Integrated Optimization and Control of a Hybrid Gas Turbine/sCO_2 Power System

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Timothy J. Held

ECHOGEN power systems

The Fine Print

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Background and overview

- FOA objective: Develop modular turbine-based hybrid heat engines for FE applications that:
  - Integrate with modular gasifiers
  - Promote the clean and efficient use of stranded fuel assets
  - **Help to better manage grid demand response for load-following**
  - Improve the efficiency and environmental performance of natural gas compression stations

- Echogen project – Hybrid Gas Turbine/sCO_2 Power Cycle
  - Leverages Echogen commercial sCO_2 power cycle development
  - Allows for tighter integration and optimization of gas turbine and sCO_2 bottoming cycles for steady-state and transient operations
  - Goals:
    - Better overall cycle efficiency than standalone optimization
    - Improved transient performance to achieve faster demand response of combined system

Team

- Echogen Power Systems (EPS)
  - Prime recipient
  - GTsCO2 design
  - Power cycle modeling and simulation
- Siemens Finspång
  - Gas turbine transient model and control simulation
- Siemens PTI
  - Grid simulation

Echogen Background

Echogen Power Systems is the industry leader in development of supercritical CO_2 heat recovery systems.

Founded in 2007, EPS has progressed from small multi-kW demonstration units to the recent multi-MW heat recovery package, the EPS100.

2007	Echogen founded
2011	Partnership with ***Dresser-Rand*** (now Siemens) for oil & gas market; development of EPS100 7.5 MW engine begins
2013	Partnership with ***GE Marine***; development of EPS30 1.35 MW engine begins
2014	EPS100 completes factory testing
2016	EPS30 testing commences with high-speed alternator subsystem test
2018	**Pursuing commercial pilot sites for all EPS products**

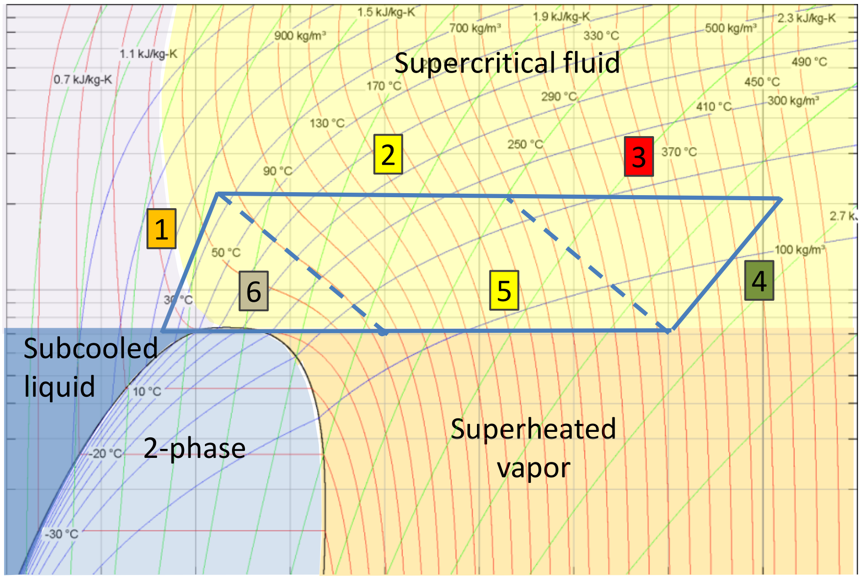
Plans for the future…

- *Introduce additional EPS engine sizes*
- *Progress to primary power & combined cycle*
- *Industrial and nuclear applications*

sCO_2 Technology Benefits

Water-Free	• Totally dry, water-free, closed-loop process • Air cooled condenser (water cooled condenser optional)
Compact	• No exhaust bypass stack required • 25-40% smaller footprint than steam; minimally invasive retrofit
Flexible	• Suitable for remote operation; no boiler operator required • 20-30 minutes to full load
Efficient	• Simple heat transfer, no boiling process (supercritical) • Direct in-stack WHX, no intermediate fluid required
Competitive	• Lower LCOE than other heat recovery alternatives • Competitive OPEX and LTSA
Clean	• Produces electricity without incremental emissions • Working fluid is stable, benign and non-flammable

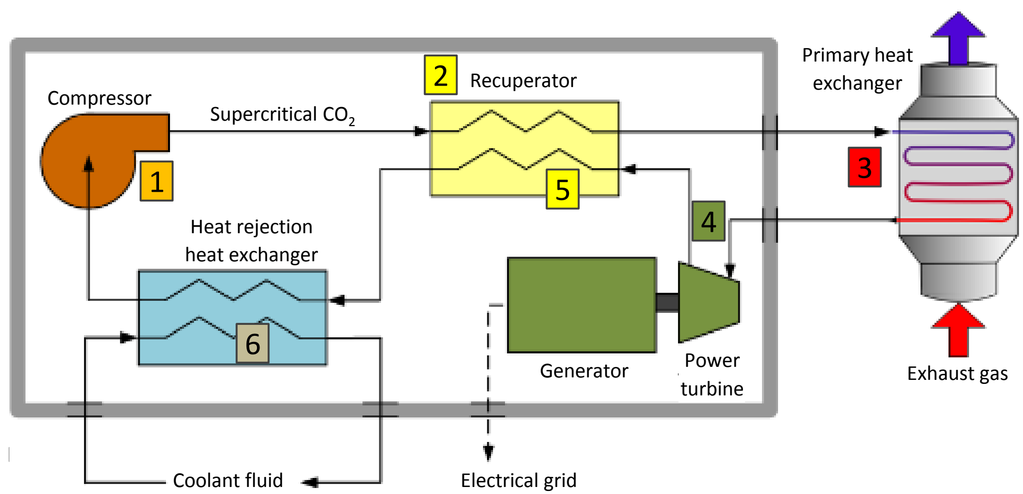
Simple recuperated sCO_2 cycle



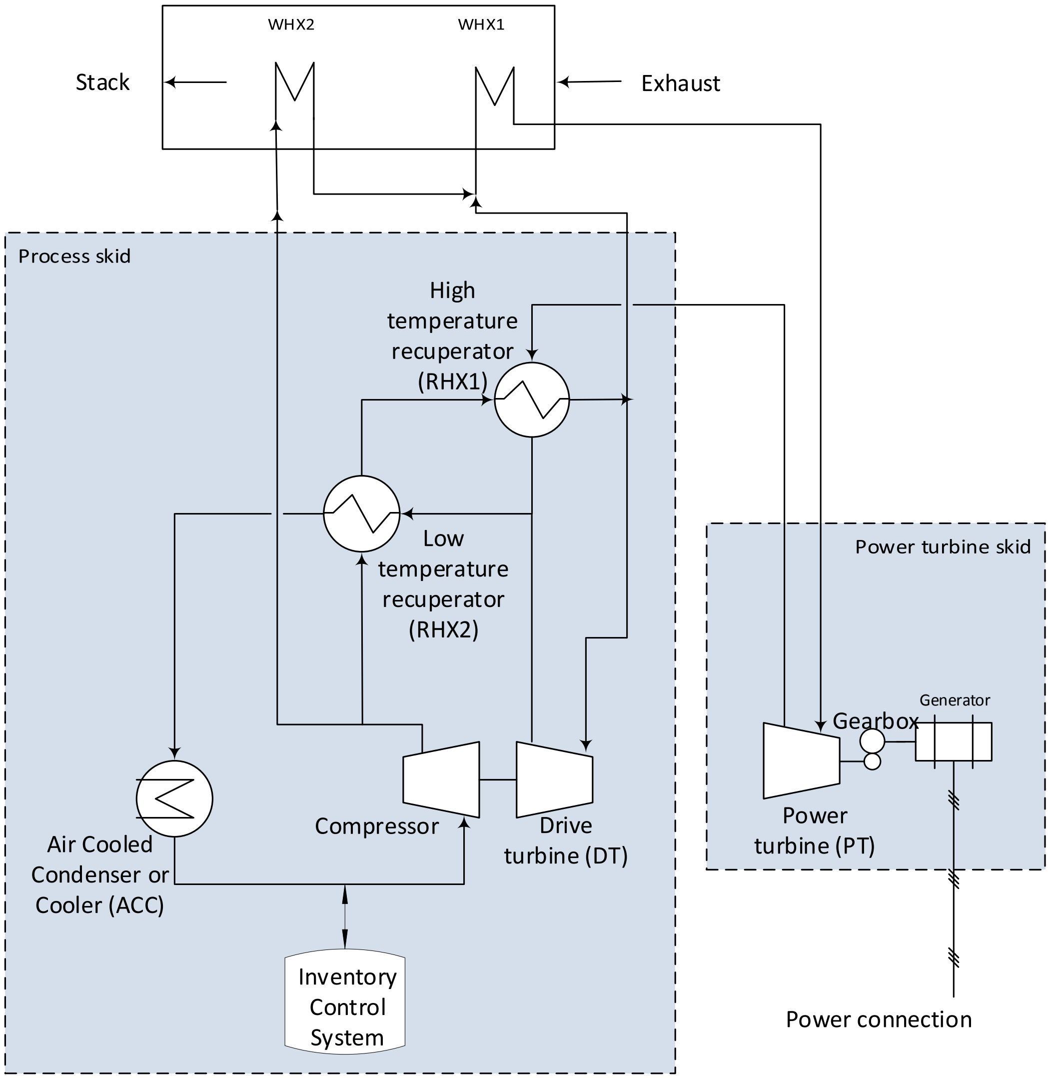
1 Compressor
2 Recuperator
3 Primary HX
4 Turbine
5 Recuperator
6 Heat rejection HX

CO_2 becomes supercritical above 31C, 74 bar. Above the critical pressure, there is no constant-temperature phase change when adding heat

1. High-density CO_2 compressed
2. CO_2 preheated at recuperator
3. External heat added at primary heat exchanger
4. High energy CO_2 expanded at turbine drives generator
5. Expanded CO_2 is pre-cooled at recuperator
6. CO_2 is cooled to high density at heat rejection HX



Not-as-simple recuperated cycle



- Cycle designed for waste heat recovery
- Reduces exhaust temperature to ~100°C
- Flexible, allows for integration of multiple heat sources at different temperatures
- Separate turbines to drive generator and compressor

Echogen EPS100

EPS100 process skid

EPS100 power skid

The EPS100 is the largest sCO_2 power loop in the world and first commercially available sCO_2 system

EPS100 Testing – Key Accomplishments

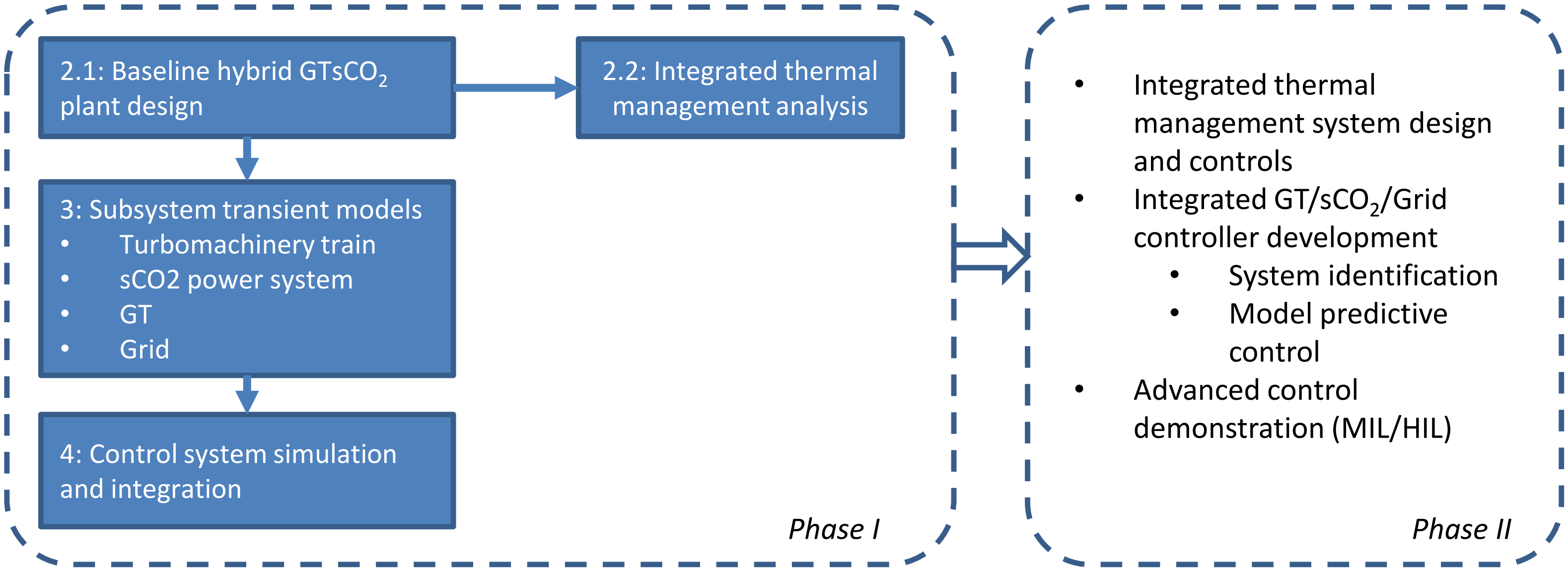
EPS100 Process Skid

EPS100 Power Skid

- Testing
  - ✓ Phase I: Validation of components - completed
  - ✓ Phase II: Full speed no load - completed
  - ✓ Phase III: Durability – completed
  - ✓ Phase IV: Endurance Run - completed
- System control and stability fully demonstrated
- Component performances meet or exceed expectations
- Turbopump run to max conditions
- Generator speed control stability demonstrated
- Power turbine electrical output = 3.1 MWe *(max power at test stand conditions, limited by steam available)*
- 330 hours turbo-pump run time
- 170 hours power turbine run time

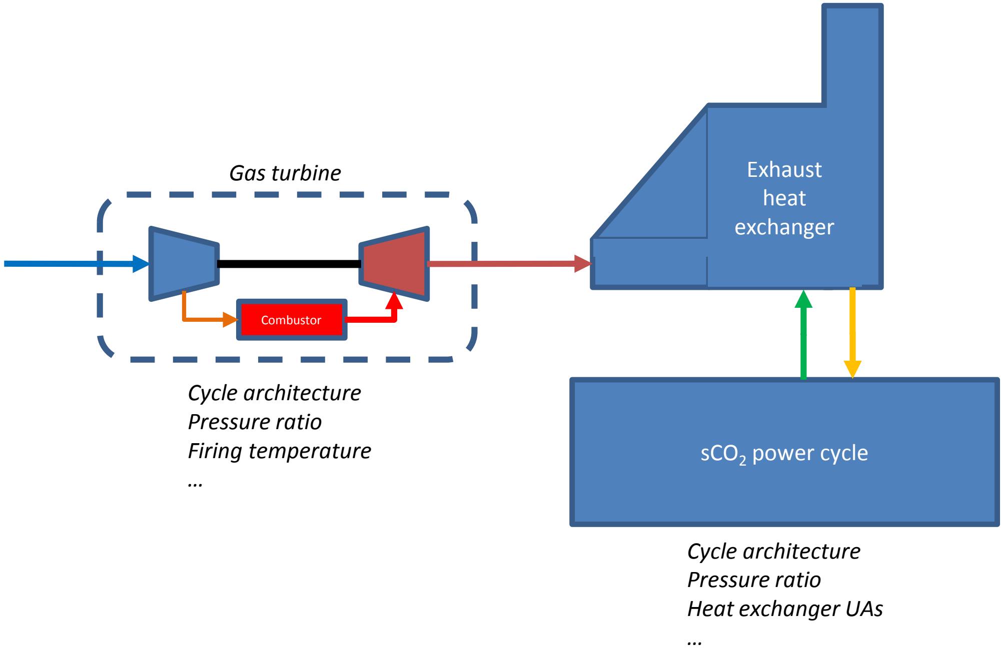
TECHNICAL APPROACH

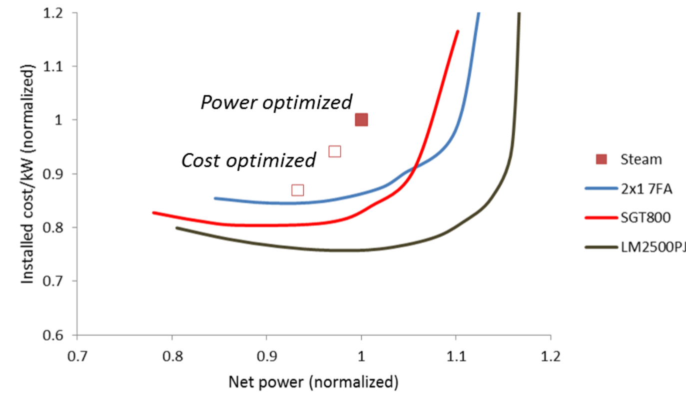
Technical approach - overview



- Two major work elements
  - Optimization of hybrid system performance
  - Optimization of hybrid system controls

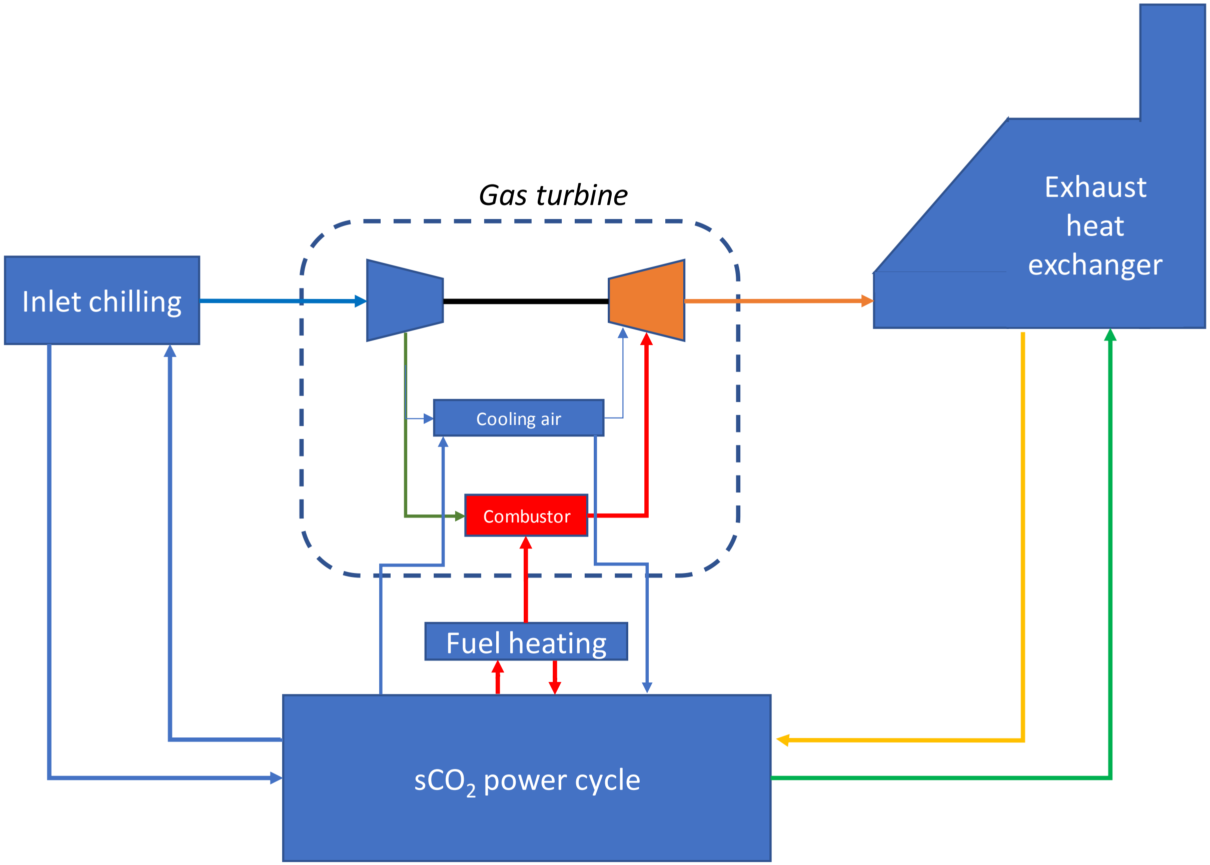
2.1 Baseline hybrid GTsCO_2 plant design





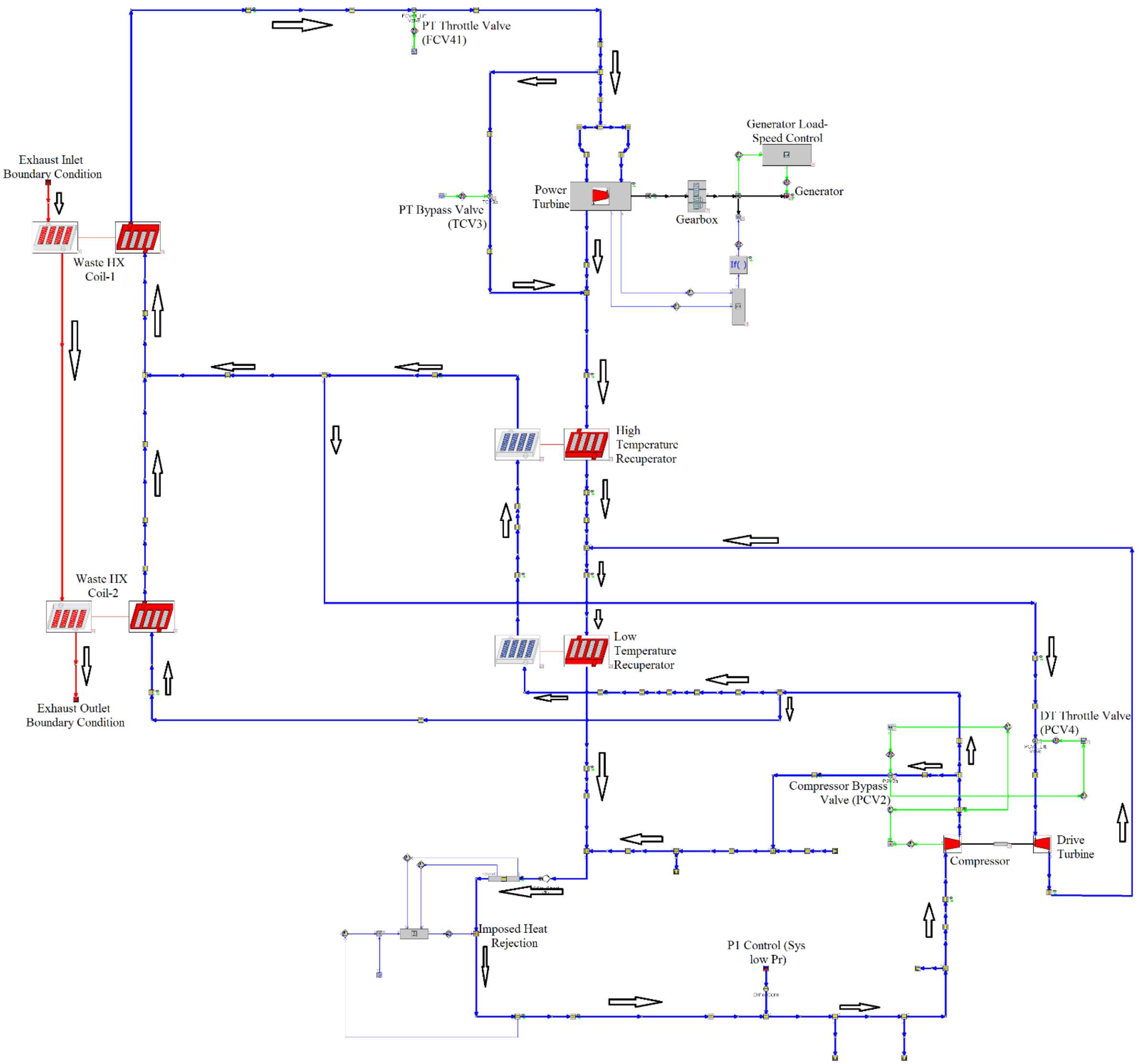
- Joint techno-economic optimization (TEO) process
  - Multivariate non-linear optimization code
  - Basis function can be capex (cost/kW), LCOE, cycle efficiency or other
  - Vary cycle parameters, heat exchanger sizing, etc. to minimize basis function
- Previous work optimized sCO_2 cycle in isolation (GT cycle fixed)
- This program, perform joint optimization of GT+sCO_2 cycles

2.2 Integrated thermal management



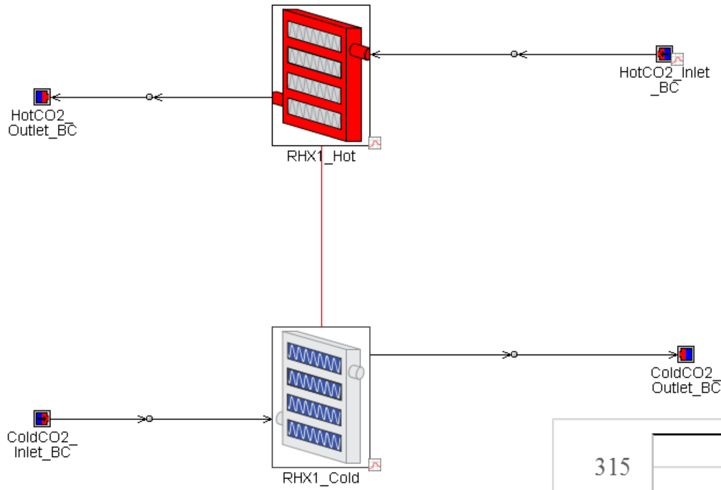
- Extension of 2.1
- Include other thermal integration processes (e.g. fuel performance heating, inlet chilling, etc.)

3: System transient model development

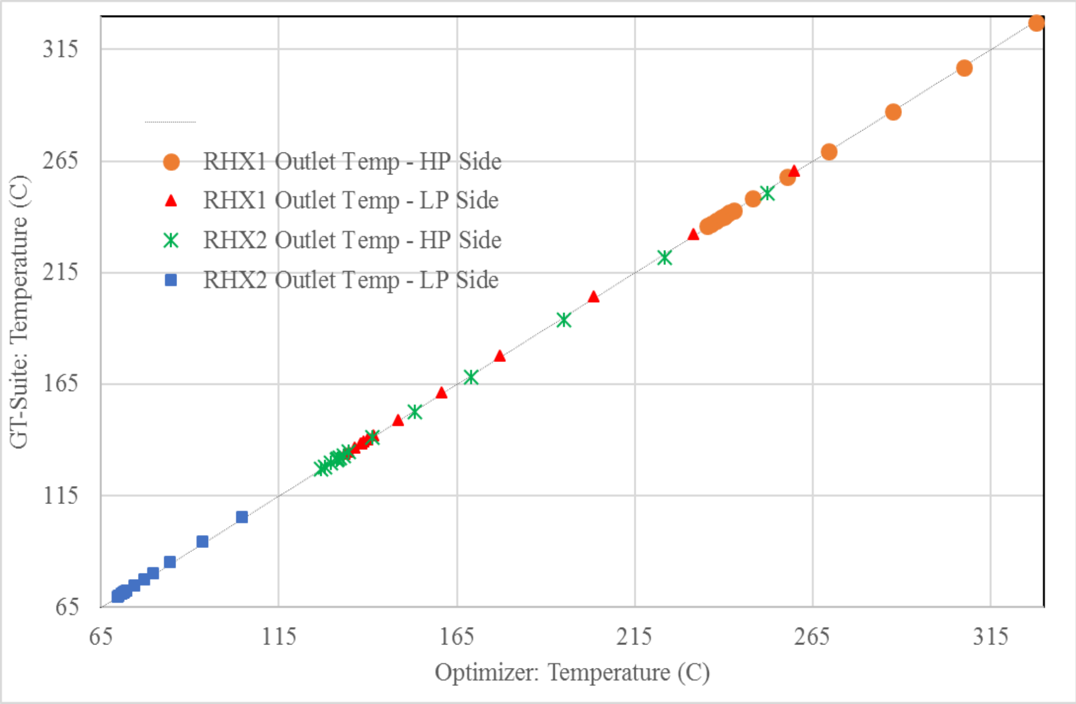


- sCO_2 system & T/M transient model in GT-Suite
- GT model using Siemens Finspång transient model
- Grid model and example demand profiles from Siemens PTI / PSS®E code
- Combine using Functional Mockup Interface (FMI) standard

3: System transient model development



- Model validation – comparison to steady-state solutions of individual component models



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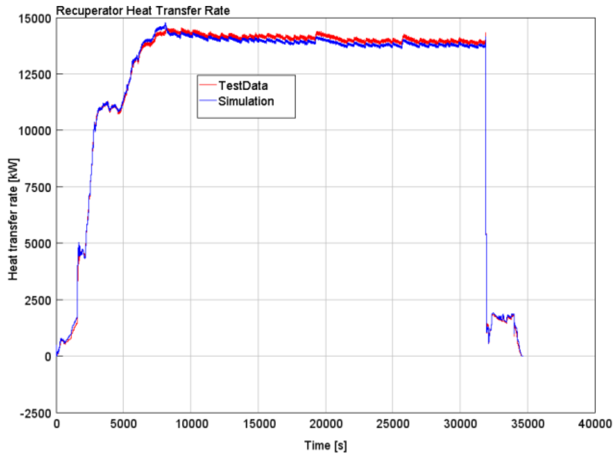
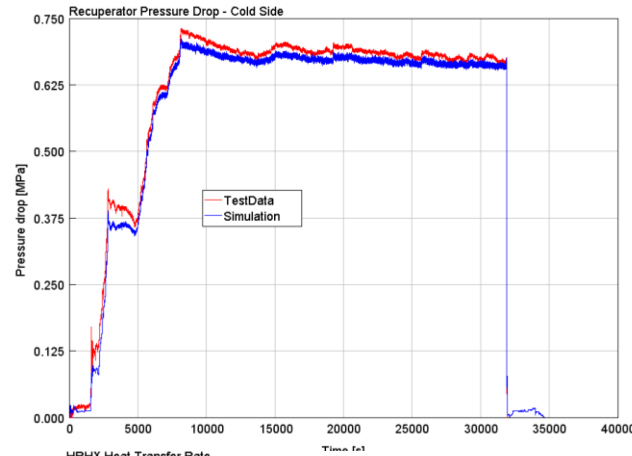
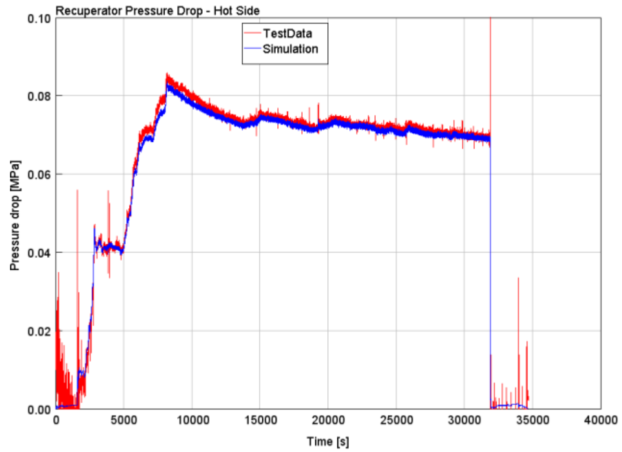
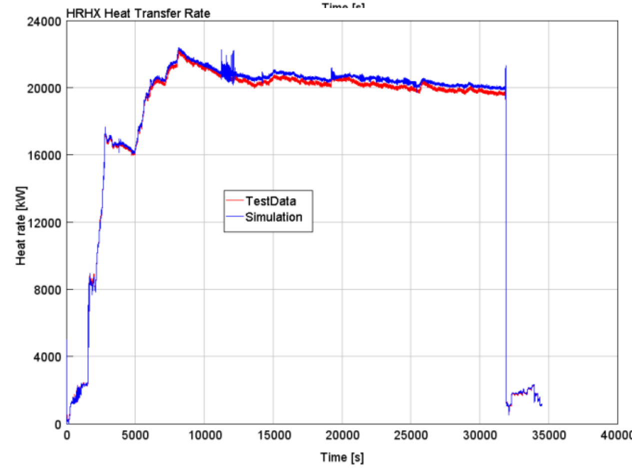


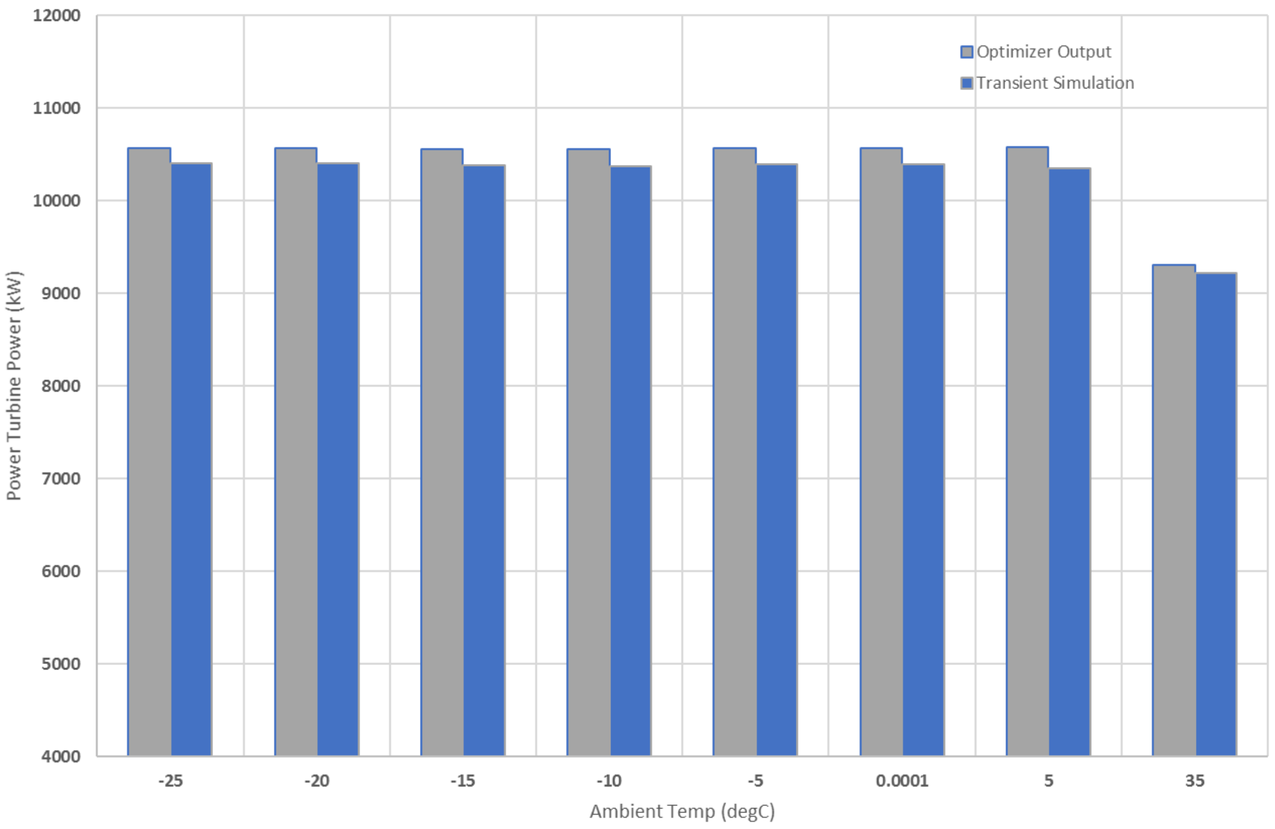






- Example transient model results validated by EPS100 test data

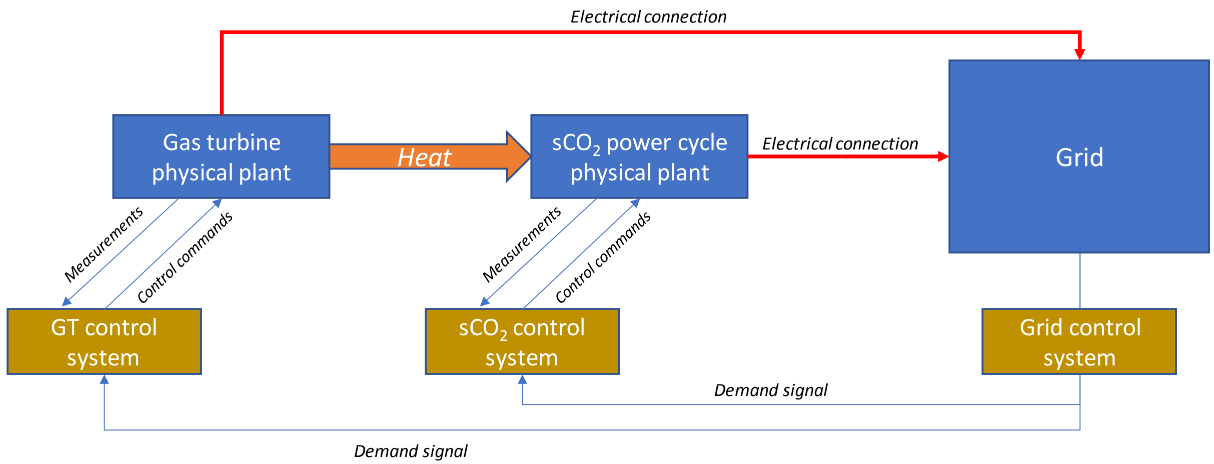
3: System transient model development



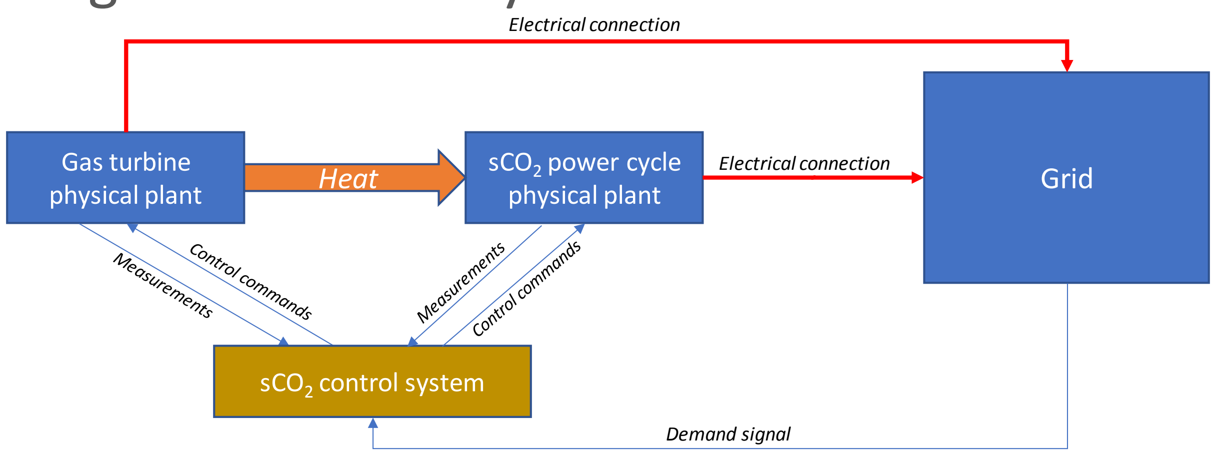
- Initial pass of isolated sCO_2 power cycle optimization completed for fixed SGT-750 configuration
- Transient model matched to steady-state code

4: Control system simulation & integration

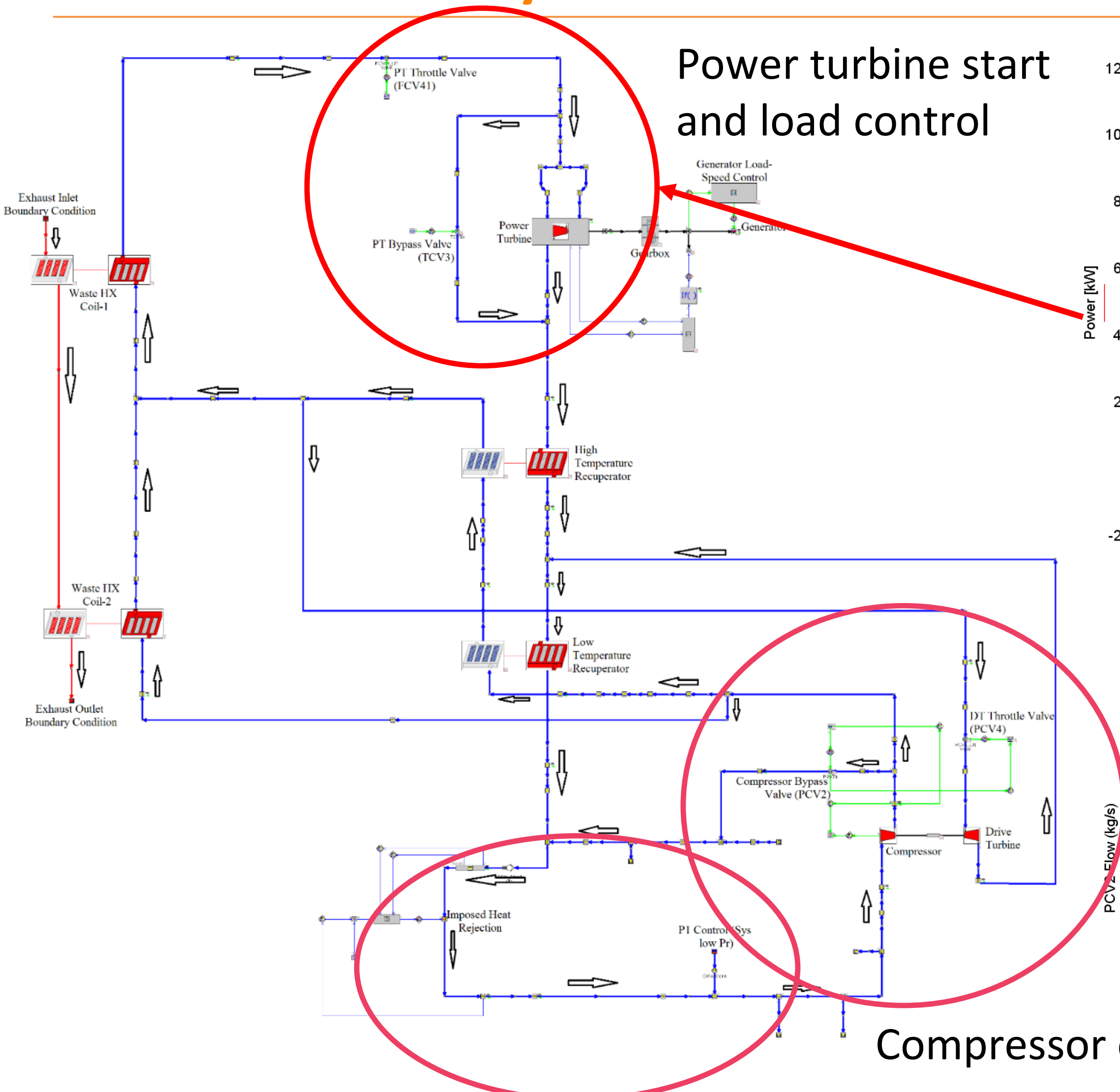
- Baseline decoupled control strategy



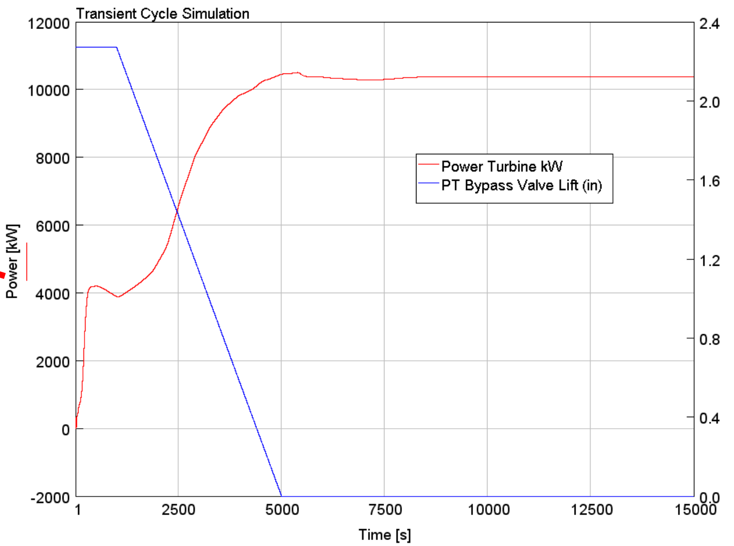
- Target integrated control system

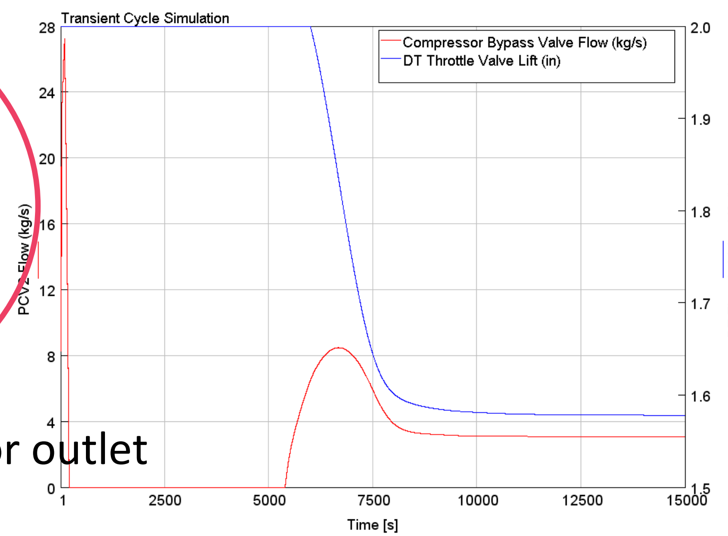


3: Control system simulation



Power turbine start and load control





Compressor outlet pressure

Compressor inlet pressure

Current status

- Evaluating GT simulation software for incorporation into TEO model
  - Also developing in-house integrated model in parallel
- Initial sCO_2 system transient model completed
- Control system model being converted to Simulink for FMI modulization