Supercritical CO$_2$ Turbomachinery Configuration and Controls for a Zero Emission Coal Fired Power Plant: System Off Design & Control of System Transients

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Introduction/Background

- **SCO₂ Recompression Brayton cycle efficiencies have been analytically shown to be very attractive**
  - Relative to an atmospheric oxy-fired supercritical steam pulverized coal plant with carbon capture
- **Previous phase defined a reference plant with a fossil heat source and identified development needs**
  - Study completed for Leonardo Technologies, Incorporated (LTI)
- **Objective of this effort was to analyze transient operation and identify any additional development needs**
  - Start-up
  - Shut-down
  - Partial load operation
• 550 MWe with Oxy-Fired Pressurized Fluidized Bed Combustor (PFBC)

• Supercritical CO2 (sCO2) power loop key components
  • Separate Generator and Compressor drive turbines
  • Recompression cycle with two compression and heat transfer elements
Zero Emissions Power and Steam (ZEPS™) Power Plant

- **Plant layout developed**
  - Used to estimate piping pressure losses and volumes
  - Assumed enhanced shell & tube HX technology
- **System model updated**
- **Equipment performance maps updated**
- **System Control Methodology assessed** for both transient and steady state operation
Variety of start-up/shutdown schemes evaluated – initially 14 valves, 4 bypass legs, & storage

Detailed evaluation of two start-up approaches
  - Spin start - concerns for thermally shocking in-bed heat exchanger
  - Motor assist bootstrap - Selected

Start-up requirements to mitigate damage to the system:
  - Prevent compressor stall
  - Prevent heat exchanger overheat
  - Do not overspeed turbines
  - Avoid low Main Compressor Inlet Temperature/Pressure

Modified start until successful
  - Flow split between the recycle and main compressors modified
  - LTR initially lagged thermally
  - Recirculating flow during heat up reduced

Final system: 6 valves, 1 bypass leg, & CO2 storage system
System Start-Up Transient (Conventional Recuperator Technology)

- Q-in MMBTUH
- Tbed Deg. F
- CO2 Pressure PSIA
- HTR Temp Deg. F
- LTR Temp Deg. F
- CO2 Flow lb/s
- GT Power MW
- CT Power MW
- CO2 Temp Deg. F

- Full Power Operation
- Loaded Operation 50-100%
- Synchronization
- Recuperator Heat-up
- PFBC Start & SCOT Fill

Hours from Start

- MW
- lb/s
- PSIA
- Deg. F
- MMBTUH
There are three shutdown scenarios envisioned:

- Planned Shutdown
- Emergency Shutdown
- Disconnect from Grid Shutdown

**Planned shutdown**
- Drop to 50% loaded power
- Fuel will be cut to the unload setting - bed temperature will drop
- Generator turbine isolation valve (V-1) will close
- Bypass valve (V-2) will open to maintain power to the compressor turbine
- Fuel to the PFBC will be cut and the oxygen will be switched to air
- SCOT CO$_2$ flow will be circulated until appropriate bed temperatures are met before CO$_2$ circulation is stopped

**Emergency shutdown and disconnect from grid are envisioned to be the same**
- System does not have the luxury of gradually reducing heat load
- Fuel and oxygen supply will be stopped
- Continue bed circulation with the recycle CO$_2$
- Generator turbine flow will be stopped by closing valve V-1
- Bypass valve V-2 will be opened to a point where flow supplied to the compressor turbine is maintained
- CO$_2$ temperature will decay and SCOT CO$_2$ flow will drop until the bed reaches a safe temperature

**There is risk of bed overheating during Emergency shutdown, mitigations:**
- Coal and oxygen feeds are stopped immediately
- Water is added to the flue gas and recycle systems to offer immediate protection of the PFBC and the solids handling equipment
Operation at Partial Load

- CO₂ mass at rated power is 229 tons
- Turbine inlet temp maintained at partial load
- Storage system required to accommodate variation in mass
  - +6% to -2%
- Make-up location at the inlet to the cooler
  - Avoid impact to the main compressor
- Drain location at the compressor outlet
  - Pressure high and temperature low - compatible for storage
Two SCOT system start-up approaches were analyzed in detail and a motor assist bootstrap was selected

- Motor on the compressor shaft will be used to force circulation and initiate preheat of the SCOT system

- No turbine performance issues during transient operation
  - Normal rotordynamic and structural limits apply

- Start-up and shutdown operation of the main and recycle compressors are within the surge, choke, and speed limits

- No new technology risks identified for the turbomachinery

- Significant transient operation benefits with compact heat exchanger designs

- Instrumentation and control challenges to maintain main compressor inlet near the critical point
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Questions?
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Back-Up
Initial Start-Up

- The SCOT system will be pressurized once the PFBC bed temperature reaches 150°F
  - Opening valve V-5 on the CO\textsubscript{2} storage tank or
  - Filling from CO\textsubscript{2} tanker trucks using a vaporizer

- Once the system is filled, valve V-5 is closed
- Generator turbine valve (V-1) is closed
- Recycle CO\textsubscript{2} flow is controlled by adjusting valve V-3
- Motor on the compressor shaft will be used to force circulation and initiate preheat
System Start-Up

- Compressor turbine will quickly begin offsetting motor power
- System control to a low flow during the initial heat-up
  - Bypass more flow through valve V-2 than the compressor turbine
- Once the recuperators have reached their average temperatures and the bed has reached 1100°F, the PFBC is switched to coal firing
  - The bypass valve admits more flow to the compressor turbine
  - Bed heat duty continually rises and increases the flow to 50% of maximum flow.
During ramp, the generator turbine will be preheated by slightly opening valve V-1.

Once 50% flow is reached, the generator turbine flow will be increased by further opening valve V-1.

- Synchronize with the grid.
Completion of System Start-Up

- Once connected to the grid, the system will increase heat duty to the desired load
- System control will be transitioned to the turbine compressor by closing valve V-2 and throttling valve V-6
  - Completing the startup