Steady State Model Update for the 10 MWe sCO2 Test Facility Program

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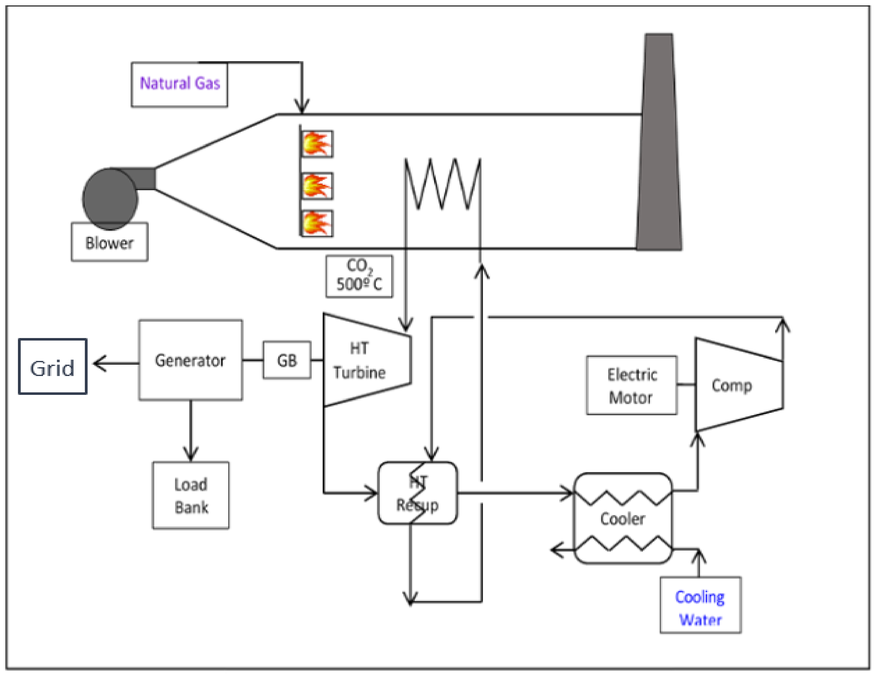
The International Supercritical CO2 Energy Technologies Symposium ● March 2 – 5, 2026 ● Pittsburgh, PA, USA

Overview

- STEP 10 MWe test facility and simple cycle test campaign
- Steady state Flownex modeling framework
- 2024 test data and Data Acquisition Periods (DAPs)
- Major model improvements
- Validation results across cycle components
- Key conclusions and next steps

STEP 10 MWe sCO_2 Pilot Facility

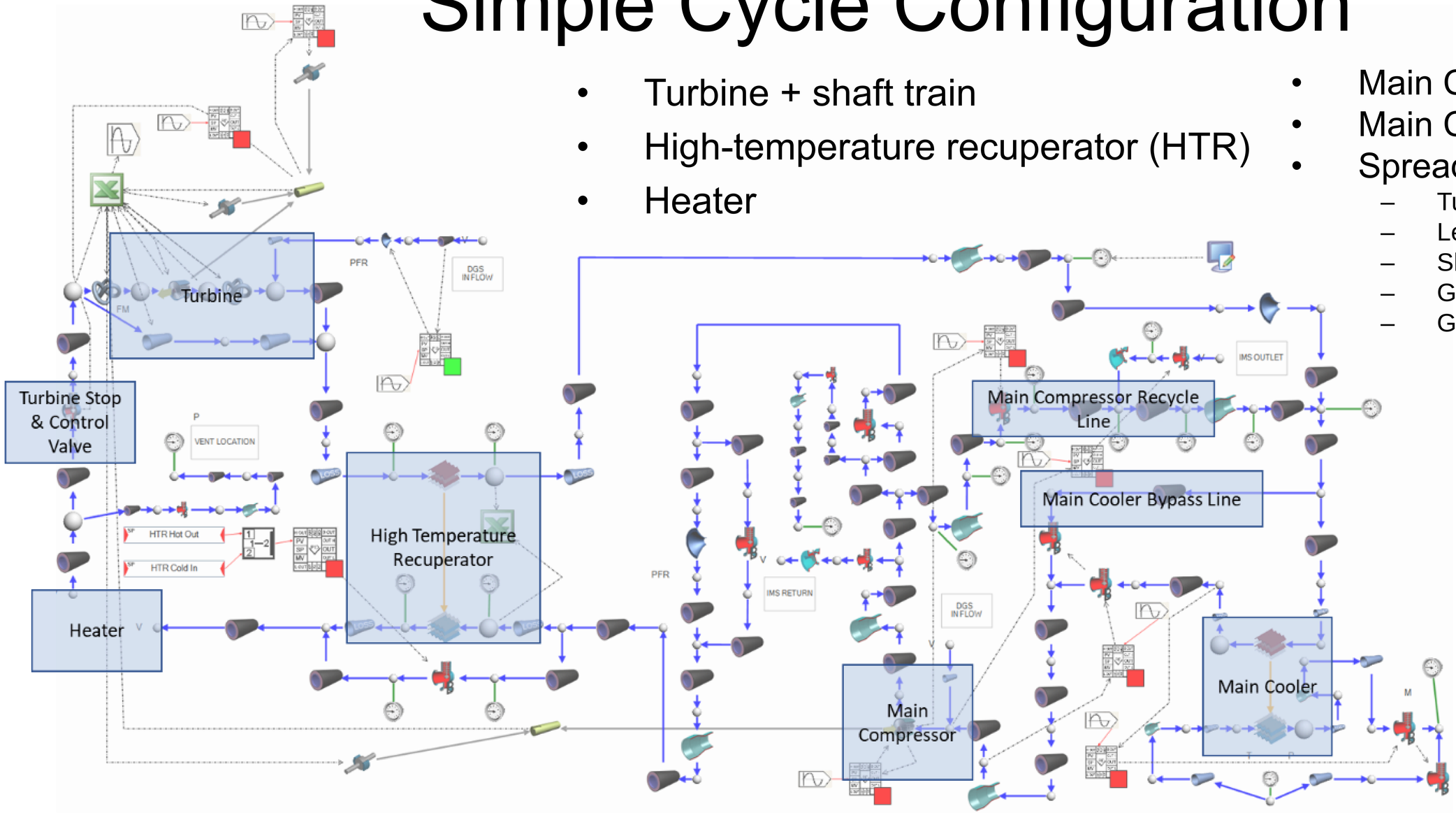
- First integrated multi-MW sCO_2 Brayton cycle demonstration in the U.S.
- Completed simple recuperated cycle testing in 2024
- Achieved:
  - TIT up to 500 °C
  - 8.25 MW_{sh} turbine power
  - 3.93 MWe net to grid



Simple Cycle Configuration

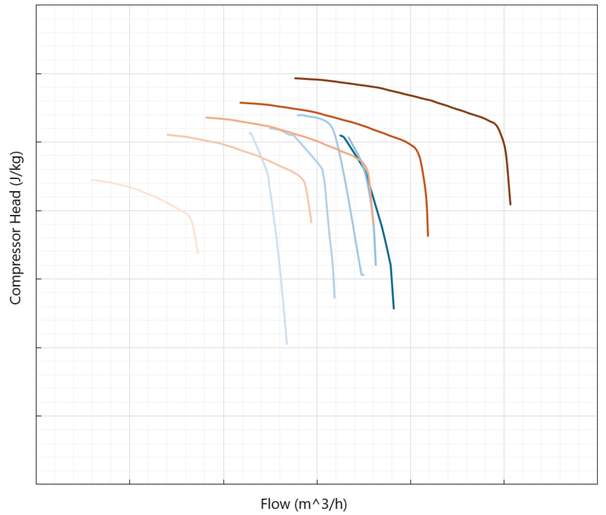
- Turbine + shaft train
- High-temperature recuperator (HTR)
- Heater

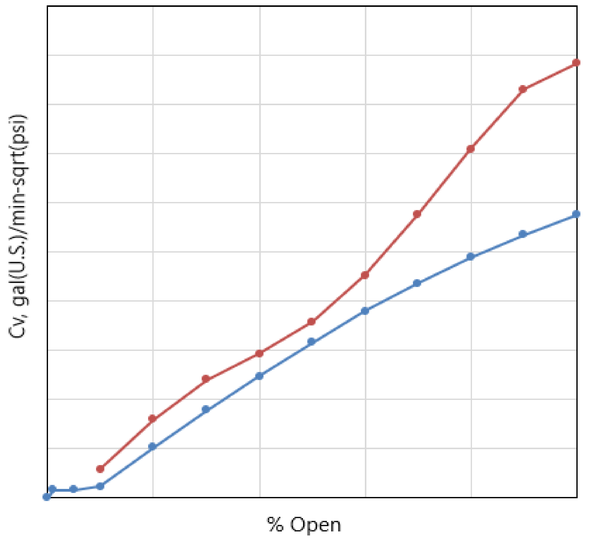
- Main Cooler
- Main Compressor
- Spreadsheet captures:
  - Turbine flow function
  - Leakage rates
  - Shaft efficiency
  - Gearbox efficiency
  - Generator efficiency



Summary of Major Model Updates

- Updated main compressor maps from 2024 test data
- Updated TSV Cv curve from latest vendor sheet
- Updated shaft train efficiencies based on commissioning
- Updated as-built piping geometry & insulation
- Added extra thermal loss from lube oil

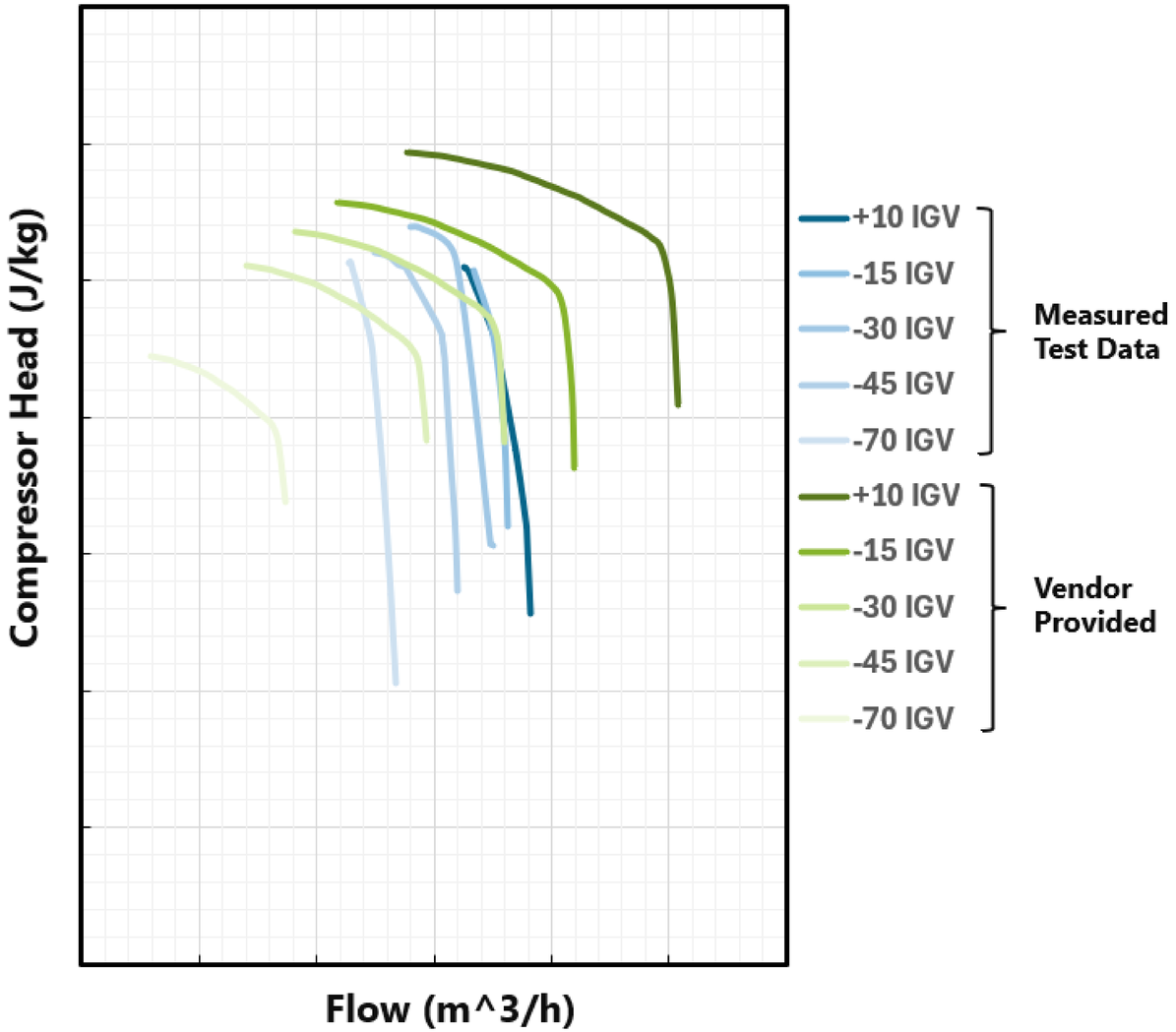




Compressor Map Update

- Vendor map did not align with as-tested performance data
- Updated using test data at nominal condition
  - 84 bar and 35 °C
  - 27,000 rpm
  - –70° to +10° IGV

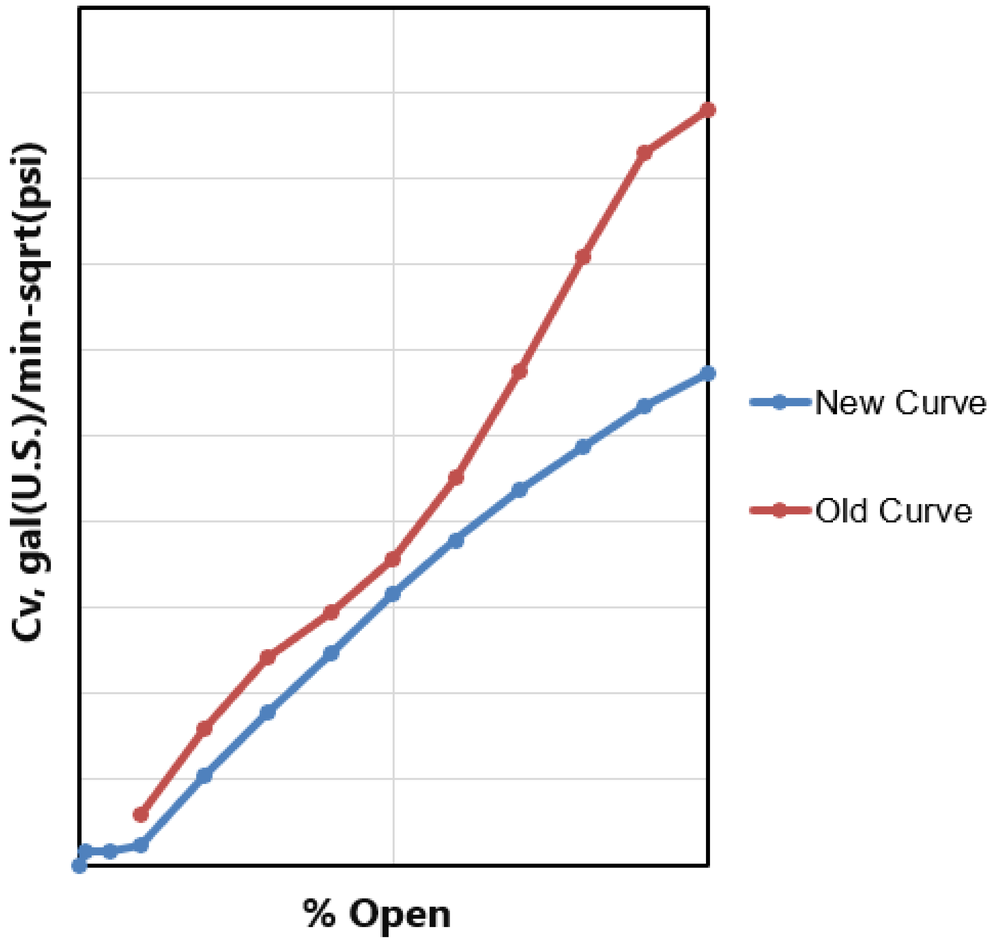
- CO_2 properties vary sharply near critical point
- Small temperature changes → large density and volume flow changes
- Accurate inlet conditions are essential for map correlation



Turbine Stop Valve (TSV) Curve Update

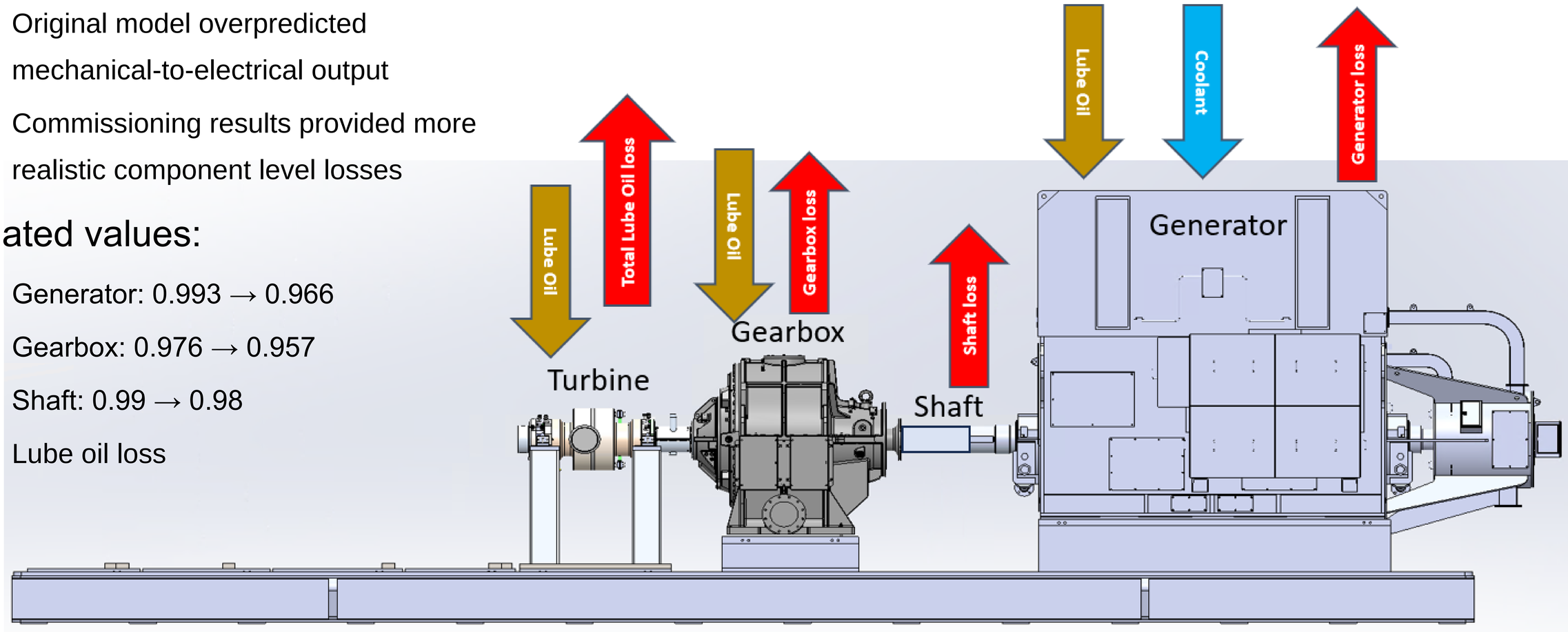
- New Cv vs % open data from vendor
- Replaced older approximated curve
- Improved turbine inlet pressure prediction

$$C_V = Q\sqrt{\frac{SG}{\Delta P}}$$



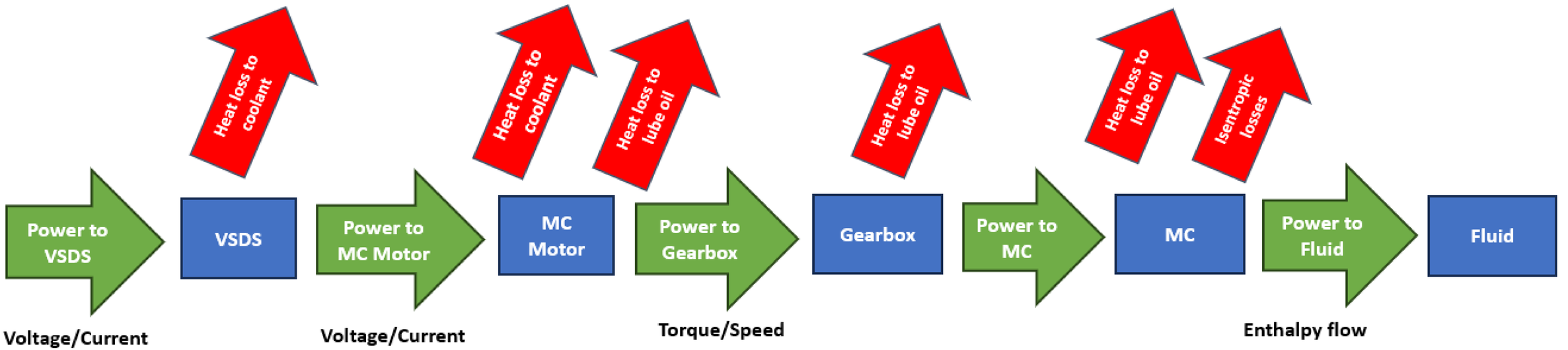
Updated Turbine Train Efficiencies

- Reason for update:
  - Original model overpredicted mechanical-to-electrical output
  - Commissioning results provided more realistic component level losses
- Updated values:
  - Generator: 0.993 → 0.966
  - Gearbox: 0.976 → 0.957
  - Shaft: 0.99 → 0.98
  - Lube oil loss



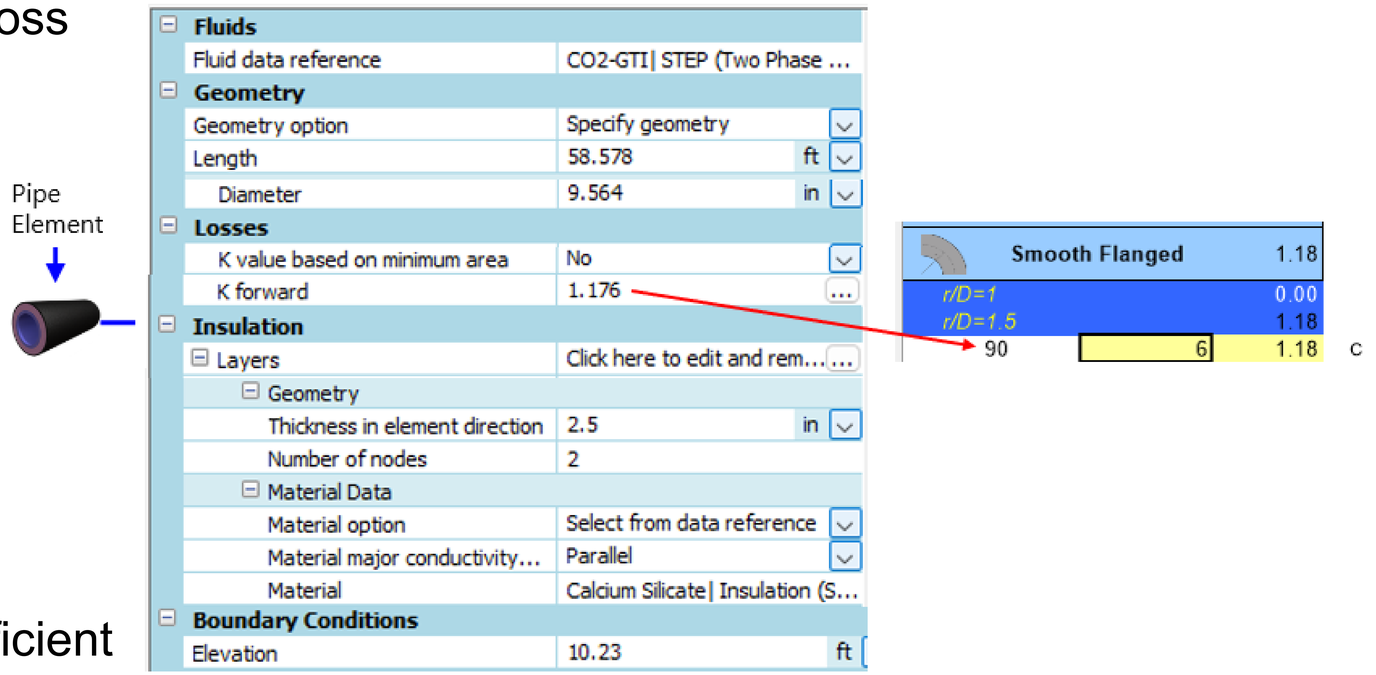
Updated Compressor Train Loss

- Added values:
  - MC gearbox efficiency = 0.987
  - MC motor efficiency = 0.968
- Improved the model's agreement with measured electrical power



Piping & Insulation Geometry Updates

- Updated all pipe lengths, bends, diameters, elevations
- Insulation type & thickness verified against as-built information
- Improved prediction of pressure drop and heat loss



K = specified resistance coefficient

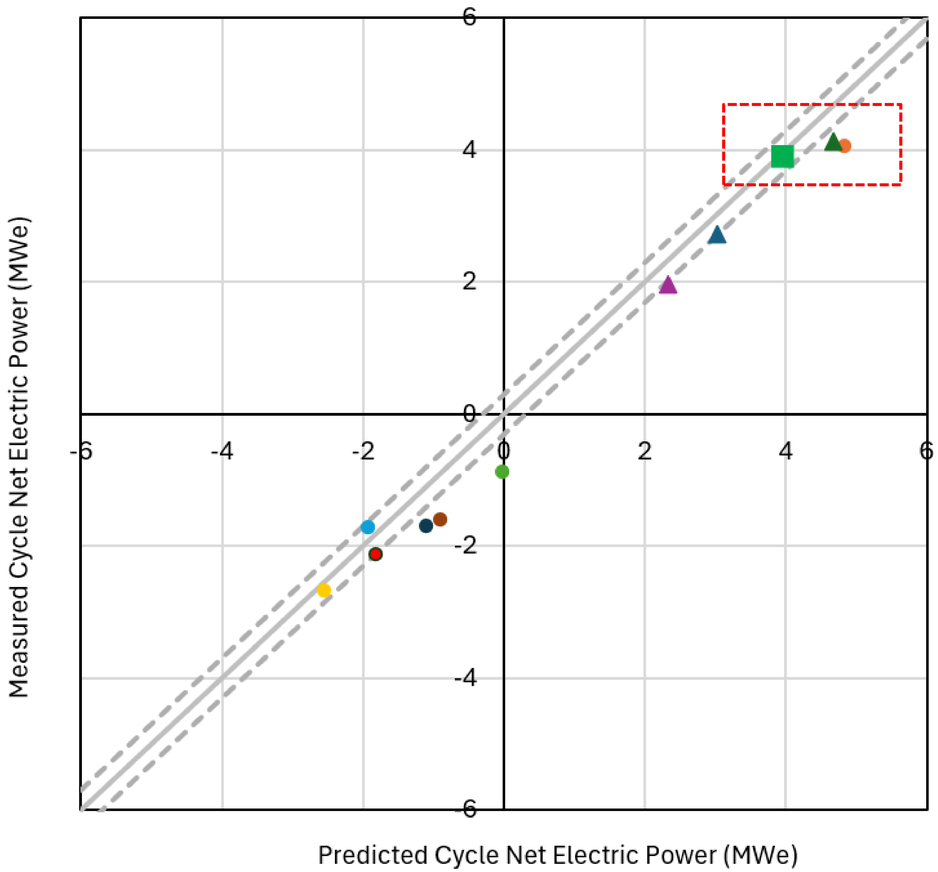
Data Acquisition Period (DAP) Windows

- 10 DAP windows selected (≈1000 s each)
- Only highlighted DAPs represent true steady state
- Others are ramp-up transitional periods where mismatch is expected in steady state model
- Model updated and anchored using DAP 8 & 9 corresponding to Simple Max conditions
  - TIT = 500 °C
  - Compressor speed = 27,000 RPM

DAP #	Test ID	Day	Turbine Inlet Temp TC-325avg [C]	Turbine Speed N-550 [rpm]	Compressor Inlet Temp TC-473avg [C]	Compressor Speed KT-3351 [rpm]	Time Slice Start [GMT]	Time Slice [sec]
1	T-8	9/10/2024	286	19998	49	27026	254/17:46:43	64000-65000
2	T-11	9/11/2024	389.6	19999	49.5	27022	255/12:26:47	44800-45800
3	T-12	9/11/2024	394.4	26612	49.5	27025	255/15:00:07	54000-55000
4	T-12	9/11/2024	492.1	26616	49.6	27027	255/16:36:57	59810-60810
5	T-13	9/12/2024	496.4	26615	34	20729	256/17:51:19	64275-65275
6	T-17	9/13/2024	502	26602	35.3	20728	257/15:22:00	55320-56320
7*	T-15	9/26/2024	319	26614	49	27024	270/19:53:25	71600-72400*
8	T-16	9/27/2024	500.5	26622	36.7	27026	271/20:25:04	73500-74500
9	T-19	10/2/2024	500.7	26617	37.3	27025	276/13:03:21	47000-48000
10	T-19	10/2/2024	498.8	26620	35	20727	276/14:10:01	51000-52000

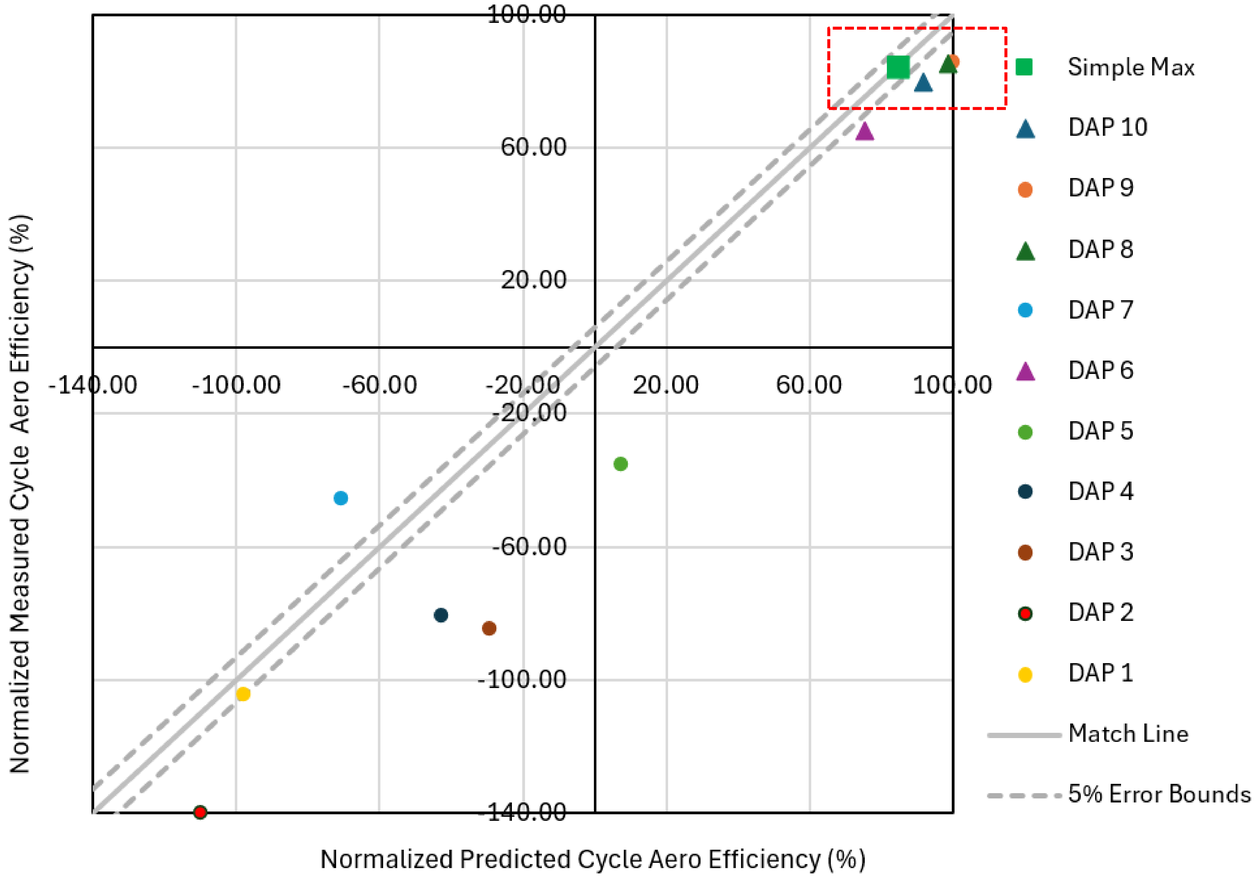
*** 800 sec avg. All others 1000 sec**

Cycle Level Validation



Net Electric Power (Measured vs Predicted)

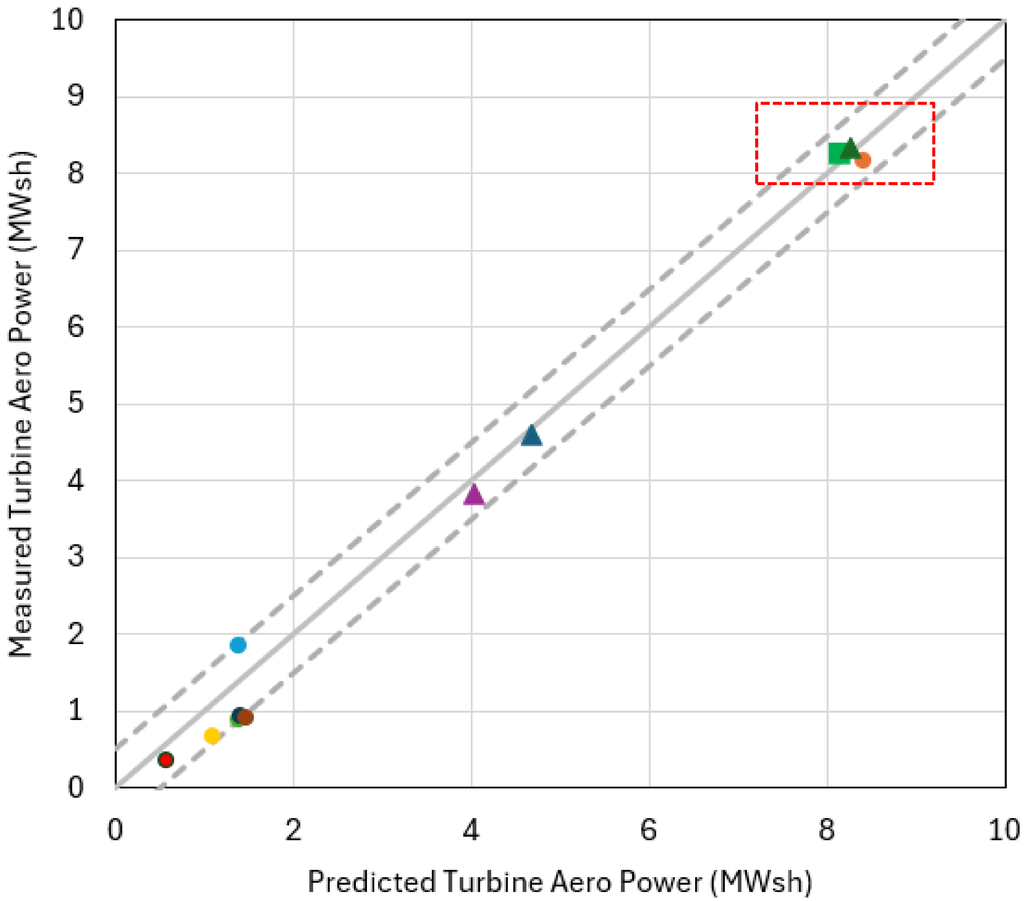
- After updates, designed point matches exactly: 3.93 MW



Normalized Aero Efficiency (Measured vs Predicted)

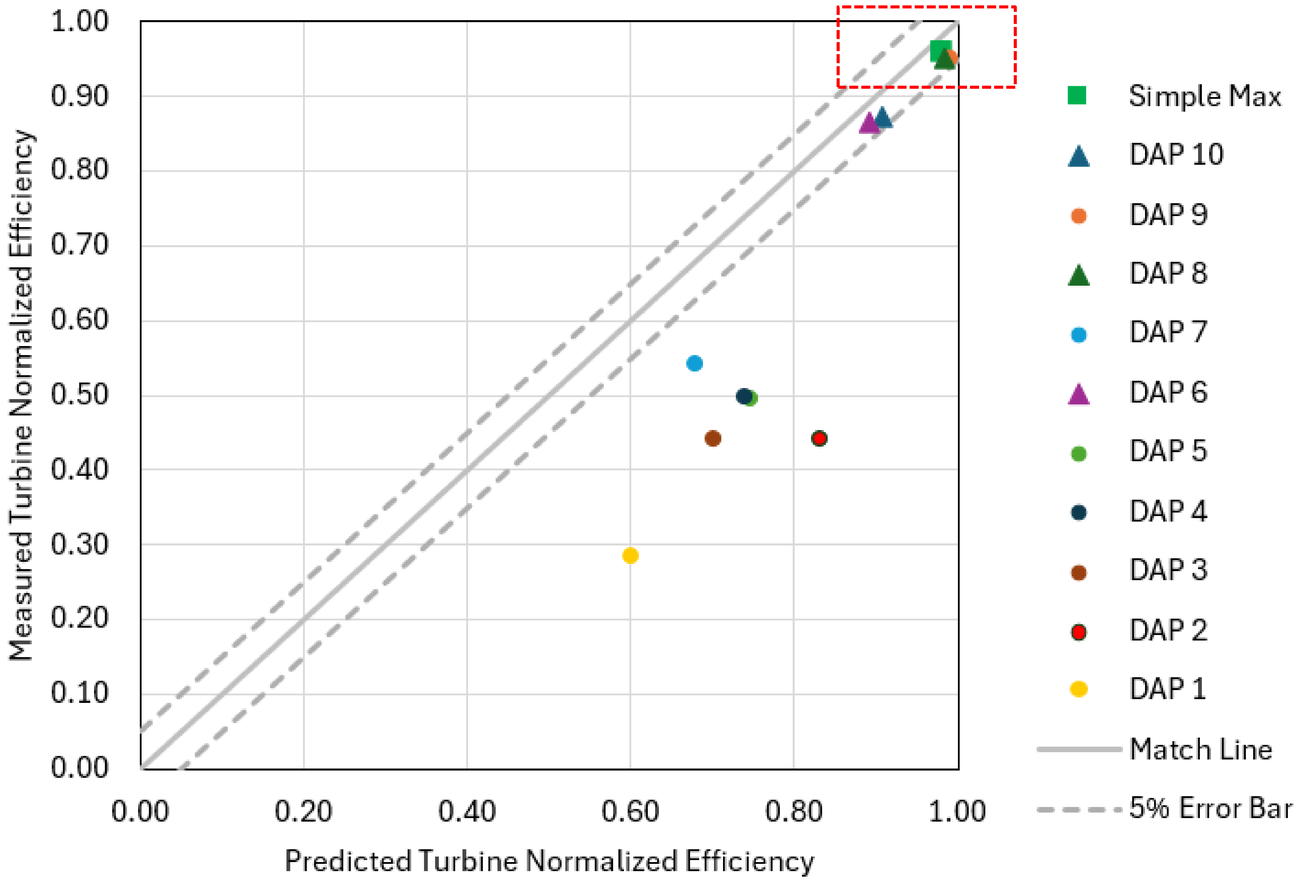
- Discrepancy falls within 1%
- Larger deviations only in ramp-up DAPs

Turbine Validation



Turbine Aero Power (Measured vs Predicted)

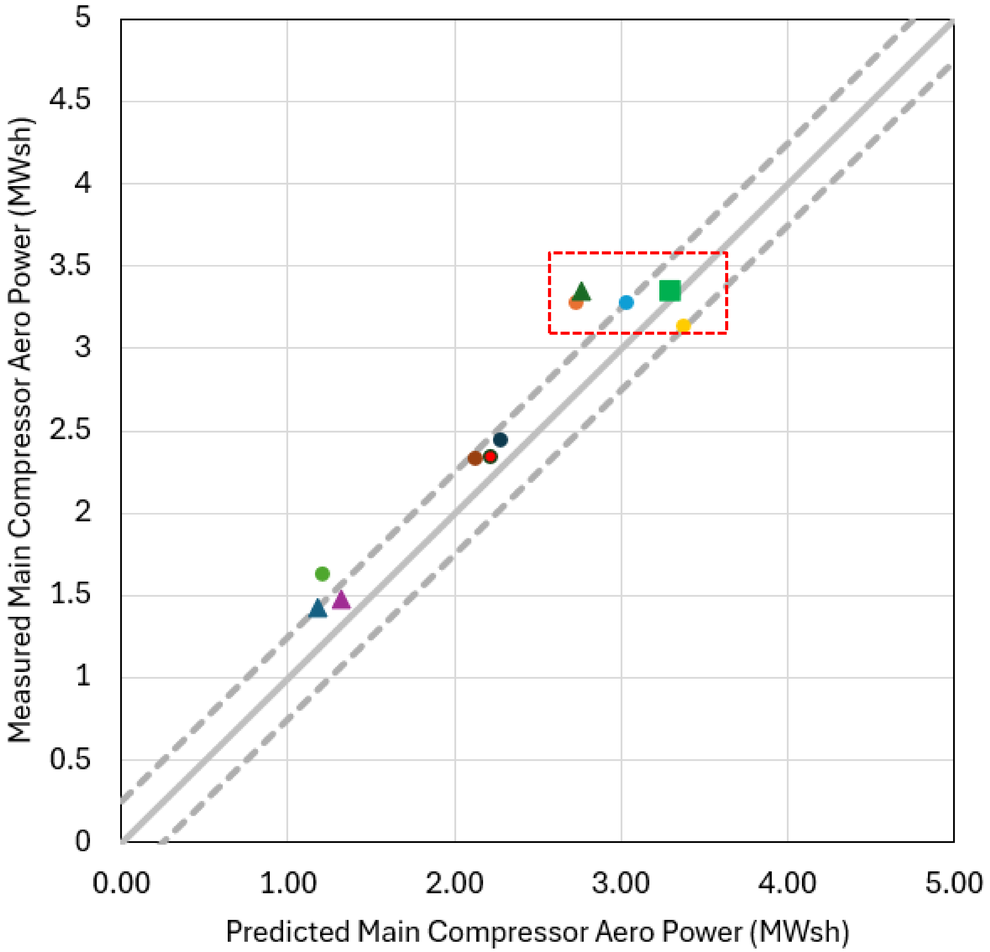
- Steady-state DAPs within 1–5% of measured values



Turbine Normalized Efficiency (Measured vs Predicted)

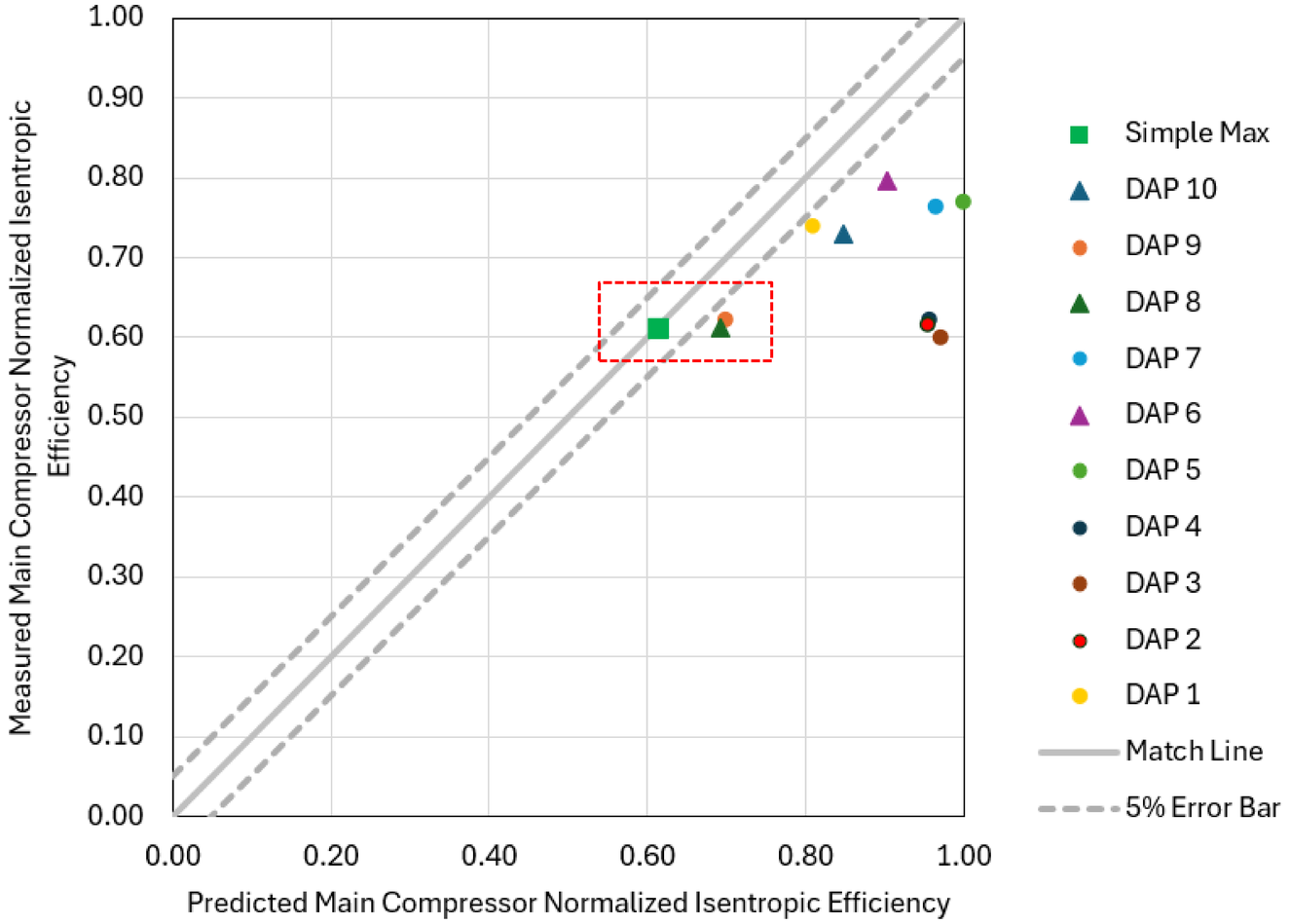
- Consistent prediction accuracy after updates
- Larger deviations only in transient DAPs

Compressor Validation



Main Compressor Power (Measured vs Predicted)

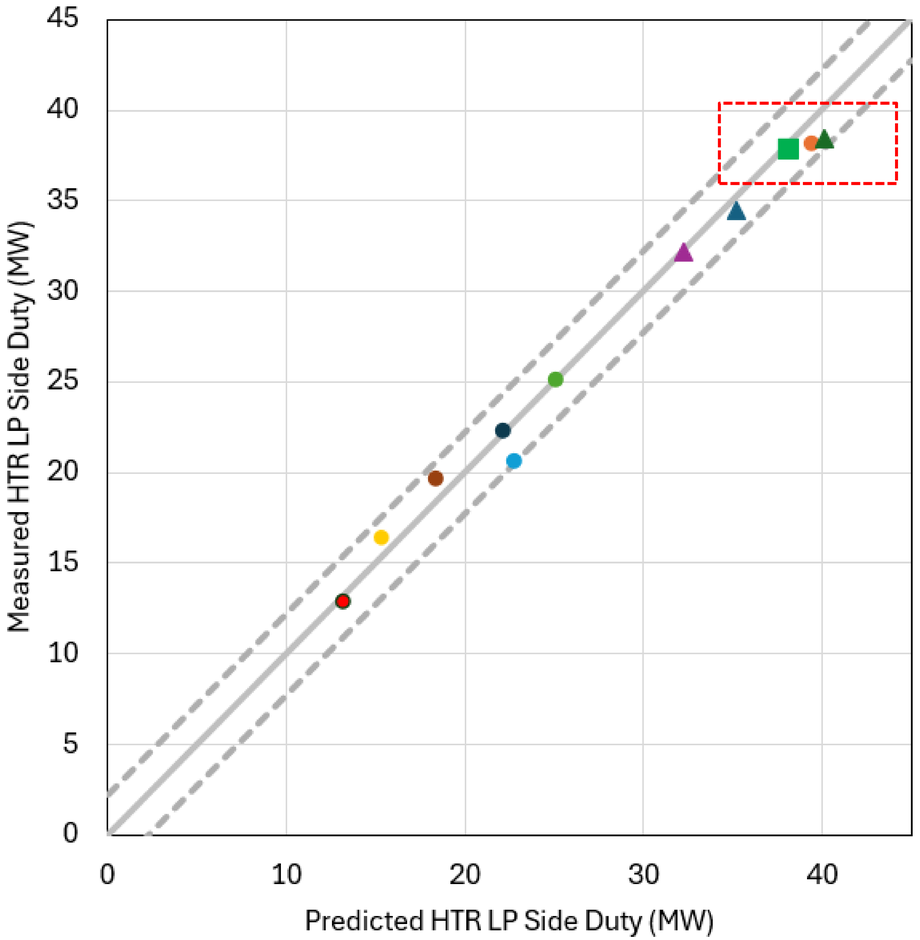
- Before update: large underprediction
- After update: within ~2%

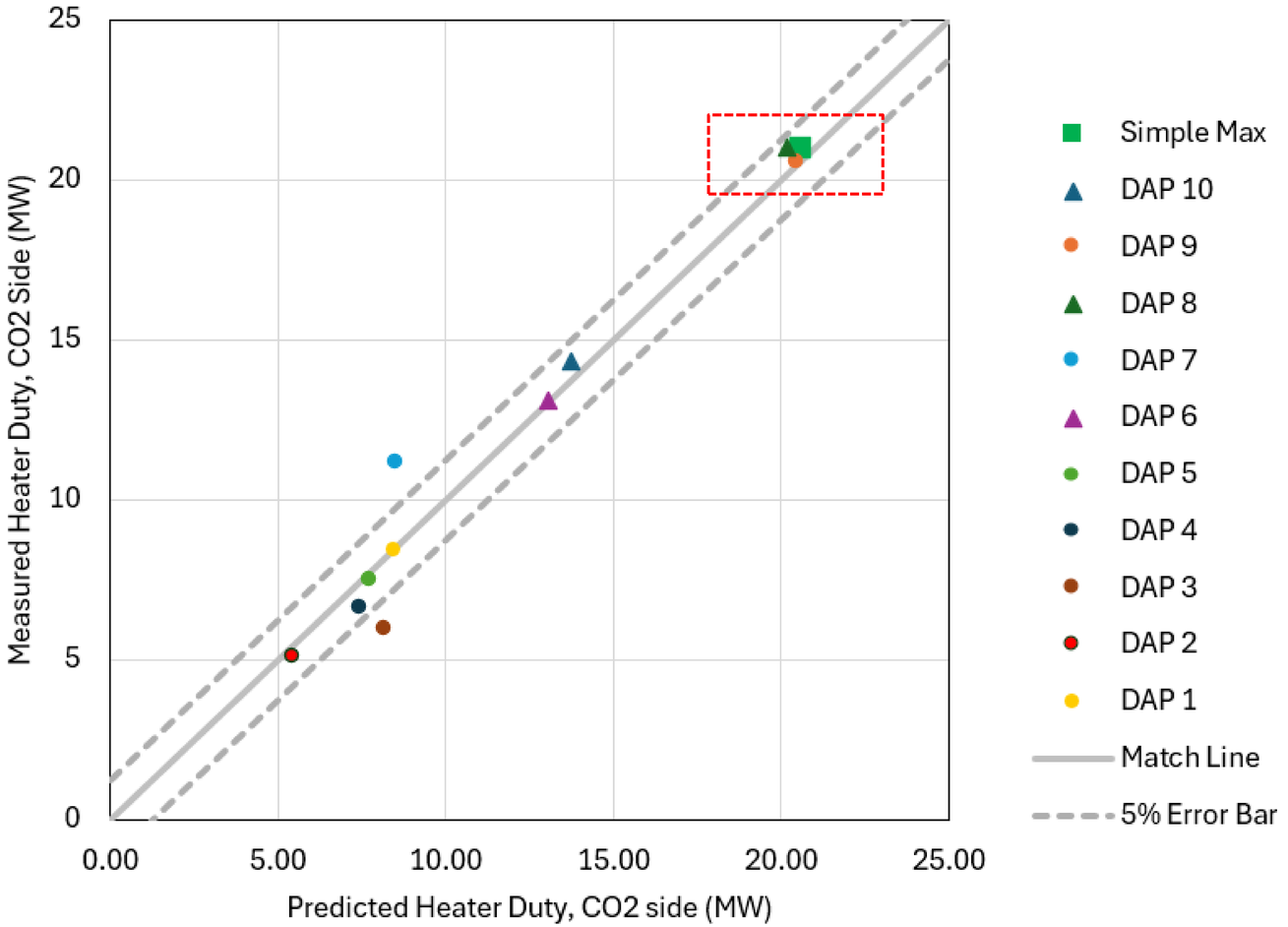


Main Compressor Efficiency (Measured vs Predicted)

- Major improvement from original >16% deviation
- Updated maps align well with operational data

Heat Exchanger Validation (HTR & Heater)





HTR Duty (Measured vs Predicted)

- Within 2% across steady state DAPs
- Same before and after results

Heater Duty (Measured vs Predicted)

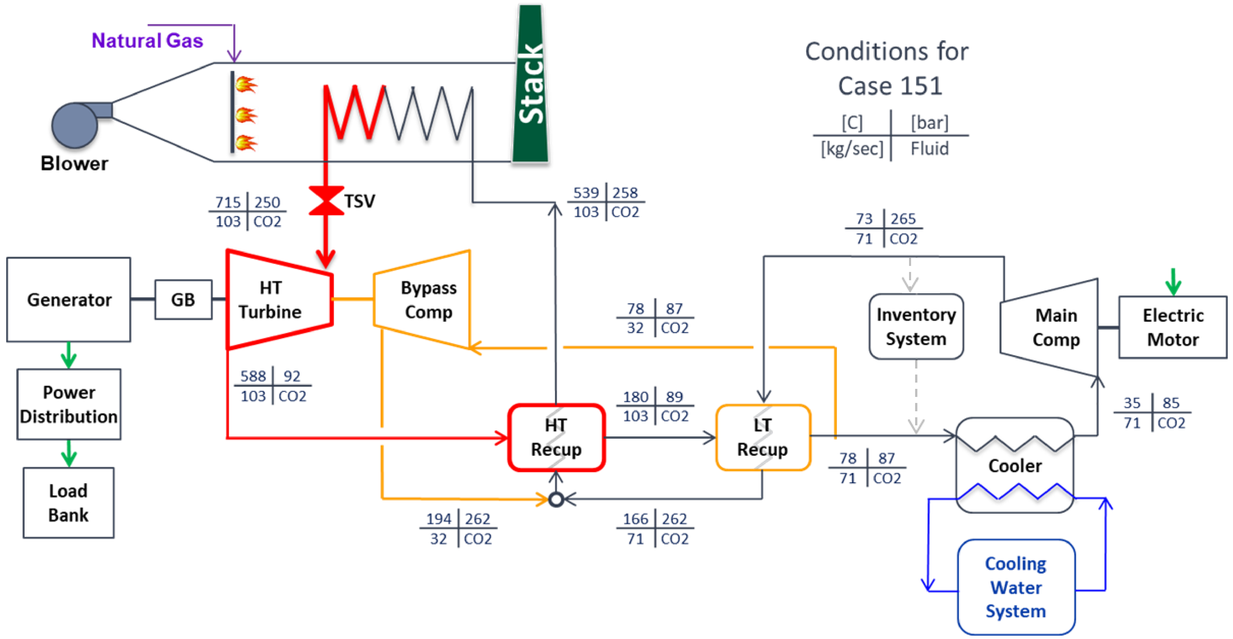
- Very strong agreement
- Heater model requires no updates

Summary of Key Improvements

- Model updated using actual 2024 test data
- Compressor map corrections: biggest reduction in error
- Turbine & shaft efficiency updates improved power prediction
- As-built piping + heat losses significantly enhanced accuracy
- Final model matches steady state data within:
  - Cycle-level: ~1–5%
  - Turbine: 1–5%
  - Compressor: ~2%
  - HTR & Heater: ~2%

Path Forward

- Incorporate new turbomachinery test data during RCBC commissioning
- Implement updated HTR model from Carleton University
- Integrate cooling tower model (NRCan support)
- Begin RCBC steady state validation and future transient modeling



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

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Questions?

Backup

DAQ Network from C.J.