Overview of CCS plant flexibility modelling

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Workshop on operating flexibility of power plants with CCS
Imperial College London
November 11–12, 2009
Motivation

Assessment of impact of operating flexibility
- Generating unit modelling and simulation
- Electricity system modelling and simulation
- Analysis of results

Summary and future work.
Motivation

Assessment of impact of operating flexibility

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Summary and future work.
Novel process concept to be evaluated.
Motivation
Assessment of impact of operating flexibility
Summary and future work.

Cost of CO₂ avoided oft-used performance metric.

Cost of CO₂ avoided

\[ CCA = \frac{(CoE)_{\text{cap}} - (CoE)_{\text{ref}}}{(CEI)_{\text{ref}} - (CEI)_{\text{cap}}} \]

where Cost of Electricity can be expressed as:

\[ CoE = \left( \frac{\text{annualized capital cost}}{\text{annual energy output}} \right) + FOM + VOM_e + \left( \frac{\text{fuel cost per unit energy}}{\text{unit energy}} \right) \]

- Need a method to predict unit utilization:
  - annual energy output
  - fuel cost per unit energy
  - CO₂ emissions intensity

- Need to assess benefit of operating flexibility
Process modelling + electricity system simulation.

Three-step process:
1. Modelling and simulation of generating unit with CCS
2. Simulation of electricity system
3. Analysis of results
Outline

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3 Summary and future work.
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Develop process model of generating unit with CCS.

Example workflow:

1. develop model of boiler and steam cycle from heat design balance at 50%, 75%, and 100% load
2. design PCC process to recover 85% of CO₂ at nominal load
3. integrate PCC process and generating unit models
4. characterize part-load performance of integrated unit
Objective is to find Pareto frontier of integrated unit.

- interested in the relationship between:
  1. heat input to boiler ($\dot{q}$)
  2. $CO_2$ recovery ($x_{CO_2}$)
  3. net unit power output ($E_{net}$)

  \[ E_{net} = f(\dot{q}, x_{CO_2}, \ldots) \]

- only interested in the ‘best’ performance (i.e., Pareto frontier)

- Find $E_{net}^*$ for feasible combinations of $\dot{q}$ and $x_{CO_2}$. 
Developed model describing Pareto frontier using linear regression:

\[ \dot{q} = f \left( E_{net}^*, x_{CO_2} \right) \]
Summary of data requirements for novel process.

Key unit parameters:
- incremental heat rate
- minimum and maximum power output
- start-up heat input
- ramp rates
- minimum up- and downtimes
- fuel cost

Initial assumption is that CO$_2$ capture process dynamics are fast.
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Analysis is electricity system-specific.


- Example workflow:
  1. Incorporate novel process into electricity system.
  2. Simulate system operation.
  3. Analyze simulation results.

Legend:
- #6 fuel-oil conventional steam
- #2 fuel-oil combustion turbine
- hydroelectric w/reservoir
- coal-fired conventional steam
- thermal nuclear

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Novel process added to electricity system.

- MEA (monoethanolamine)-based PCC (Post-Combustion Capture) added to 500 MW_e coal-fired unit at Austen
- Plant load and CO₂ recovery are flexible

Legend
- Oil-fired conventional steam
- Natural gas combustion turbine
- Hydroelectric w/ reservoir
- Coal-fired conventional steam
- Thermal nuclear
- Amine-based CO₂ capture

Overview of CCS plant flexibility modelling
Electricity system operation simulated.

For each time period, select units that will satisfy:

- demand
- reserve requirement
- physical constraints on equipment

such that overall benefit is maximized.
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Cost of CO₂ avoided estimate is easily had.

Cost of CO₂ avoided

\[
CCA = \frac{(CoE)_{cap} - (CoE)_{ref}}{(CEI)_{ref} - (CEI)_{cap}}
\]

where Cost of Electricity can be expressed as:

\[
CoE = \left( \frac{\text{annualized capital cost}}{\text{annual energy output}} \right) + FOM + VOM_e + \left( \frac{\text{fuel cost per unit energy}}{} \right)
\]

Simulation directly provides:

- Cost of Electricity
- CO₂ Emissions Intensity

so estimate of Cost of CO₂ Avoided is readily obtained, if desired.
At $40/\text{tonne},$ flexible case delivers least power.
Flexible case commits more to reserve markets.
Overall utilization similar: base vs flexible.

- Utilization is similar between base case and flexible case.
- However, flexible case has better economics as costs are lower.
- Cost of CO₂ avoided wouldn’t reflect this.
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Summary and future work

- Able to quantify benefits from operating flexibility.
- Operating flexibility shifted capacity from energy market to reserve markets.
- Assessment of dynamic performance needs to be included!
- Sensitivity analysis.
Acknowledgements

- National Sciences and Engineering Research Council (Canada)
- Eric Croiset, Peter Douglas, Ali Ekamel — University of Waterloo
- Paul Graham — Energy Technology Division, CSIRO