Experimental Operation and Future Design Considerations of a sCO_2 Turbine Stop and Control Valve

Joshua Warren (SwRI)
George Khawly (SwRI)
Mark Stevens (GTI Energy)

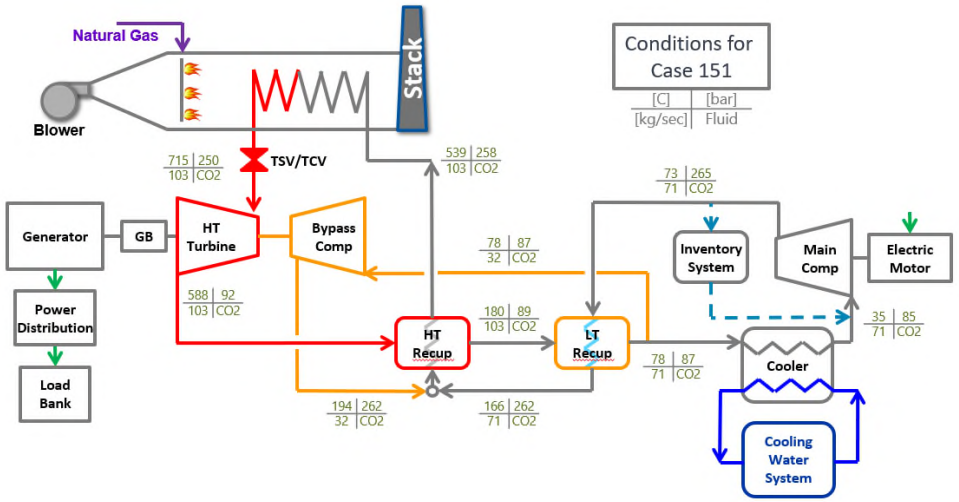
Paper #69

Supercritical Transformational Electric Power (STEP) Demo Project

- **Objectives:**
  - Advance sCO_2 power from TRL3 to TRL7
  - Demonstrate pathway to net plant efficiency > 50%
  - Demonstrate control and operability at **500°C** and **715°C** turbine inlet temperature with **10 MWe** power generation
- **Accomplished:**
  - Simple Cycle (SC) operation – 4 MWe to grid
  - Reconfiguration to RCBC – Final stages of installation
- **Project Partners:**

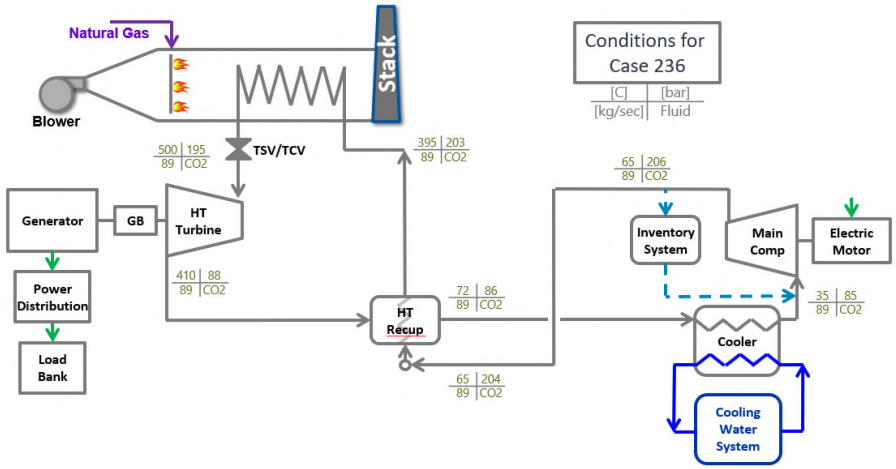
www.STEPdemo.us

Background



- RCBC configuration reaches 715°C at 250 bar turbine inlet
- Turbine stop and control valve is 2 independently controlled valves configured back-to-back in the same body
  - Driven by leakage and structural considerations
  - Also influenced by safety redundancy related to overspeed scenario

Background



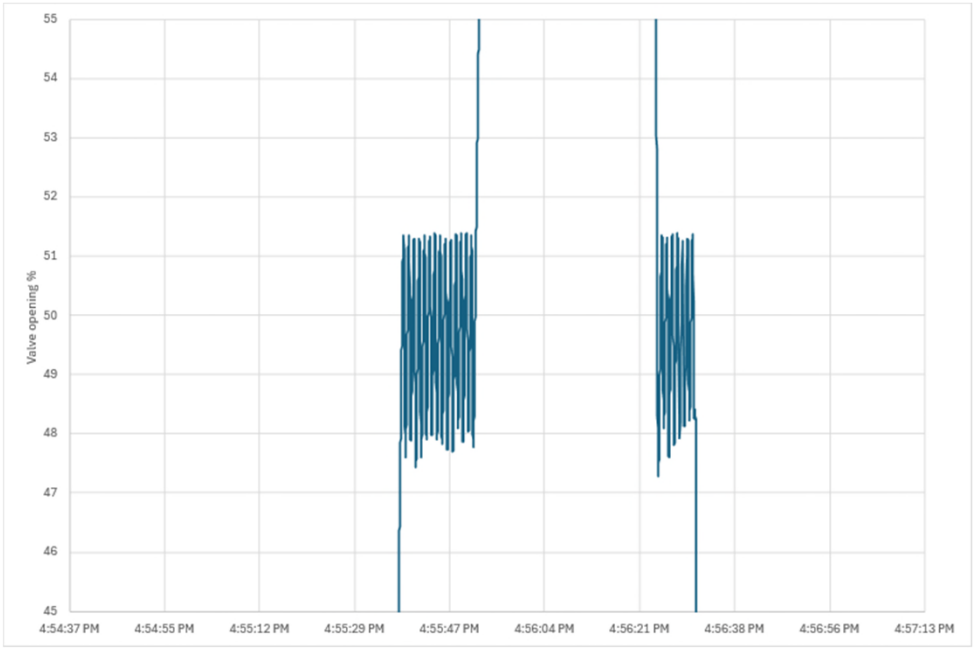
- Simpe Cycle configuration reaches 500°C at 195 bar turbine inlet
- Separate low-temperature valve was procured with same flange-to-flange dimensions
  - Driven by manufacturing challenges and delays with full-temperature rated valve
  - Stainless steel body

Valve Design Conditions

Description	High Temp		Low Temp	
	TSV	TCV	TSV	TCV
Working fluid	sCO2 (>99% pure)		sCO2 (>99% pure)	
Design Pressure	280 bara		280 bara	
Design Temperature	725 C		550 C	
Volume flow	2929 m^3/hr		2929 m^3/hr	
Nominal pipe size	8" sch 160		8" sch 160	
Minimum life	>10,000 hrs		>10,000 hrs	
Fail position/timing	closed, <200 ms	closed, <1 s	closed, <200 ms	closed, <1 s
Control accuracy	+/- 1% FS	+/- 0.2% FS	+/- 1% FS	+/- 0.2% FS

- Duplicated flow, pressure, and safety requirements
- Changing temperature requirements leads to significant change in available materials
  - Valve body
  - Sealing methods

Valve Commissioning

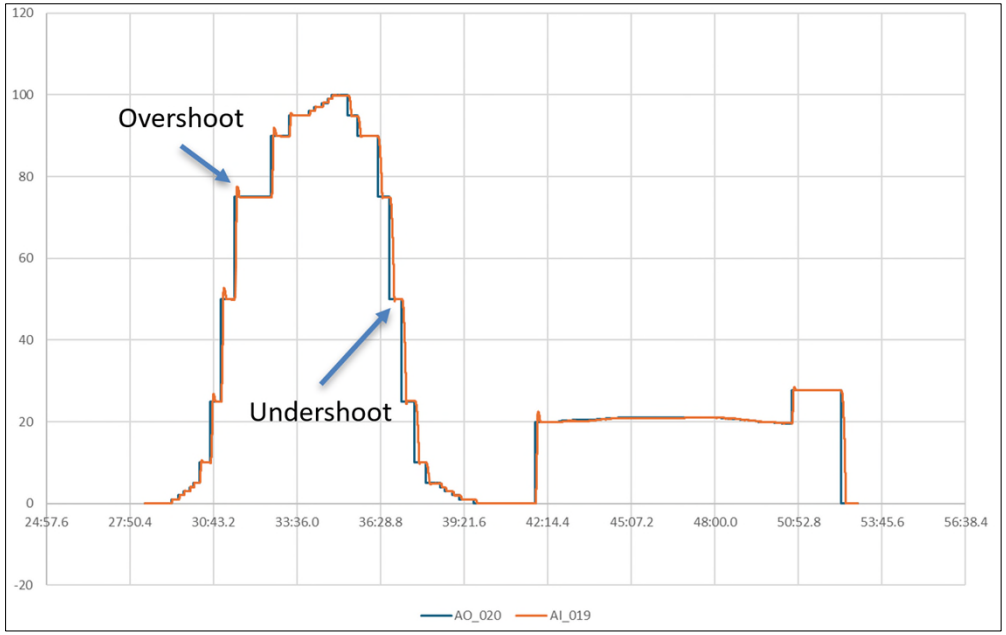


Original oscillation behavior after 10% demand step change

- Valve tested as-received
- Showed oscillations at +/- 1.5% (nominal position)
- Not acceptable for use as turbine speed controller

Valve Commissioning

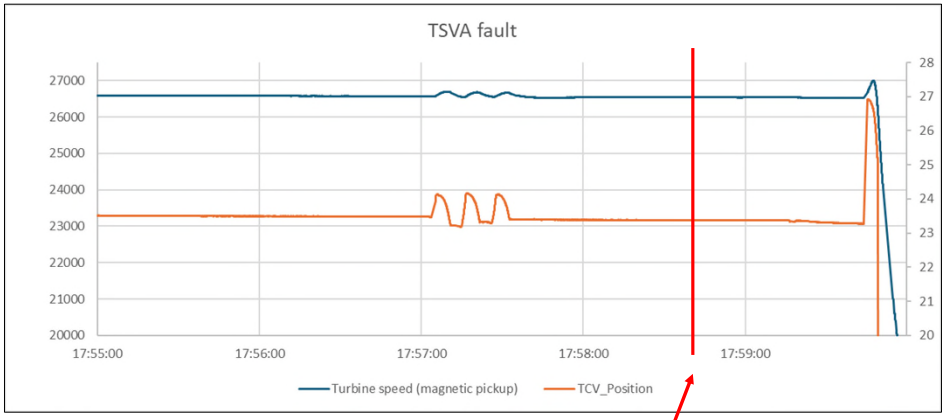
- Tuning performed on internal actuator PID controls
- Successive tuning performed on DCS controls while operating
- Maximum overshoot ~10% of step demand
  - 25% step change led to 2.7% overshoot
- Undershoot ~3-4% of step change



After tuning: Valve displays no oscillation and minimal over/undershoot

Valve Commissioning

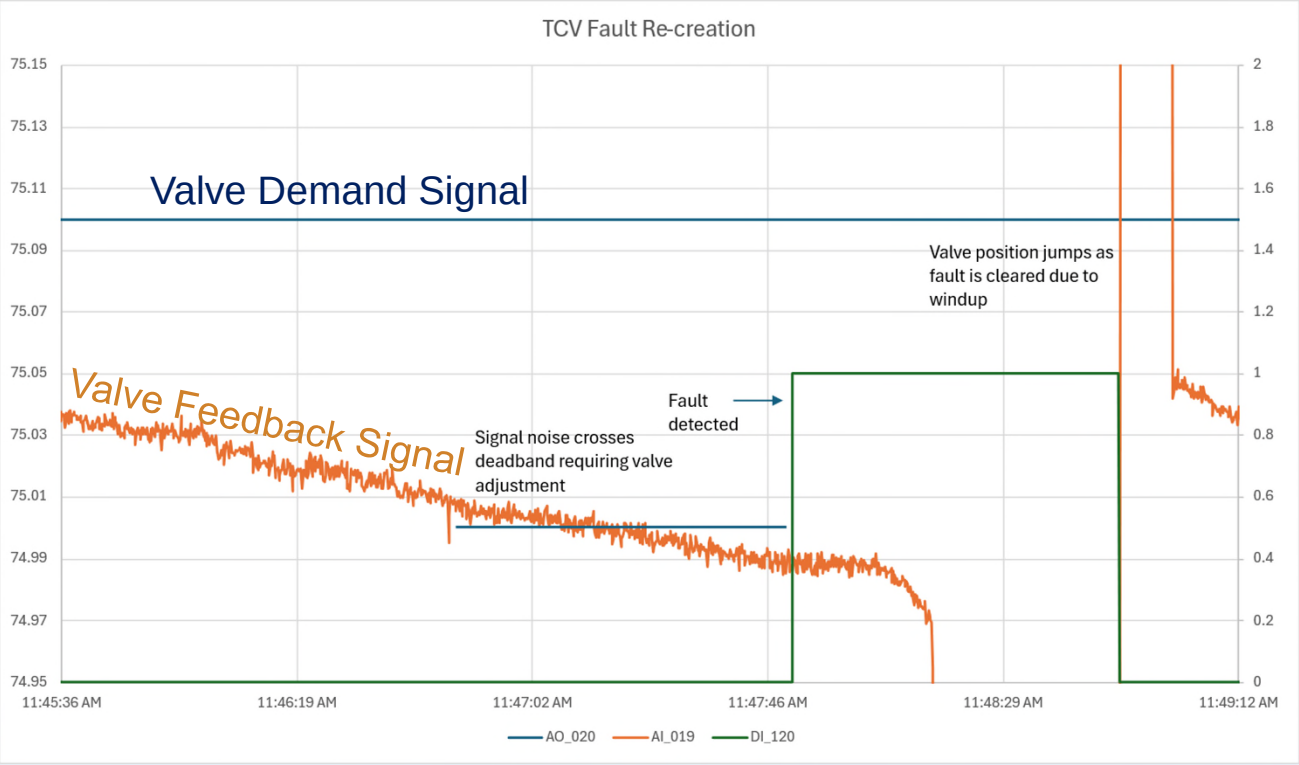
Control Based Issue



Internal actuator fault detected here

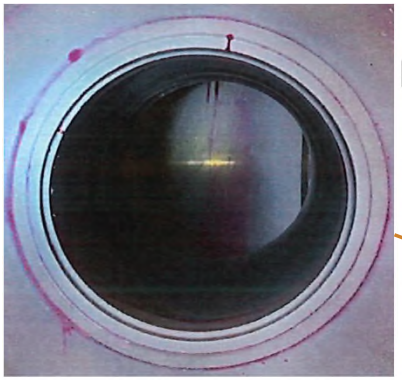
- Small oscillations were a warning sign
- Valve was drifting (very small magnitude) with no change in position demand
- Fault ensued
- 60 second auto-reset on fault logic but not on controls
- Led to rapid opening of valve after auto-reset triggered

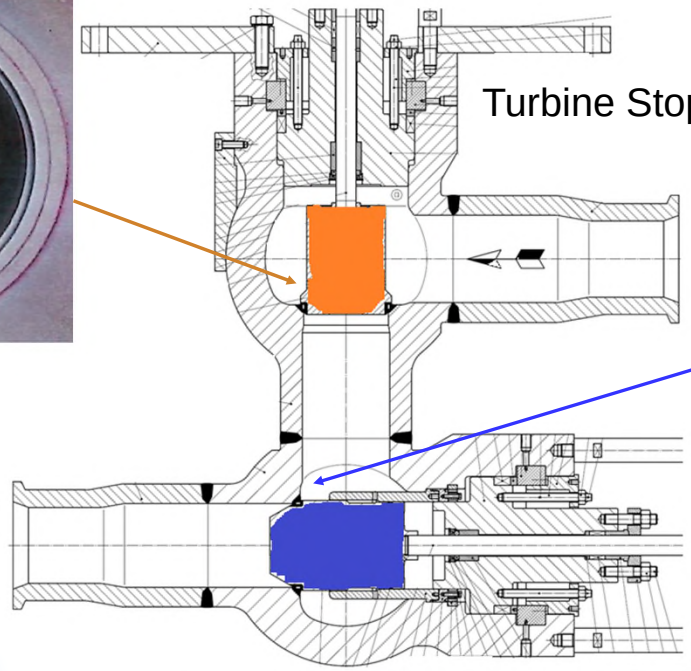
Fault Re-Creation



- Valve software was re-worked with coordination of supplier
- Valve solenoid controllers (PWM) re-tuned
- Valve actuator PLC re-tuned
  - Iterated a couple times
- Overshoot reduced to 1.4% on 25% step change
  - 5.6% of nominal step
  - ~Half of original commissioning value

Valve Inspections After Operation





Turbine Stop Valve

Turbine Control Valve

Operational Data

Operational data for the TCV outlet temperature(green) with the rate of change in temperature (red) and flow through the valve (blue)

- Data showed large swings in turbine inlet temperature (valve exit temp) during hot re-starts
- Valve warranty limit was 4°C/hour
- Valve was re-worked with new “clamped” seats instead of welded

Future Design Recommendations

Actuator and Valve Design

- Accuracy of position – influences style of controls
- Cooling requirements – dry or wet cooling
- Duty cycle – continuous operation vs short bursts
- Fail position
- Flow curve (Cv/Kv)
- Leakage class designation
- Operating load – needs to overcome fluid forces for emergency closure
- Precision – necessary for speed control and grid synchronization
- Preload – related to leakage class
- Process temperature – can lead to fire hazard in event of hydraulic leak
- Seat type – welded, clamped, etc.
- Stroke time – consider normal and emergency conditions

Mechanical and Pressure Vessel Design

- Cooling requirements (if any) – may be necessary for seal materials
- Flaw size and location allowables
- Machinability of material
- Manufacturing method
- Operating pressure
- Operating temperature
- Pipe size and flange type
- Ramp rate (pressure) – important to prevent rapid gas decompression of seals
- Ramp rate (temperature) – important to manage thermal stress
- Sealing of valve stem
- Seat materials and finish – consider wear, thermal stresses, galling (specifically in reference to emergency closure scenario)

Not an exhaustive list but intended as guidelines

Gratefully Acknowledging the Support from U.S. DOE-NETL and Project Partners

www.STEPdemo.us

Questions?