Dynamic Energy and Environmental Dispatch: Achieving co-benefits of power systems reliability and air quality

K. Max Zhang, Richard Schuler, Monica Nguyen, Crystal Chen, Santiago Palacio, and Keenan Valentine

Acknowledgement: Collaborations with Mike Swider and Wesley Hall at NYISO; Valuable discussions with Tim Mount, Bill Schulze, Bob Thomas, Dan Shawhan and Ray Zimmerman.
High Electric Demand Days (HEDD): A “peak” problem

• Heat Waves

• Power Systems
  – Reliability is compromised
  – Cost of electricity is high: expensive peaking generators

• Environment
  – High ozone air pollution
  – Double threats to public health: heat and air pollution
# New York City

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*Note: The table likely represents temperature data for different stations in New York City, with specific values for each day from May 13 to July 18.*
## Washington DC Metropolitan Area

### Calendar

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**Air Quality Index (AQI) Category**
- Very Unhealthy
- Unhealthy
- Unhealthy for sensitive groups
- Moderate
- Good
USA TODAY (July 4, 2012): "In New York City, police officers drive through streets using loudspeakers asking people to turn down their air conditioning during the day. The power grid can't handle it."
MOU among Northeastern States to reduce HEDD emissions

- “Conflict” between power systems reliability and air quality
  - Currently the mechanisms for achieving the reductions proposed by air quality regulators emphasize on emission controls of peaking units.
  - Con Edison’s review indicated that peaking units play important roles in reliability, black start, load pocket support, and voltage support.
  - A 2009 NYISO analysis showed that proposed HEDD programs may lead to “exceedances of reliability criteria”.

<table>
<thead>
<tr>
<th>State</th>
<th>NOx (tons per day)</th>
<th>Percent Reduction from HEDD Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>11.7</td>
<td>25%</td>
</tr>
<tr>
<td>DE</td>
<td>7.3</td>
<td>20%</td>
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<td>MD</td>
<td>23.5</td>
<td>32%</td>
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<td>NJ</td>
<td>19.8</td>
<td>28%</td>
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<td>NY</td>
<td>50.8</td>
<td>27%</td>
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<td>PA</td>
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<td>32%</td>
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<tr>
<td>Total</td>
<td>134.9</td>
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Our Vision for HEDD

• **Supply side:** incorporating air quality forecasting into wholesale day-ahead and real-time electricity markets;
  – dispatching generators taking into account the time- and location-dependent contributions of their NOx emissions to ozone formation

• **Demand side:**
  – **Dynamic prices** of electricity linked to wholesale LBMP to incentivize load reduction from critical peak hours
  – Deployment and smart management of **building thermal storage** to shift loads from critical peak hours
  – incentivize the off- peak charging of **electric vehicles** as those vehicles penetrate into the automotive market, shifting daytime mobile emissions to nighttime point source emissions

• **Hypothesis:** the overall costs to the society in achieving those benefits will be lower than acting on the power reliability and air quality separately.
Major Achievements in Year One

• Emission modeling (in collaboration with NYISO)
• Dynamic pricing modeling (in collaboration with NYISO)
• Thermal storage modeling
• Assessment of emission impacts from
  – Dynamic pricing
  – Thermal storage
  – Challenges
Load Responses

• Critical hours
  – Spread over 90/50/80 highest load hours for NYC, Long Island and the rest of the New York State, depending on market conditions and customer responsiveness
  – Capacity costs applied only during critical peak hours

• Elasticity
  – For residential: from multi-year pilot in Northern Illinois. More recent data can be incorporated.
  – For Commercial and Industrial: non-experimental programs in the eastern US.
  – Applied for Critical Peak period price ratio
Evaluating Impacts

Modified Load Profile → OPF Solver (MatPower) → Hourly generation profile

Dynamic Pricing → Filtered Historical Data → Linear Regression Emission Model

Existing Load Profile

Air Quality Result → Air Quality Model (CMAQ) → SMOKE (Sparse Matrix Operator Kernel Emissions)
Emission Predictions: Preprocessing

- 600+ generator data sets (from EPA)
- Filtering: Find minimum generation via greedy deterministic search
Emission Predictions: 2-Step Regression

- Automated 2\textsuperscript{nd} order regression analysis
- Brute force greedy search to add components

\[ \beta_0 + \beta_1 P + \beta_2 P^2 + \beta_3 \Delta P + \beta_4 \Delta P^2 + \beta_5 |\Delta P| + \beta_6 \frac{\Delta P}{P} + \beta_7 \left(\frac{\Delta P}{P}\right)^2 + \beta_8 \frac{|\Delta P|}{P} + \beta_9 P \Delta P + \beta_{10} P |\Delta P| + \beta_{11} \Delta P |\Delta P| + \beta_{12} \frac{\Delta P \Delta P}{P} + \beta_{13} \frac{\Delta P |\Delta P|}{P} \]

- Step 1: Heat Input vs. Gross Load Regression
- Step 2: Emissions vs. Heat Input Regression
Emission Predictions: $R^2$ Statistics

- Define an acceptable $R^2$ parameter and record the regression for each generator

Heat Input vs. Gross Load

Step 1: 73% of datasets with $R^2 > 0.9$
90% of datasets with $R^2 > 0.7$

Emissions vs. Heat Input

Step 2: 40% of datasets with $R^2 > 0.9$
64% of datasets with $R^2 > 0.7$
Deriving the efficiency of thermal storage from single building level modeling
Optimize System Costs

Use heuristic methods to allocate cooling loads in order to reduce system costs.
Aggregated thermal storage to reduce system costs in NYCA
System Costs Reduction

Ice Storage System Penetration

New System cost/Original System Cost
Linking power and environmental systems

Electricity markets

Load Forecast

Dispatch modeling

Emission Forecast

Weather Forecast

Air Quality Forecast
Demand-side resources and Extreme Weathers

- Hot temperature: High demand
- Drought: low hydro
- Stagnant condition: Low wind outputs
A "secondary" problem
– Formed by reactions of NOx and VOC in the atmosphere

A daytime problem
– Peak around noon and early afternoon; no formation at night

A seasonal problem
– High concentrations occur in the summer months; low during winter

A regional problem
– Emissions in one state may cause ozone problems in other states; emissions from one place may be more inductive to
NO$_x$ Emissions Versus Peak Electricity Demand on Ozone and Non-Ozone Exceedance Days

NJ-NYC-CT-RI-SE MA
(June 1 - September 15, 2002)

Source: EPA Region 1
HEDD Emissions

- HEDD unit operations are a significant contributor to NOx emissions on high ozone days;
- The NOx cap and trade program, although effective generally has, by its very nature, had limited success in reducing emissions from HEDD units on HEDD days;
- EPA and State workgroups estimate that using a cap and trade mechanism alone to provide sufficient financial incentives to cause the clean up of HEDD units would need an 18:1 retirement ratio and such a strategy would consume 74% of all available CAIR allowances for 12 HEDD days.
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  - Currently the mechanisms for achieving the reductions proposed by air quality regulators emphasize on emission controls of peaking units.
  - Con Edison’s review indicated that peaking units play important roles in reliability, black start, load pocket support, and voltage support.
  - A 2009 NYISO analysis showed that proposed HEDD programs may lead to “exceedances of reliability criteria”.


How can we achieve co-benefits and What need to be considered?

• Electricity markets
  – Critical to ensuring system reliability
  – Require air quality information in advance

• Supply and demand
  – Supply: How can we effective dispatch generators to achieve the co-benefits?
  – Demand: A lot of opportunities on the demand-side
    • Demand response
    • Dynamic pricing
    • Price responsive demand
Our Vision for HEDD

- **Supply side:** incorporating air quality forecasting into wholesale day-ahead and real-time electricity markets;
  - dispatching generators taking into account the time- and location-dependent contributions of their NOx emissions to ozone formation (*focus of the first year*)
- **Demand side:** dynamic retail prices of electricity linked to wholesale LBMP — incentivize load reduction and inductive to ozone formation
  - incentivize the off-peak charging as electric vehicles penetrate into the automotive market, shifting daytime mobile emissions to nighttime point source emissions
  - how might environmental concerns affect that customer behavior?
- **Hypothesis:** the overall costs to the society in achieving those benefits will be lower than acting on the power reliability and air quality separately.
Envisioned Operational Mechanism

**Day-ahead Market**

12:00 am
Forecasting (48 hr-ahead) of locational-based damage functions for NOx emissions from Hour 0 to 23 in the operating day

5:00 am
Bids (taking into account the damage functions) submitted for day-ahead market

11:00 am
Day-ahead schedules and LBMPs (reflecting the damaging functions) posted from Hour 0 to 23 in the...

**Real-time Market**

2 Hr prior to the O.H.
Forecasting (24 hr-ahead with adjustment) of locational-based damage functions for NOx emissions for the operating hour

75 min prior to the O.H.
Bids (taking into account the damage functions) submitted for real-time market

15 min prior to the O.H.
Dispatch signals and calculation of real-time LBMPs (reflecting the damage function).
Tools

• Power Systems
  – SuperOPF model
  – NPCC network and Eastern Interconnect network
• Air Quality Forecasting
  – National Air Quality Forecasting Capability (NAQFC): operational
  – Decoupled direct method (DDM) to evaluate the contribution of emissions from individual power plants efficiently
  – NAQFC+DDM will forecast the time- and location-dependent (TLD) NOx contributions to ozone formation, which are then employed to quantify the TLD human health costs of NOx emissions
• An very intensive computational problem integrating different components!
• We aim to make the proposed dynamic energy and environmental dispatch operational to have an impact.
Point Sources of NOx Emissions in the U.S. and Canada

Layer 1 NO[22]+NO2[22]

September 2, 2010 12:00:00 UTC
Min (51, 158) = -11.18, Max (272, 165) = 0.733

NOx Emissions
- Mobile Sources
- Area Sources
- Point Sources (All Layers)

Nighttime
Daytime