Emissions Consequences of Wind Motivated Thermal Power Plant Ramping

Karen Studarus

9 December 2010
Emissions and the Power System

• Wind Power
• Motivations From Last Week’s Coal Talk
• Essential Power System Economics
• Ramping Thermal Plants
• Consequences of Ramping Thermal Units
  – Part Load Operation
  – Are Emissions Transients Significant?
  – Bentek’s example in Xcel plant in CO
  – Nationwide effects
• Comparison of Steady State Emissions
• Breaking Policy News led by Xcel plant in CO
Electric Power from Wind

• Appeal
  – None of the emissions associated with fossil fuel combustion
  – Zero Fuel Cost

• Cost: $57-113/MWh (Lazard 2010)

• Rapidly Growing (US and Global Trends)

• Ramping events
Wind Energy as % of Total Electricity Consumed in US

Wind Resource is Variable & Uncertain

BPA Wind (Two weeks April 2009)

Bonneville Power Administration  http://transmission.bpa.gov/wind/default.cfm
“Serve the load at lowest cost.”

- Historical mandate to vertically integrated utilities
- Yields the heart of our optimization:

\[
\text{minimize:} \sum_{i=1}^{n_{Gen}} \text{Cost}_i(P_{G_i}) \\
\text{subject to:} \sum_{i=1}^{n_{Gen}} P_{G_i} = P_D
\]

- Translates well to deregulated energy market

\(\text{(For identical cost functions, maximizing individual generator profit yields the same solution as minimizing costs.)}\)

So why not use exclusively the cheapest source?
Economics-New Capacity

- Simple boiler, no environmental control: 2¢/kW-hr
- Coal supercritical: 10.5¢/kW-hr, 14¢/kW-hr with 90% carbon capture
- IGCC 11.5¢/kW-hr, with carbon capture 16¢/kW-hr
- Gas combined cycle 9¢/kW-hr
- Nuclear 12¢/kW-hr
- Solar tower 12, solar trough 20, PV 16-20¢/kW-hr
- Wind 6-11¢/kW-hr (including tax credits)

http://www.ethree.com/clientlist.html

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- Now they are looking again at gas. If gas prices stay down, this could be a longer term direction.
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Why use many sources?

• Diversified investment
• Limitations in availability
• Most fundamentally: **Time varying demand makes a mixture of sources cost optimal.**
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Unstable Fuel Prices

Coal is Cheaper, Gas is Unstable

Retail gasoline: $22.5/million Btu

Coal=1.25 $/Million Btu

Coal=2.5

Why use many sources?

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Sustainable Energy –
without the hot air

David JC MacKay

“THIS BOOK IS A TOUR DE FORCE ... AS A WORK OF POPULAR SCIENCE IT IS EXEMPLARY”
The Economist

“THIS IS TO ENERGY AND CLIMATE WHAT FREAKONOMICS IS TO ECONOMICS.”
Cory Doctorow, boingboing.net

Sustainable Energy –
without the hot air

David JC MacKay

www.withouthotair.com
David Mackay: “We need to choose a plan that adds up.”

2008, USA

Nuclear heat: 22.5 kWh/d

Wind: 0.5 kWh/d
Solar electricity: 0.008 kWh/d
Hydro: 2.3 kWh/d

Oil for electricity: 1.3 kWh/d

Natural gas for electricity: 19 kWh/d

Coal: 61 kWh/d

Electricity from fossils: 27 kWh/d

Inputs to electricity power stations

Delivered electricity (37 kWh/d total)

Non-electrical energy use – chemical energy and heat

Biomass: 10 kWh/d

More oil: 105 kWh/d

2050?

Wind: 42 kWh/d

Nuclear: 42 kWh/d

Biomass: 42 kWh/d

Solar in deserts: 42 kWh/d

http://www.inference.phy.cam.ac.uk/mackay/presentations/SEWTHA3/mgp00150.html
Example 2050 US plan (MacKay)

2100 GW of wind (60-fold increase)
525 one-gigawatt nuclear power stations (five-fold increase)

http://www.inference.phy.cam.ac.uk/mackay/presentations/SEWTHA3/mgp00150.html
Why use many sources?

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• Limitations in availability

• Most fundamentally: **Time varying demand makes a mixture of sources cost optimal.**

  – Other constraints limit the behavior of each plant:
    • Plant size
    • Reserve requirement
    • Security
    • Losses
    • Congestion
    • Emission limits

    • Ramp Rates
    • Minimum Up Time
    • Start-Up Time
    • Flow Rates,
    • H2O /Fuel supply

    • **At All Times**
Time Varying demand → Gen Mixture

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Simulated Schedule – Western US

“Easy week” 2006  No Wind/Solar

Simulated Schedule – Western US

“Easy week” 2006, with 30% Wind and Solar

Simulated Schedule – Western US

“Hardest week” 2006, with no Wind/Solar

Time Varying demand ➔ Gen Mixture

“Hardest week” 2006, with 30% Wind/Solar

Balancing Burden Increases with Wind

“Hardest week” 2006,

Figure 6.45 Study Area – Week of April 10th – Net Loads Plus Exports by Penetration

Why Ramping is Good

• By ramping down fossil fuel plants (taking advantage of all available wind in the system) the unit burns less fuel and emits fewer tons of gas and particulate.

Burn less → Emit Less
Why ramping is problematic

• Units are most efficient at higher output power.
• Backing off units to part load increases specific emissions.
• Pollution controls are tuned to anticipated operating set-point.
• Affects both NG and Coal plants
  – Coal SO2 scrubbers can be very sensitive, increasing specific SO2 emissions
  – NG efficiency can fall off precipitously at part load, increasing specific CO2 emissions

Emissions/MWh vary with unit output
Coal I/O Characteristic 2008

I/O for Colstrip4 \( Y = 864.414 + 9.59862X^1 - 0.000266566X^2, nres=16139 \)
Natural Gas I/O Characteristic 2008

I/O for River Road1 (Y = 572.981 + 2.29325 \times X^1 + 0.00978965 \times X^2, nres=2074.27)
NG Input Output Characteristic Month

RiverRoad1-HRvsP Aug2008 (Natural Gas)
3rd Possibility: Ramping Even Worse

• Specific Emissions (lbs/MWh) of thermal unit increase more than modeled, offsetting advantage of running at lower power.

• Ramping causes combustion instabilities that result in high emissions for many hours after a ramping event.

• Proposed by Bentek in 2009 presentation to the Natural Gas Industry with one compelling wind induced example

• Upon looking at more data, the Bentek example does not appear to be representative. Emissions are much higher variance than this example suggests.
On July 2, The Cherokee Plant Was Cycled

Actual Generation At Cherokee Plan
Unit No 4

Source: CEMS
Higher Heat Rates Drives Increased Emissions

Emissions & Rates At Cherokee
(All Units – 7/2/2008)

Source: CEMS
Cherokee Transient Event
But “stable days” are high variance
Cherry Picked Example?

• Could this example day be chosen to vilify coal? Is the Cherokee event worth individual scrutiny?

• More comprehensive statistical study required to see if this anecdote generalizes.
Specific Emissions in Excess of Expected

- Hourly emissions as reported to EPA
- Jan2008-July2010,
- All combustion units in the continental US
  - 1238 Coal Units (2009 count)
  - 2909 NG units
  - 231 Other Fuel units (e.g. Wood, Petroleum Coke)

Transients do not appear to be statistically significant.
Event Detection

Colstrip unit: 4 starting 01-Apr-2009 (Coal)

Data
- ssCandidates (0.25*cap)
- eventCandidates
- Pmin, if used as such

Parameters:
- Start: tau=8, ssT=0.25, eT=0.25
- End: tau=8, ssT=0.25, eT=0.25

MWh/h

hour
Specific Emissions in Excess of Expected

Transients do not appear to be statistically significant across national generation portfolio, for SO2, NOx or CO2.
Value in Emissions Transient Model?

- Transients do not appear to be statistically significant across national generation portfolio.
- Next: Make sense of the tails. What characterizes events where the transient is significant, like Cherokee’s Unit 4 on July 2\(^{nd}\) 2008? What do the outliers have in common, and should we predict them?
- Consider Startup/Shutdowns
- Steady State emissions differences b/t Coal and NG are already driving policy.
## Specific Emissions (Steady State)

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<th>Unit Type</th>
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CCS = 90% Carbon Capture and Sequestration, PC = Pulverized Coal, *CC = Combined Cycle, IG = Integrated Gasification, NG = Natural Gas

All emissions values are lifecycle, not just combustion

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Cherokee plant in CO at the fore

• Colorado’s 2010 Clean Air-Clean Jobs Act incentivizes cuts to NOx pollution, so major changes are happening now
• Retrofitting coal and replacing with natural gas both on the table
• Changes anticipate future CO₂ regulations
• PUC expected to rule on the plan today.

Nation watching Xcel's plans for aging coal-fired power plants

By Mark Jaffe
The Denver Post

POSTED: 11/07/2010 01:00:00 AM MST

Colorado is looking to cut air pollution by cleaning up or shutting aging coal-fired power plants, and the way it is done may have national implications on how utilities make electricity.

The Clean Air-Clean Jobs Act, passed last spring, gives Xcel Energy financial incentives to cut pollution by closing or upgrading old coal plants or switching to natural-gas plants.

"This is the first fuel-switching bill in the nation — will it set a precedent?" asked William Yeatman, an energy analyst at the libertarian Cato Institute.
Coal → NG trend nationwide

Breaking Away From Coal

By CLIFFORD KRAUSS
Published: November 29, 2010

HOUSTON — Progress Energy Carolinas, one of the nation’s largest coal users, is facing a dilemma last winter.

Several of its coal plants needed scrubbers to reduce emissions and meet North Carolina pollution standards, and the plant was being overhauled. It was expected to cost nearly $2 billion, nearly 10% of the company’s annual revenue.

Plunging natural gas prices and the push for clean energy have made natural gas a more attractive option than coal for many utilities. Gas-fired plants cost less to build and run, and they produce less pollution than coal plants.

Energy analysts say the shift from coal to gas is likely to continue over the next few years.
Thanks.
Colstrip - NOx vs P - June 2008
Colstrip - Jun08 SO2 vs Power

![Colstrip1-SO2vsP Jun2008 (Coal)](image)
Feb08 Load not cause of SO2 variance
Increasing HR Var. Same Plant 2006-2009

I/O for CentraliaBW212006 \( Y = 2274.37 + 2.71583 X^1 + 0.00721152 X^2, \text{nres}=22070.1 \)

I/O for CentraliaBW212009 \( Y = 4293.28 + 0.998788 X^1 + 0.00559457 X^2, \text{nres}=52127.7 \)
SO2 Features for 142060 events, scaled by max value

- fuelType
- postDurationHr
- preDurationHr
- durationHr
- preMagMW
- postMagMW
- eMagMW
- meanExcessPrior
- meanExcessAfter
- meanExcessDuring
Steps in Event Detection
Steps in Event Detection

finding cycling events

- data
- zeros and nans
- first neighbors
- threshold, if used as such
- threshold from median

MWh/h

hour
Steps in Event Detection