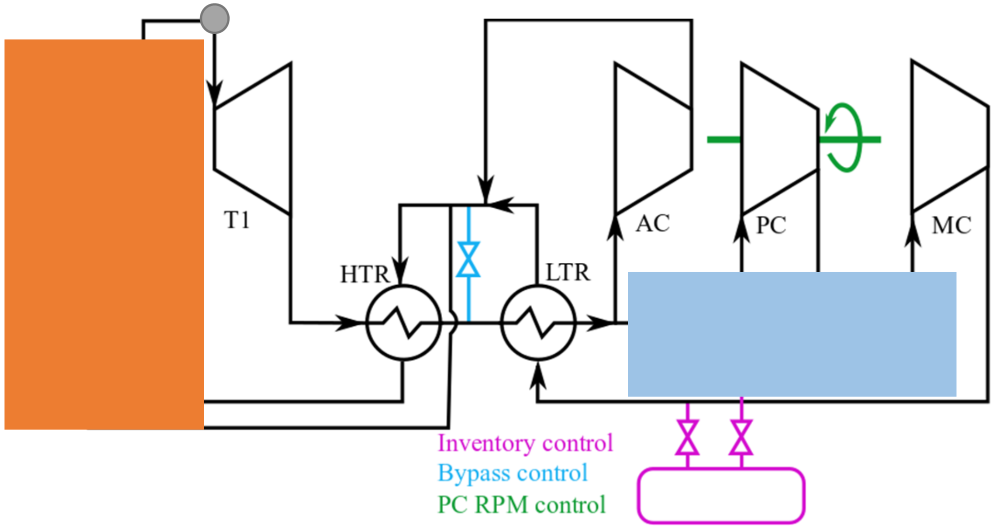
Elementary controllers

Temperature control loops integrated in the model to ensure:

- Safe operation of turbomachinery
- Molten salt beyond its freezing point (290°C)

TIT controlled under operation temperature

MSOT controlled by molten salt mass flow rate

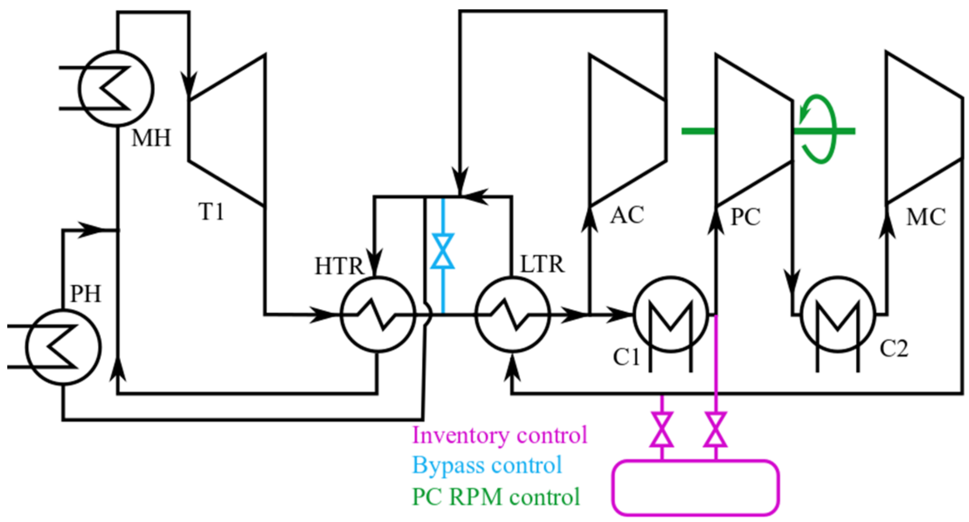


MCIT and PCIT controlled by mass flow rates of cooling water

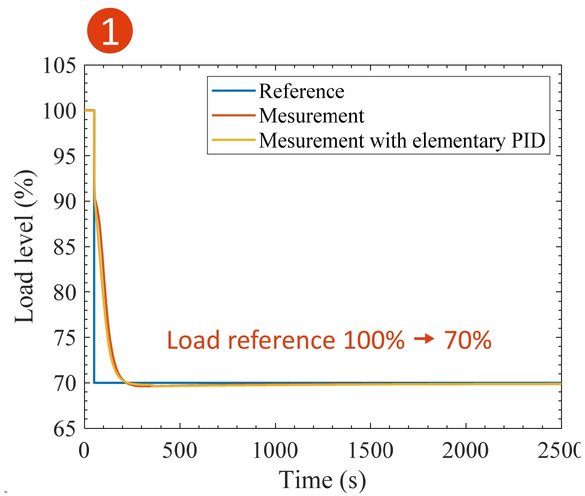
Part load control strategy

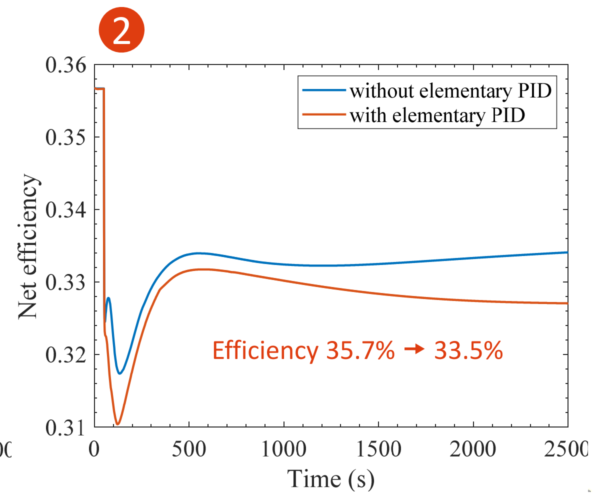
Three method to control the cycle load level

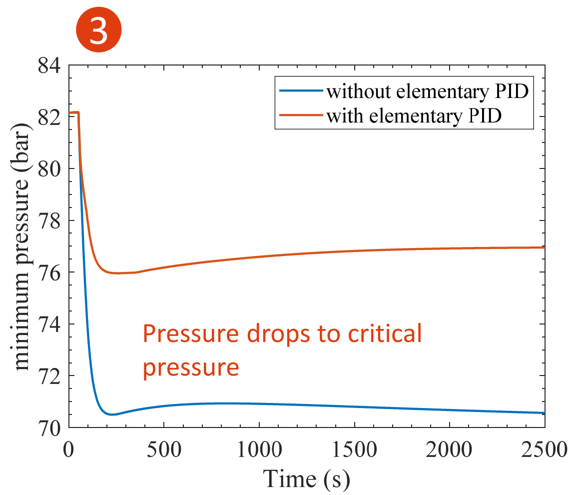
- Inventory control: inject or release sCO_2 from the cycle
- Bypass control: bypass the fluid from outlet of LTR cold side to outlet of HTR hot side
- Variable PC rotation speed control: adjust the rotation speed of pre-compressor



Inventory control (1)

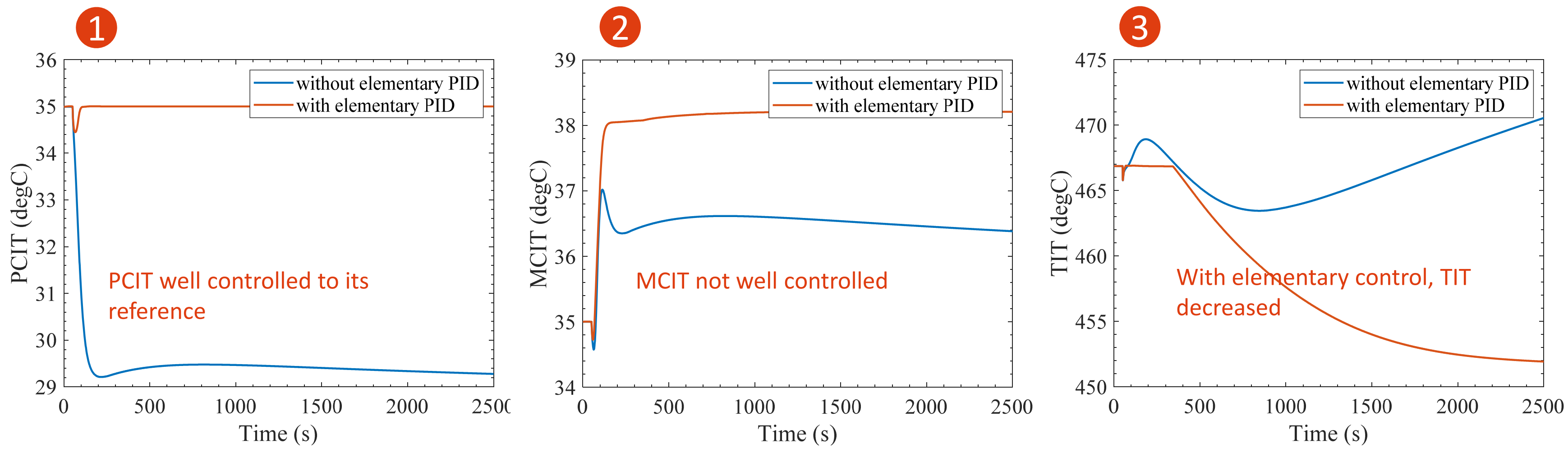






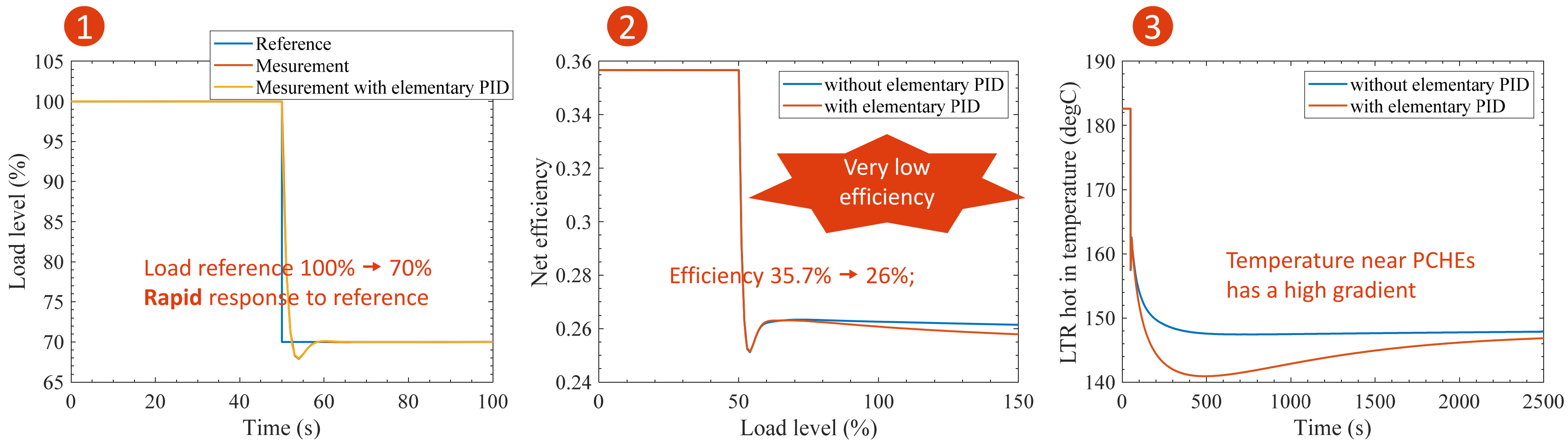
- Response time (to reference): ~150s
- Cycle efficiency: a drop of 2.2%
- Pressure protection is important to protect compressor operation

Inventory control (2)



- ➢ MCIT not well controlled: limit of pressure drop in water side of cooler 2 when the cooling water mass flow rate augments to decrease MCIT
- ➢ Conflict between MSOT and TIT control

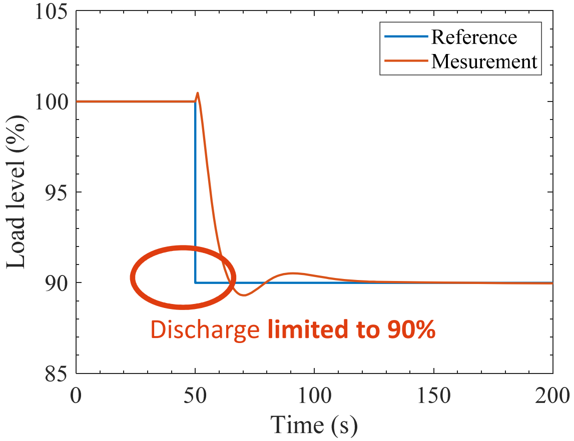
Bypass control



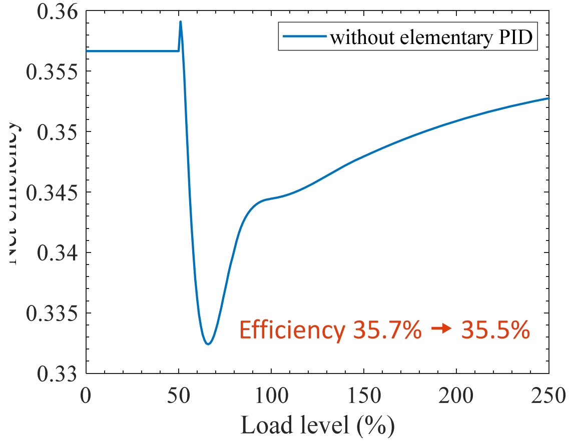
- Response time (to reference): <10s
- Cycle efficiency: a drop of 9.7%
- High gradient of temperature for PCHEs

Variable PC rotation speed control

1



2



- Response time (to reference): ~80s
- Cycle efficiency: a drop of 0.2%

Conclusions and perspectives

- A dynamic model developed for a sCO_2 recompression cycle with intercooling and preheating in Dymola
- Importance of elementary temperature control loops
- Advantages and disadvantages of three control strategies
  - Inventory control: maintain the cycle efficiency within a certain range but the response time is relatively slow
  - Bypass control is rapid but would have a drop on cycle efficiency
  - Variable PC rotation speed can keep the cycle efficiency better than inventory control but it is limit on the achievable load level
- Combination of three methods could help propose an optimized global control strategy with a good balance between efficiency and response speed for the whole range of load


Questions?