2021 LEAP Workshop

Rapid Load Response of SOFC-GT Hybrid Systems to Grid Demand

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Disclaimer

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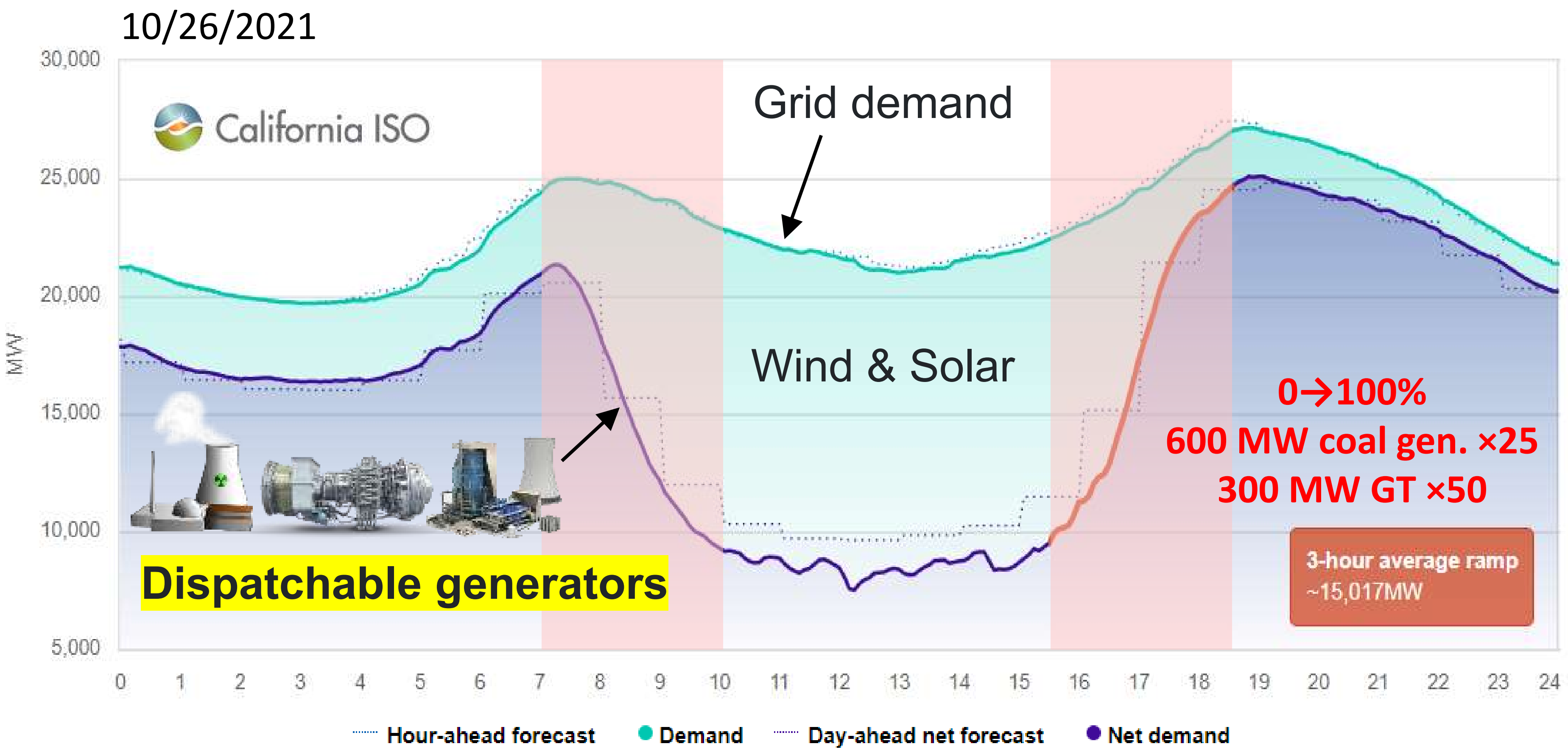
Improved flexibility requirements



Requirements:

- *Deep turndown*
- *Rapid ramping*
- *Fast start-up*

Challenges:

- *Increased emission at part load*
- *Phase-out*

Rapid load transition is essential for integrated energy systems

SOFC-GT hybrids in integrated energy systems

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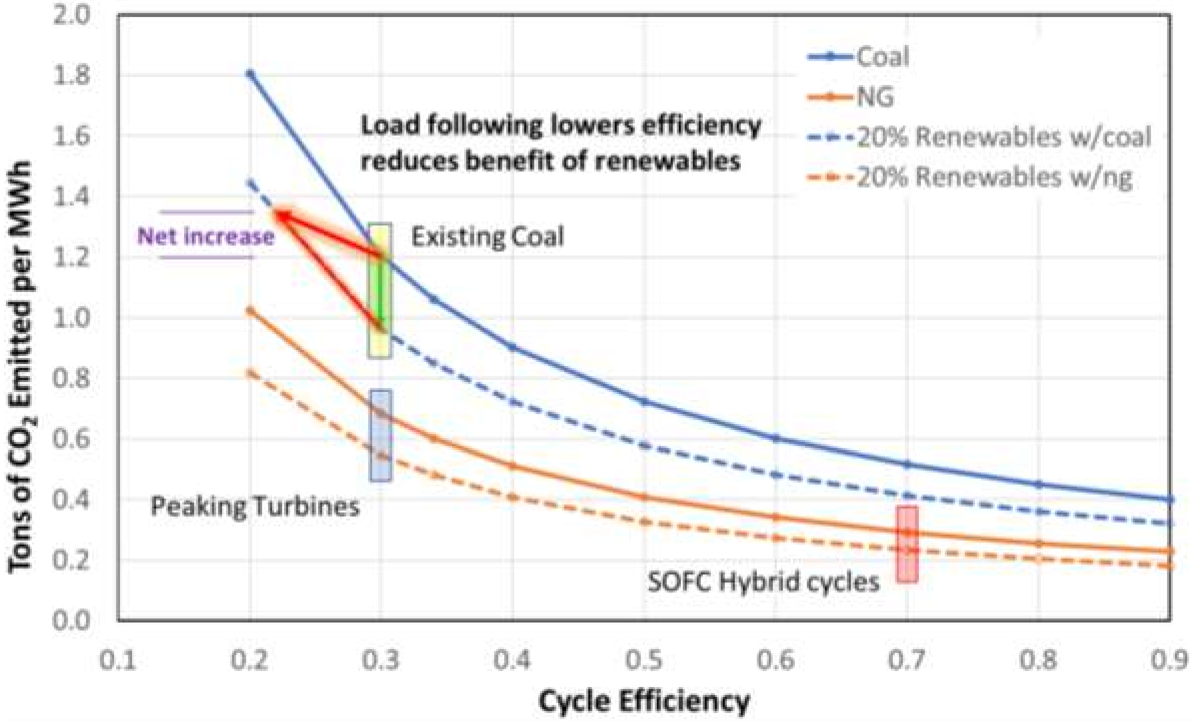
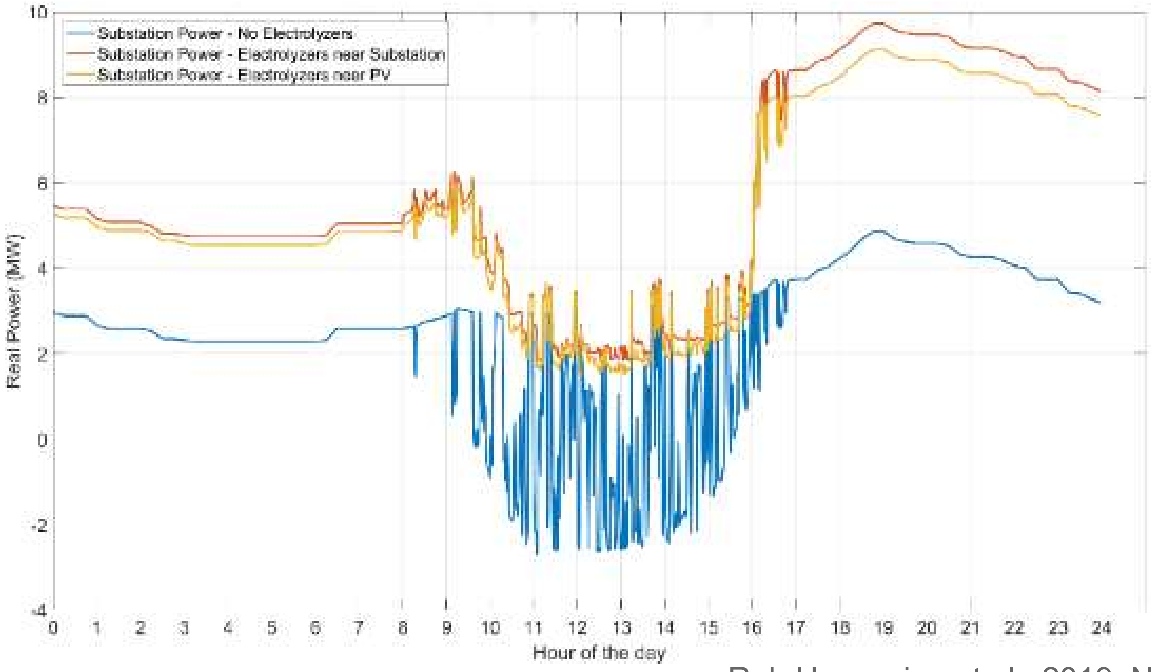




Rob Hovsapian et al., 2019, NREL

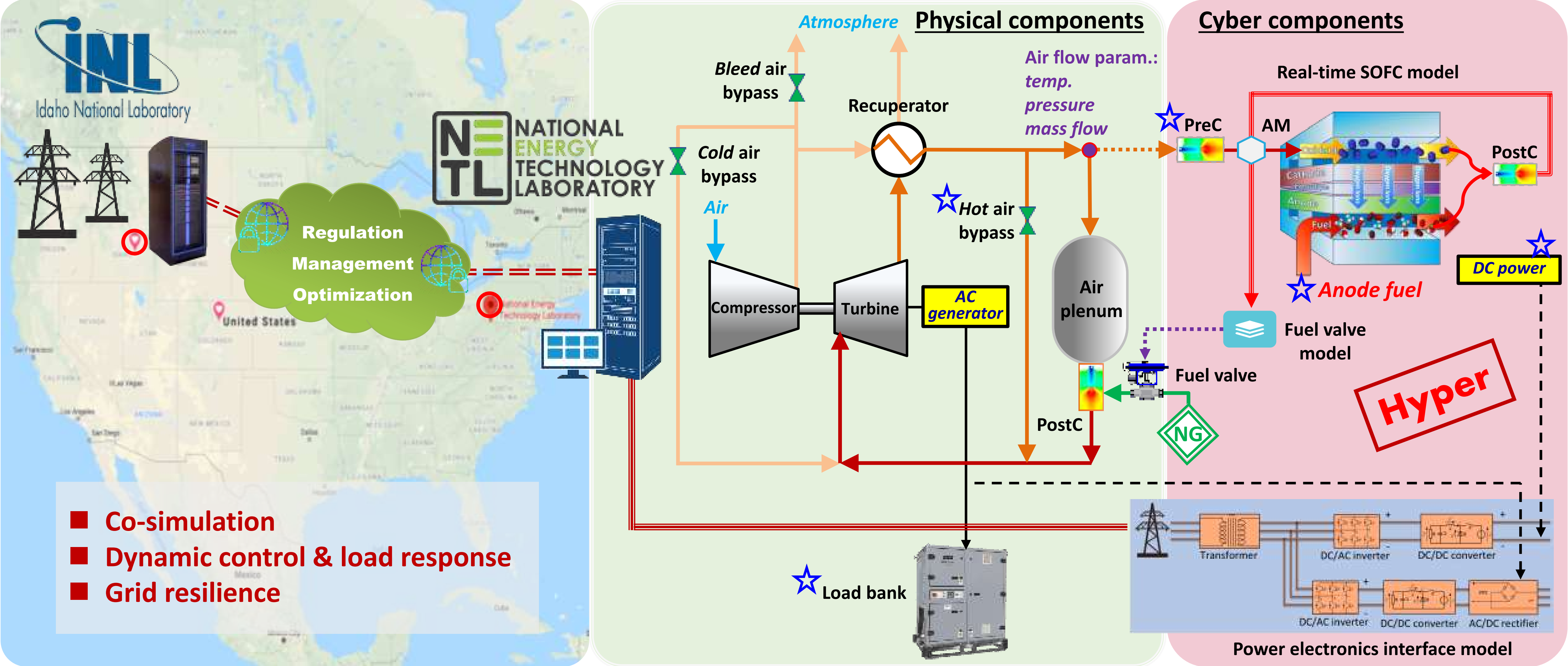
High efficiency –

low emission <0.3 tons CO_2 per MWh (>75% reduction *vs.* conventional coal generator)

Rapid load transition –

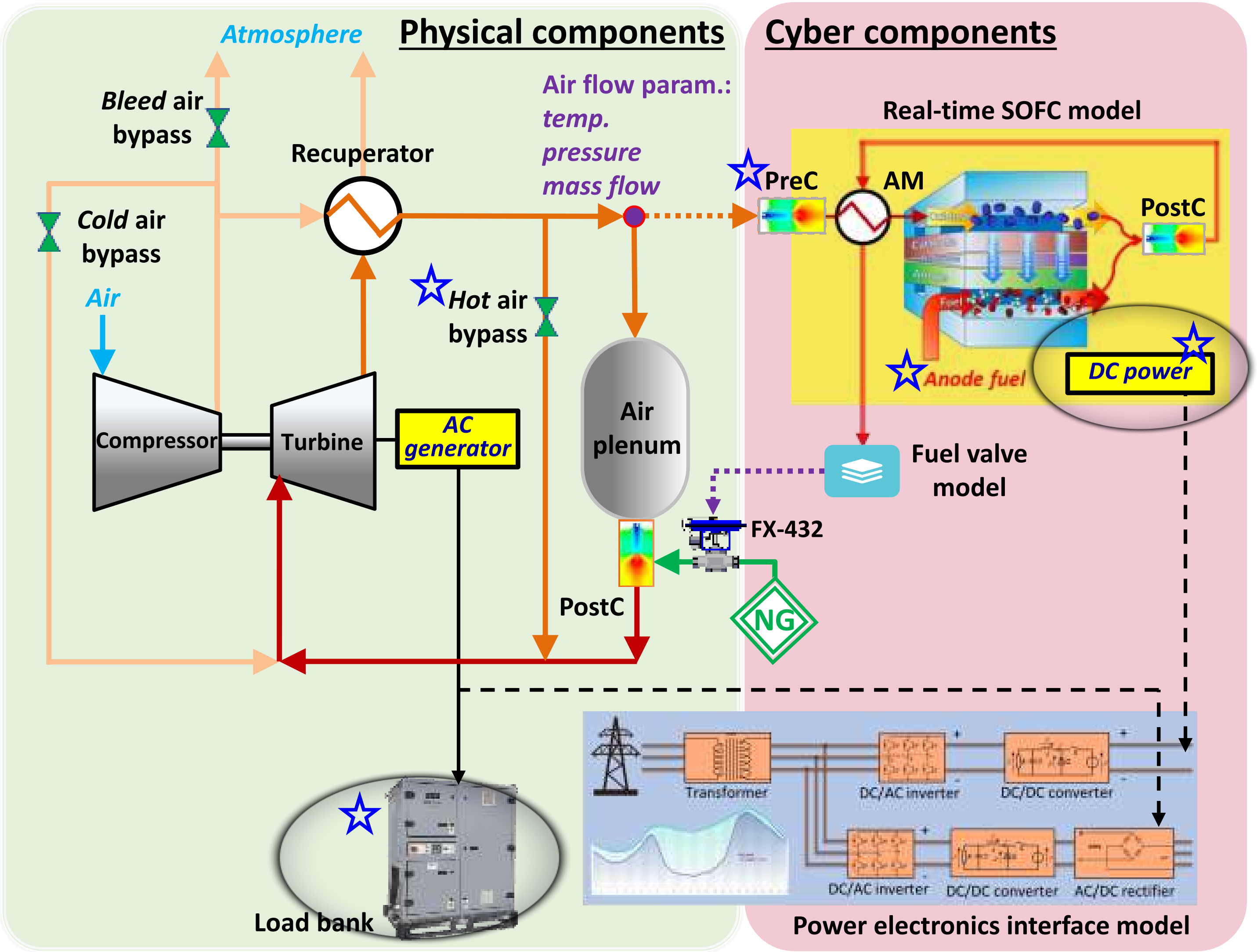
reduced capacity requirement and load cycling of energy storage batterie / electrolyzers

Co-simulation platform between NETL and INL



- Co-simulation
- Dynamic control & load response
- Grid resilience

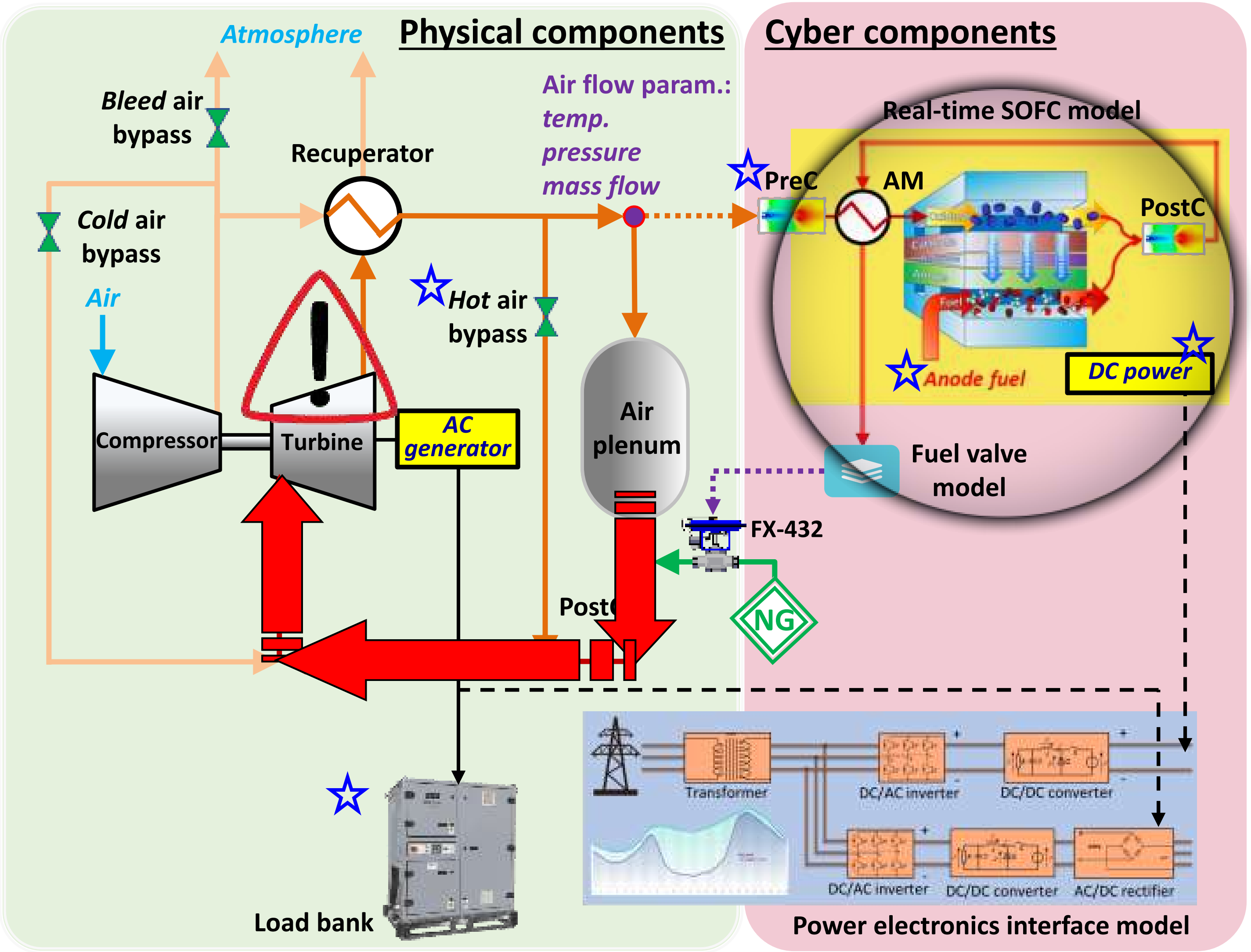
Rapid load transition strategies (50% turndown in 10 s)



***Strategies*:**

- *Ramp SOFC & GT load concurrently*

Rapid load transition strategies

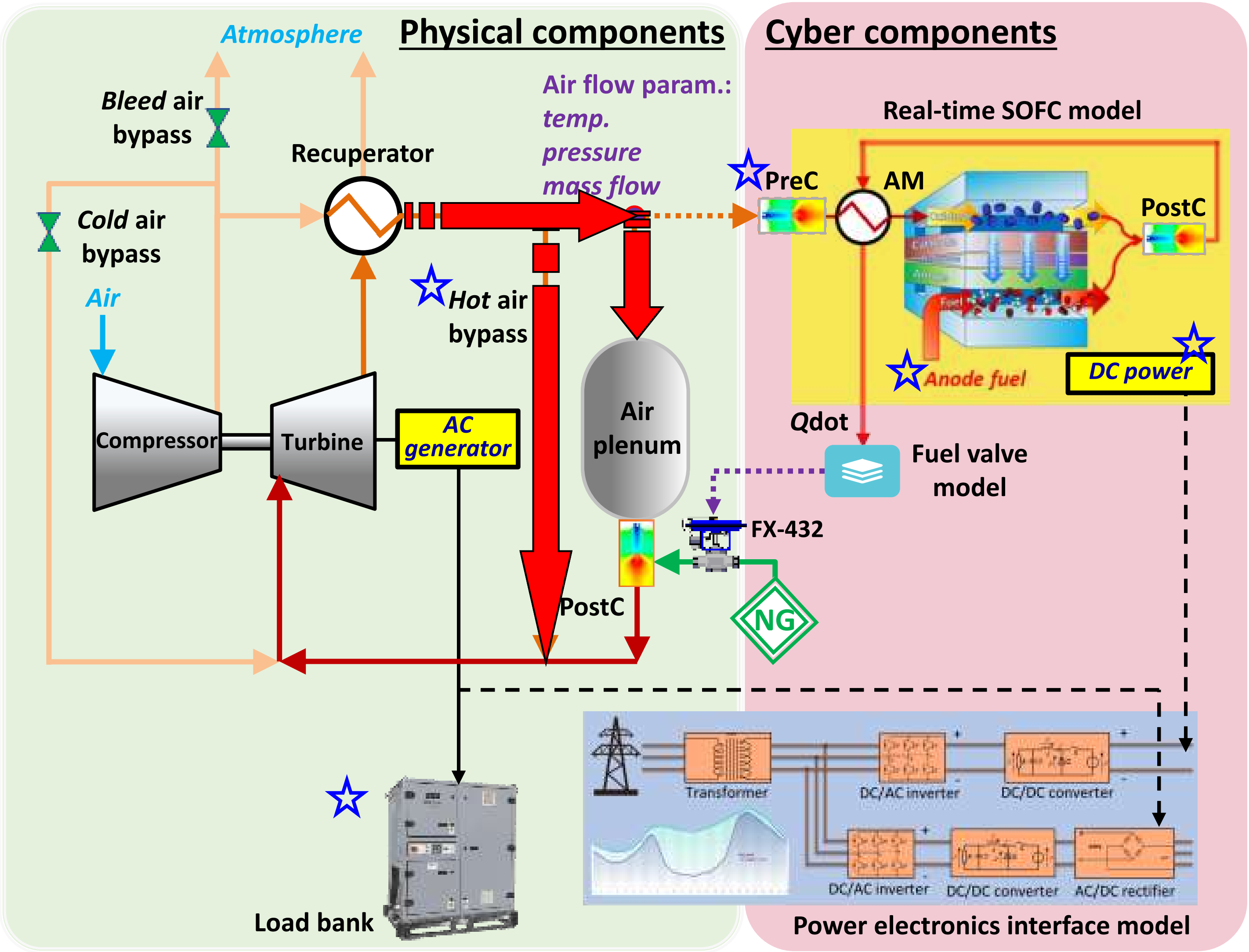


***Strategies*:**

- *Ramp SOFC & GT load concurrently*
- *Manipulate SOFC anode fuel valve*

(maintain SOFC FU at 65%)

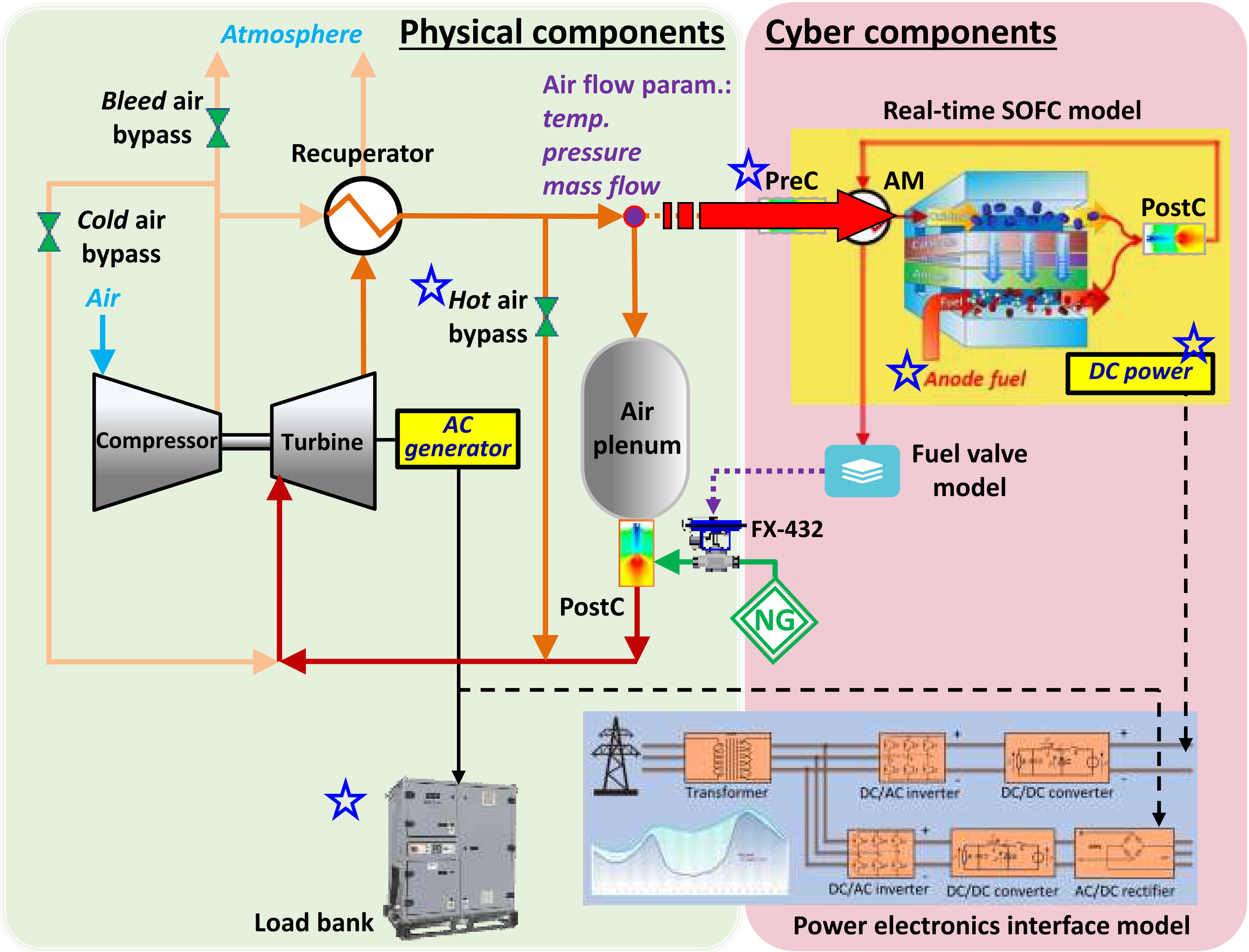
Rapid load transition strategies



***Strategies*:**

- *Ramp SOFC & GT load concurrently*
- *Manipulate SOFC anode fuel valve*
  (maintain SOFC FU at 65%)
- *Manipulate hot-air bypass valve*
  (vary SOFC air flow)

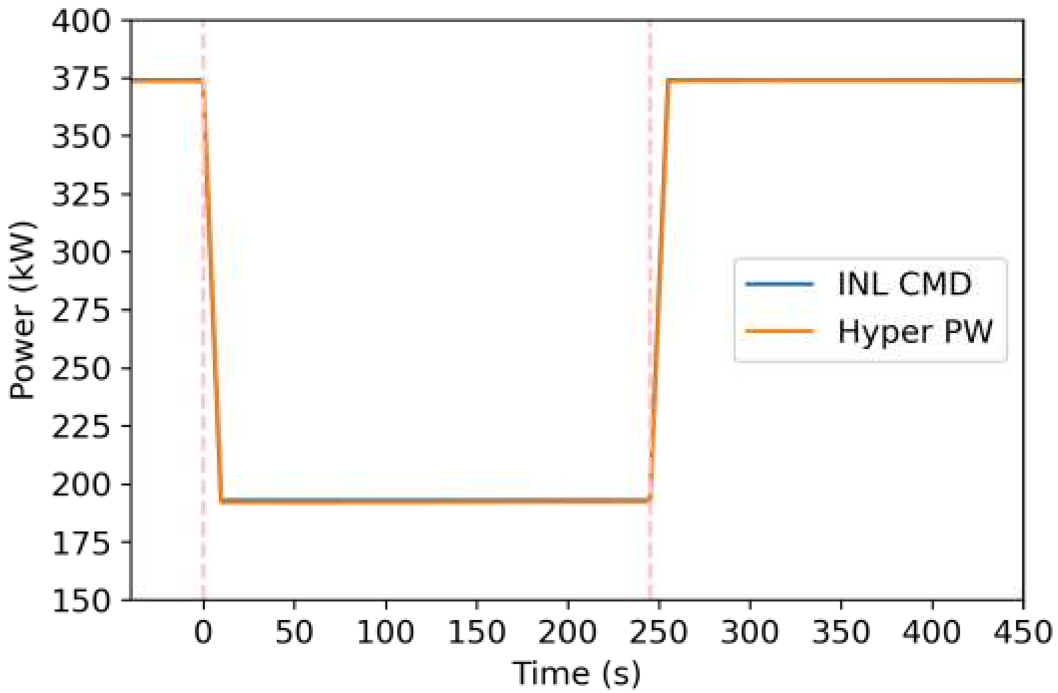
Rapid load transition strategies

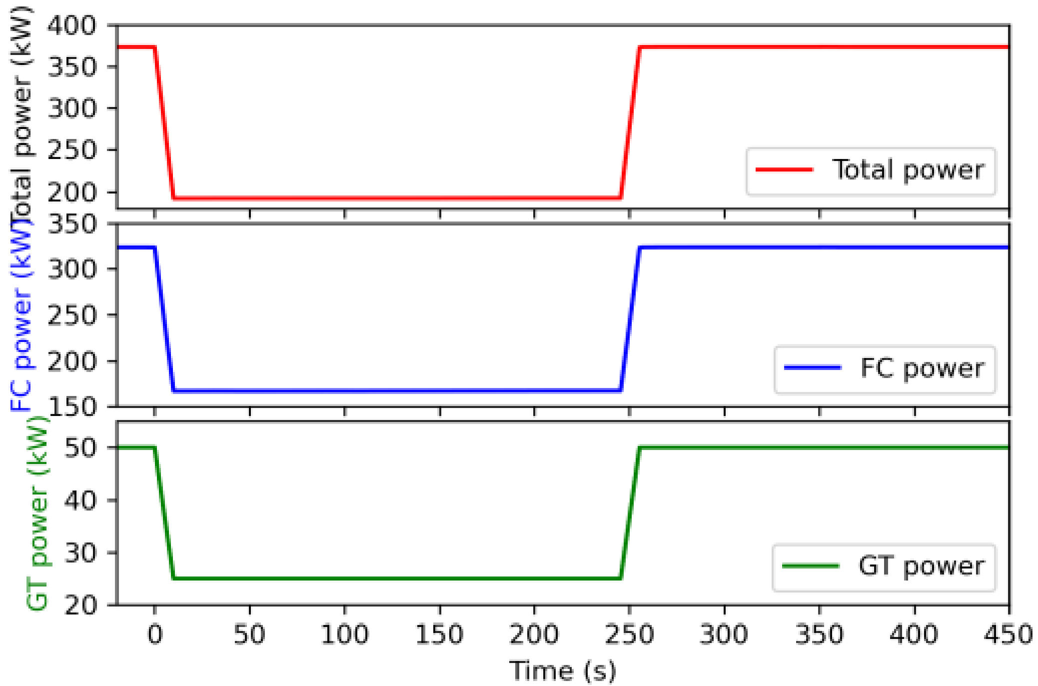


***Strategies*:**

- *Ramp SOFC & GT load concurrently*
- *Manipulate SOFC anode fuel valve*
  (maintain SOFC FU at 65%)
- *Manipulate hot-air bypass valve*
  (vary SOFC air flow)
- *Manipulate fuel to pre-combustor*
  (maintain cathode inlet air temp.)

Rapid Load Response to Grid Demand Signals



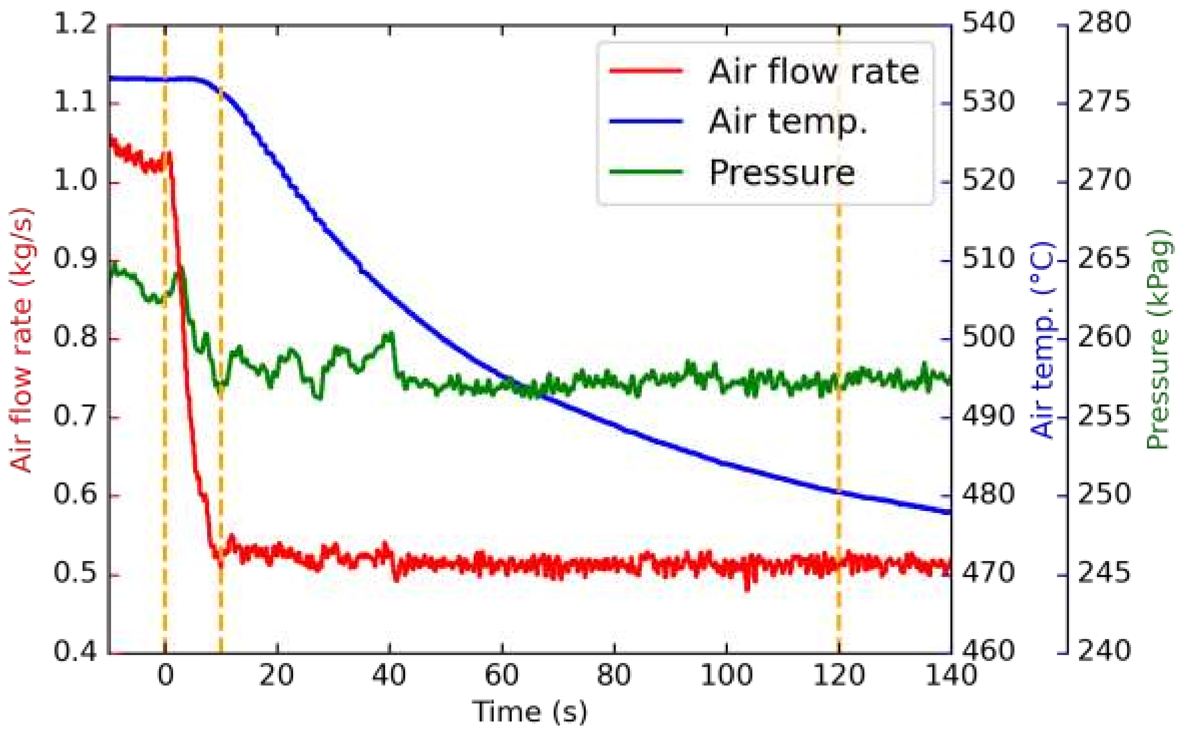


- NETL's Hyper facility load followed INL's grid demand signals
- Total power 373.6 kW → 192.6 kW (48.4% turndown) → 373.6 kW
- SOFC power 323.6 kW → 167.6 kW (48.2% turndown) → 323.6 k
- GT power 50 kW → 25 kW (50% turndown) → 50 kW

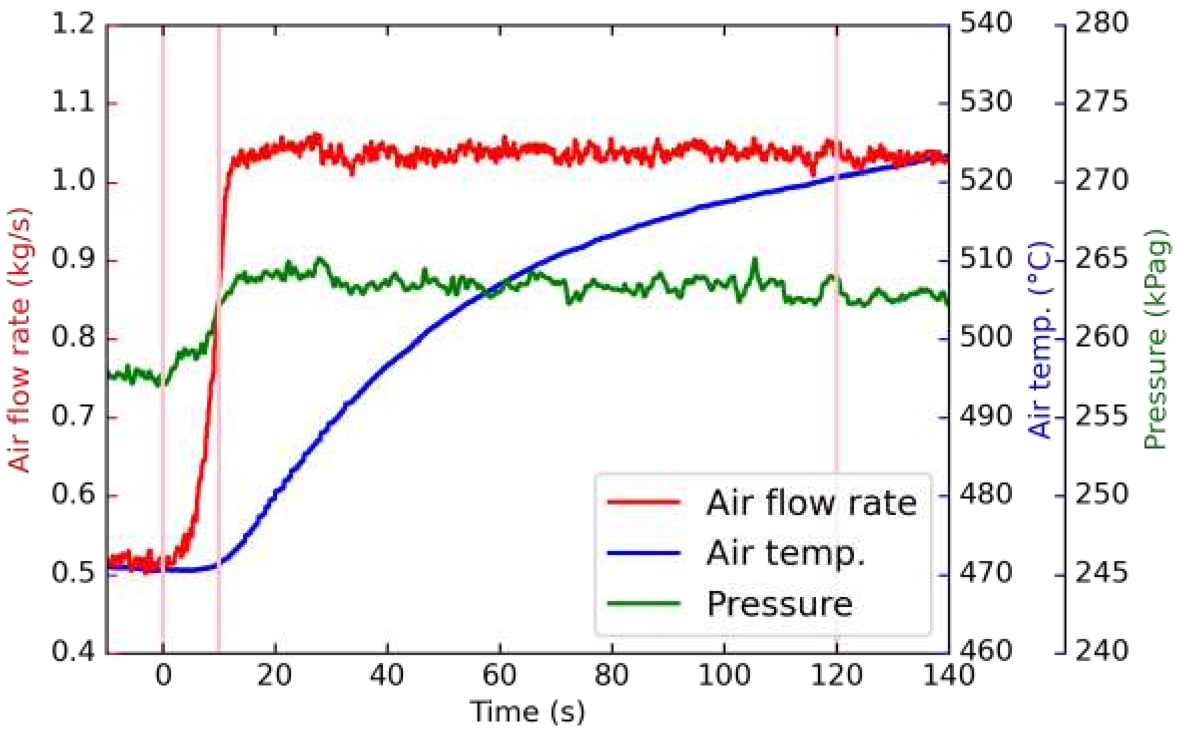
in 10 seconds

Air parameters measured from hardware (*live inputs to the CPS SOFC models*)

Turndown

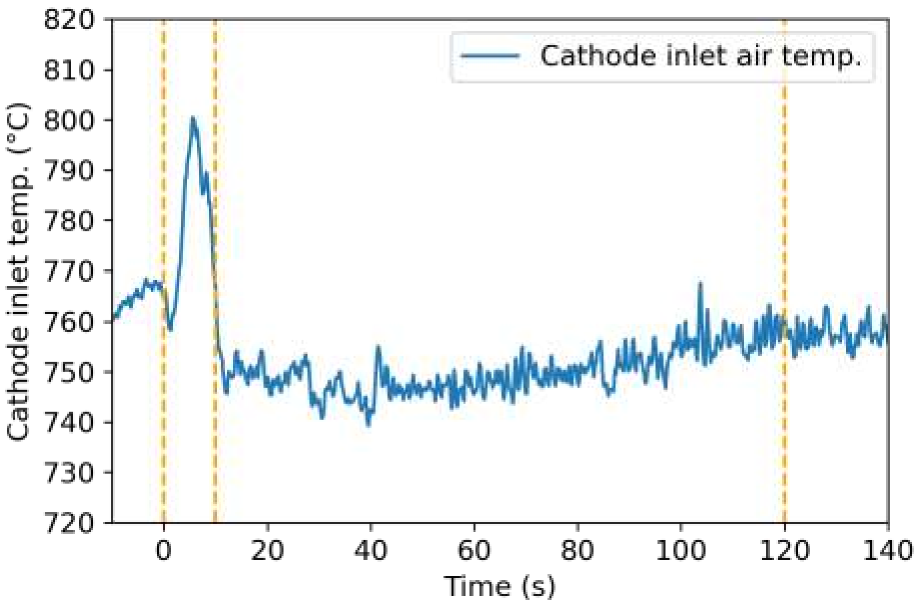


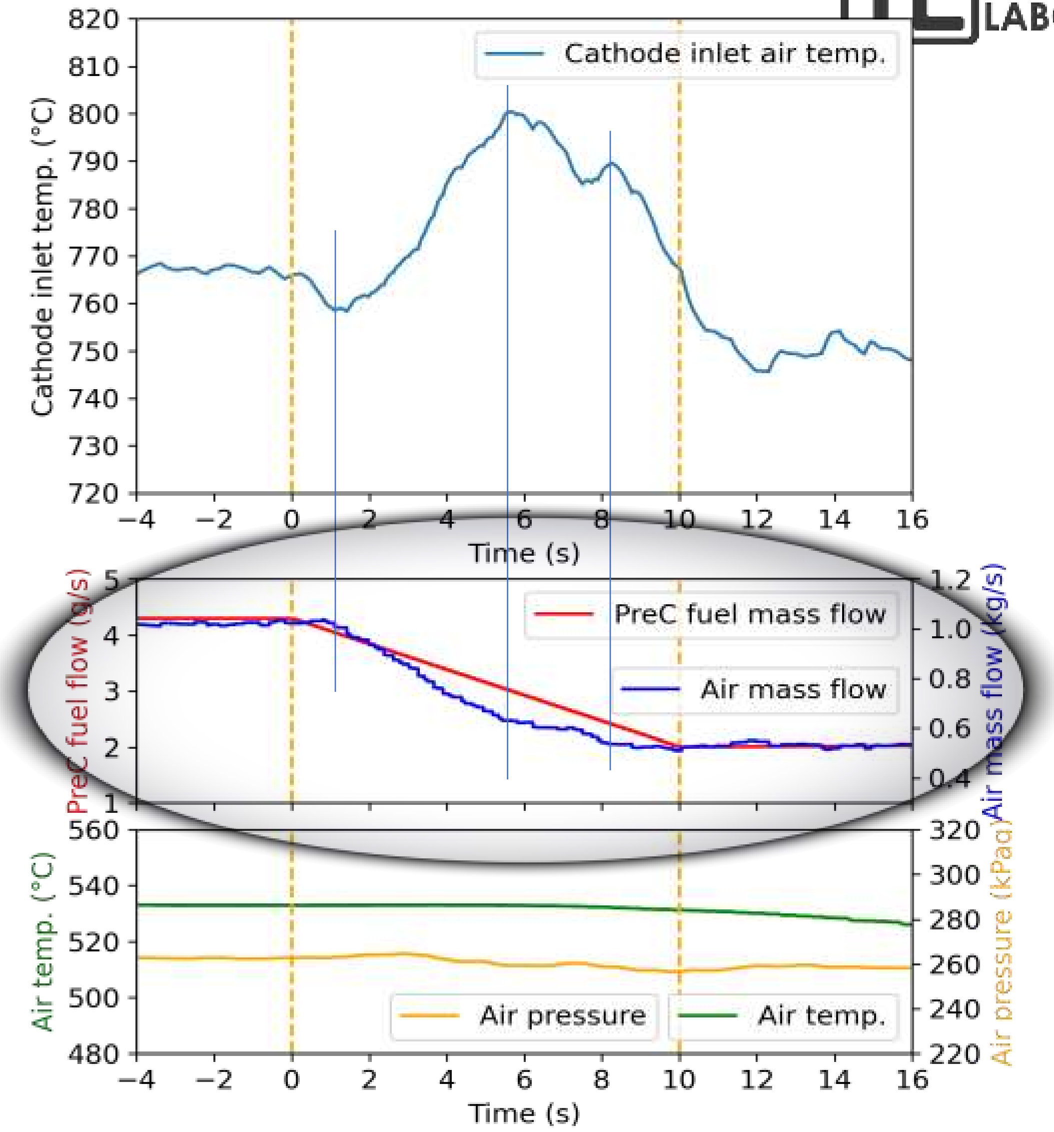
Ramp up



- **The air flow rate was manipulated by the *hot air* bypass valve (25% opening → 100%)**
- **Air temperature transient reflected the coupling of SOFC-GT hybrid and the value of hardware-based simulation**

Cathode inlet air temperature (turndown)

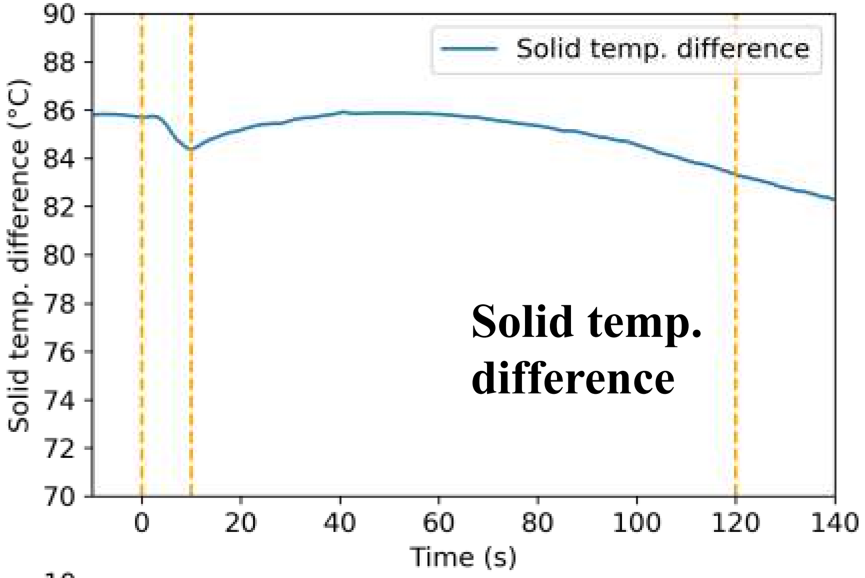


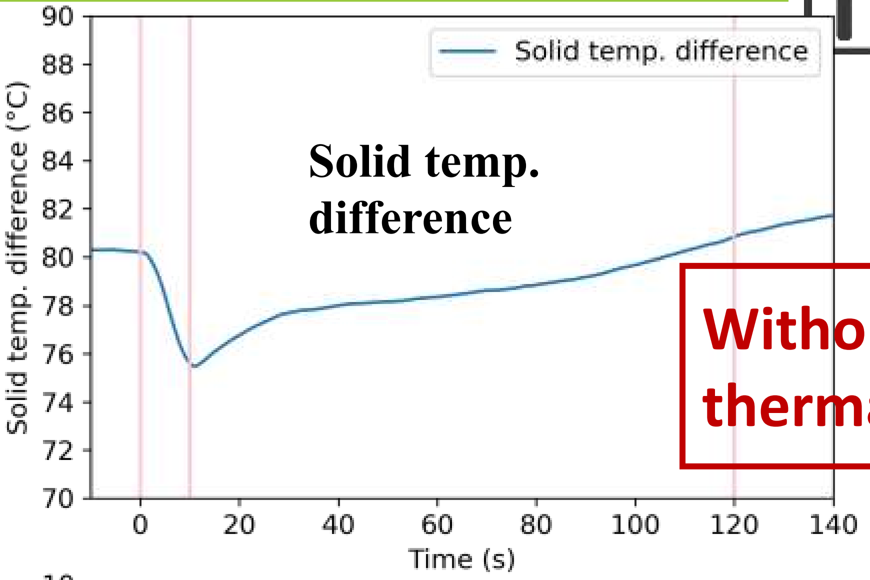


- **Pre-combustor fuel flow and cathode airflow varied linearly**
- **Actual transients from real control hardware (i.e., *hot air* bypass valve) caused non-linear temperature response**

SOFC solid temp. difference & temp. gradient

Turndown

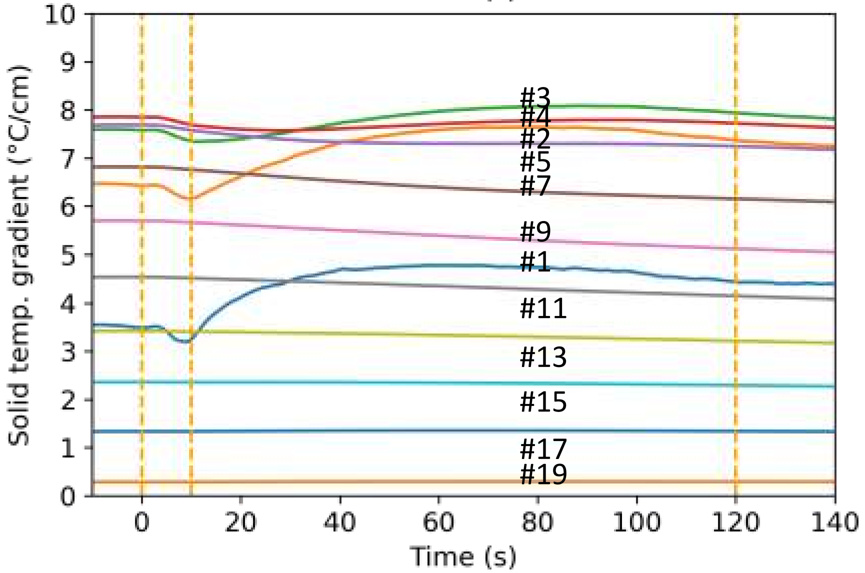


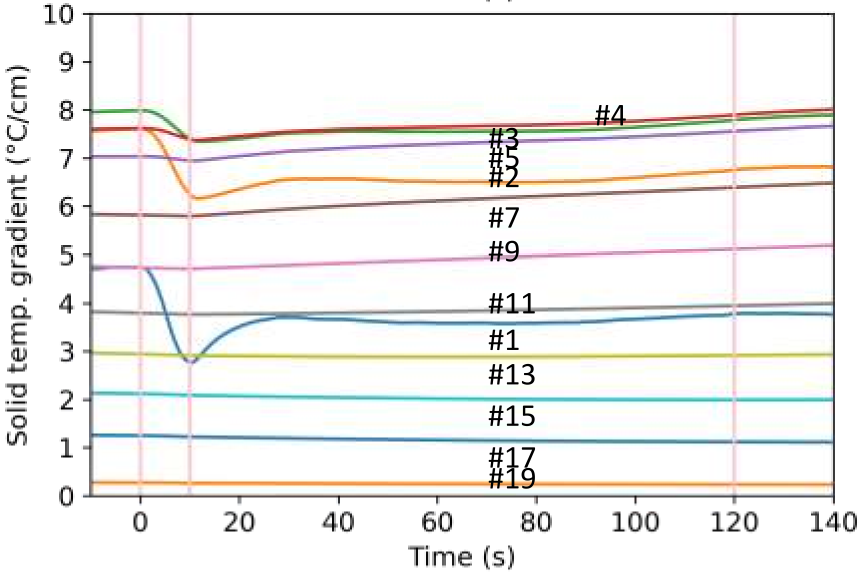


Ramp up

Without violating thermal constraints

Solid temp. gradient

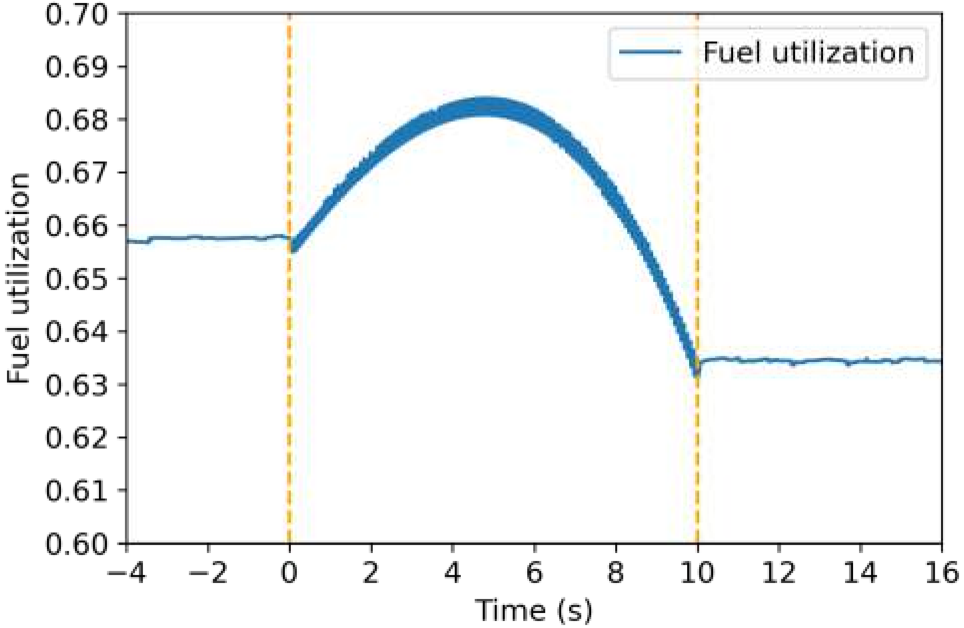




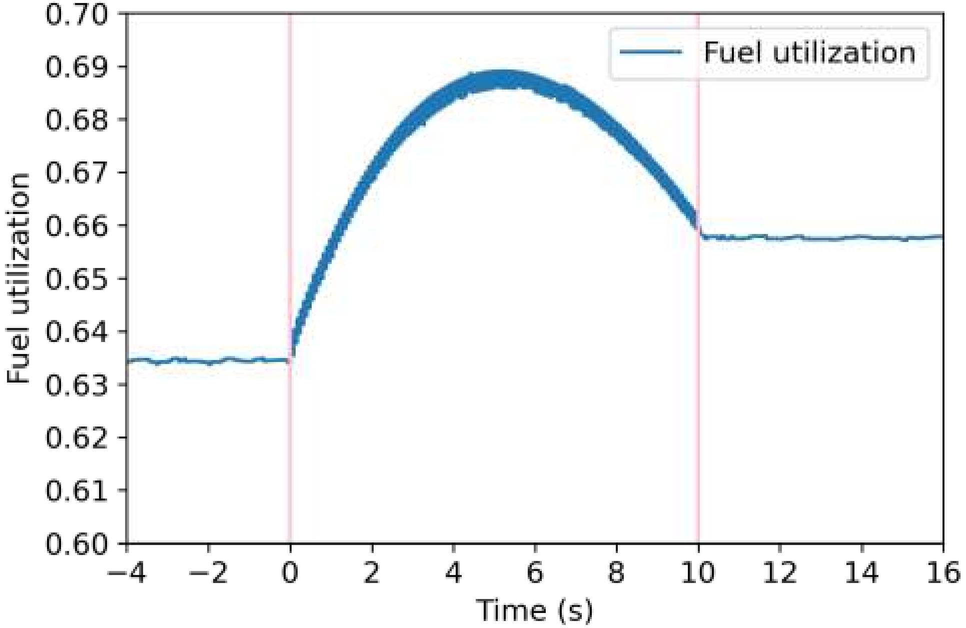
Solid temp. gradient

SOFC fuel utilization

Turndown



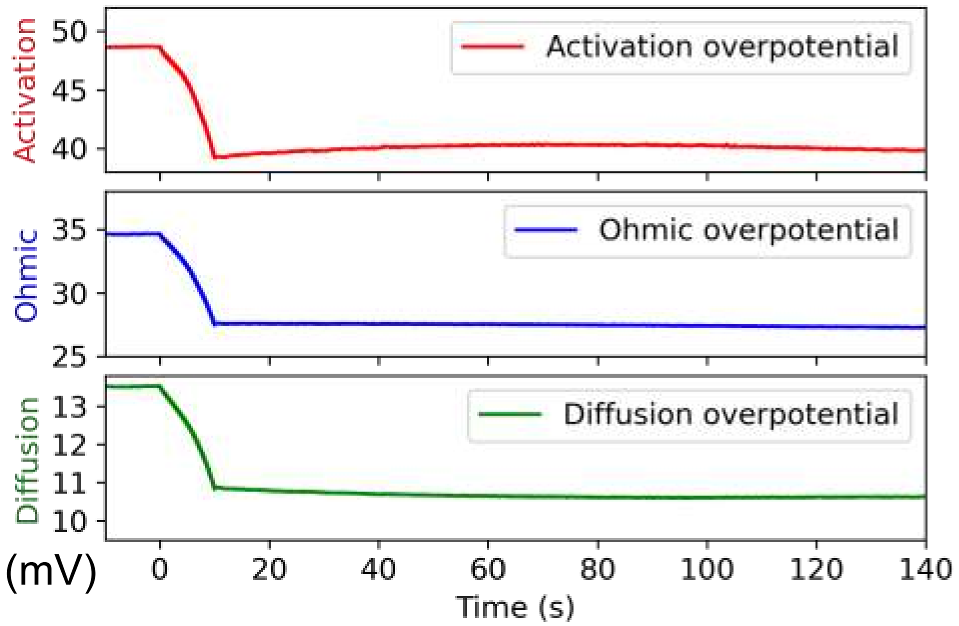
Ramp up



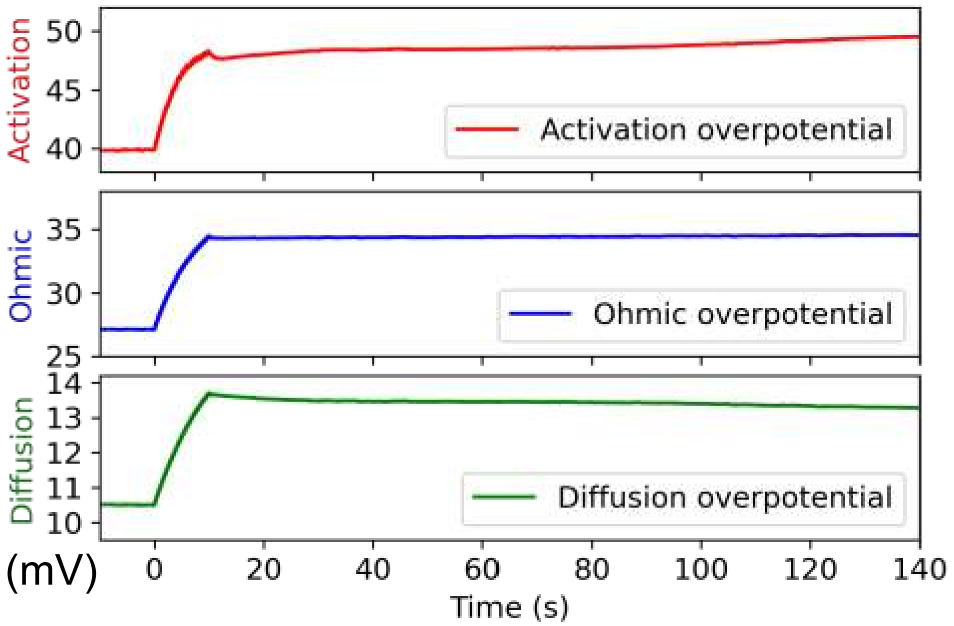
- SOFC current load and anode fuel valve opening varied **linearly**
- **Non-linear** transients were observed due to fuel mass flow transitions

SOFC overpotentials (on node #1)

Turndown



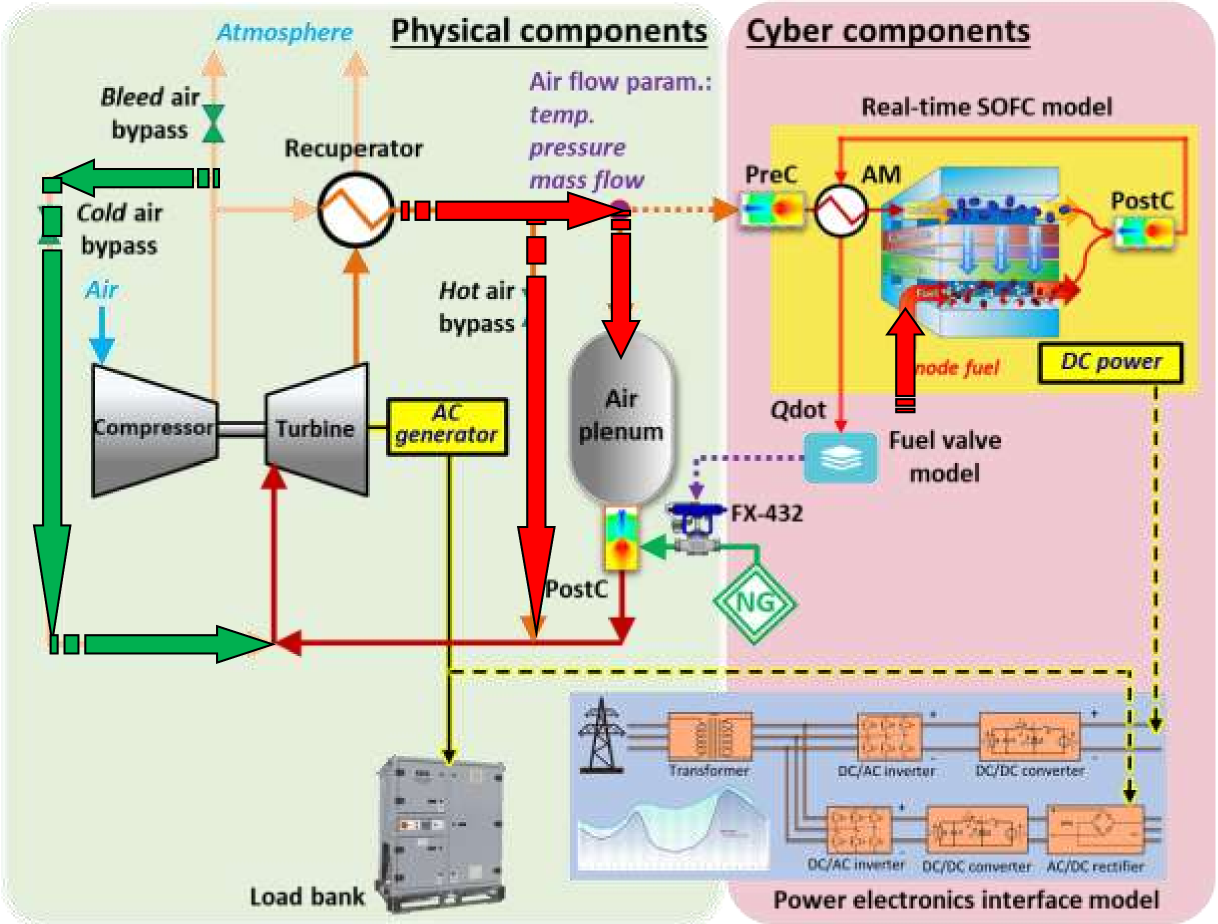
Ramp up



- **Diffusion overpotential was much lower than the activation and ohmic overpotentials**
- **Fuel transfer limitation can be negligible during load transitions**

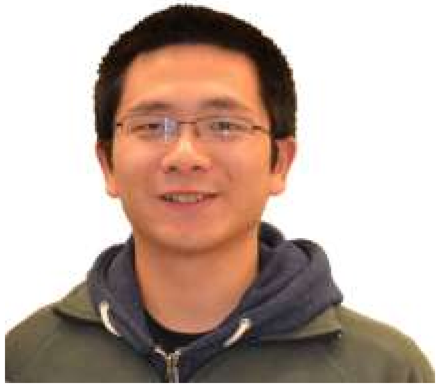
SOFC was protected without violating operability constraints

The need for adaptive controls



- There could be a paradigm shift for the intended application of SOFCs: from large baseload to flexible load responsive systems to maintain grid stability
- This study highlighted the non-linear nature of tightly coupled SOFC-GT system components, especially the non-linear response of SOFC cathode inlet temperature controls
- Adaptive controls are under development

Thanks



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