An Analysis of the Effects of Drought Conditions on Electric Power Generation in the Western United States

by

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Study Background

- Work funded by National Energy Technology Laboratory (NETL)
  - Existing Plants Research Program – research component focuses on water use at power plants
  - Study evaluated availability of water at power plants under drought conditions and how that effects the electric power system in the drought region

- Drought is very pervasive in the U.S.
  - Many regions experience frequent droughts; some say western states have been in drought since 1999
  - Serious drought affected southeastern states in summer/fall 2007

- Drop in water levels due to drought can be double-edged sword for power sector
  - Water-cooled plants shutdown or curtail power output if water level drops below water intake structures
  - Low river flows and reservoir levels can reduce power from hydroelectric plants
Overall Study Methodology

- Simulate operation of a regional power system under non-drought conditions (base case)
- Simulate operation of a regional power system under drought conditions
- Compare results of both simulations from an operational, cost, and environmental perspective
- Draw conclusions that may be applicable to all U.S. electric power systems
Scope of Power System Simulation Analysis

- Western U.S. – Western Electricity Coordinating Council (WECC)
  - Argonne developed verified unit inventory in previous studies
  - Experiences frequent droughts
  - Region has substantial hydropower resources (28% of capacity in average year; up to 40% in wet year)
- Data obtained from public sources – unit characteristics & system loads from DOE/EIA, Federal Energy Regulatory Commission, and WECC publications
- Simulate operation of wind and hydropower plants; thermal plants served remaining loads; simulate their operation with a unit level hourly probabilistic dispatch model developed by Argonne
- Verified methodology and model operation against actual 2006 WECC data
- Simulated operation in 2010, 2015, and 2020; model results included:
  - Monthly unit generation (in Megawatt hours [MWh])
  - Monthly unit production costs ($)
  - Distribution of monthly and hourly system-wide electricity prices
  - CO₂ emissions (million tons) – CO₂ from biomass was neglected; accounts for only 1% of generation in West. Emission factors obtained from Energy Information Agency by fuel type
Simulation Modeling Assumptions

- Normal and drought hydropower scenarios – lowest hydropower generation between 1980 – 2005 chosen to represent drought year
- Future system additions followed current WECC plan & EIA Annual Energy Outlook (AEO) 2008 – units added to maintain 15% reserve margin in each WECC region
- Expansion candidates included
  - 600 MW coal unit – advanced cooling system; little to no surface water use
  - 400 MW combined cycle unit – advanced cooling system on steam turbine portion
  - 230 MW gas turbine unit
  - 50 MW geothermal unit
  - 30 MW municipal solid waste unit
  - 80 MW biomass unit
  - No new nuclear units
- Accounted for existing & new wind generation – matched AEO regional totals
- Chose drought scenario based on U.S. Drought Monitor, operated by University of Nebraska Lincoln
- Units affected by drought were obtained from water intake database
System Dispatch Methodology

- Non-dispatchable Resource Module
- Argonne Peak Shaving Algorithm
- Probabilistic Dispatch

WECC Hourly Loads -> WECC Unit Inventory

Non-Dispatchable Resources

Dispatch Hydropower Resources

Dispatch Thermal Resources

Results: Generation, Emissions, Costs, Prices
Choosing a Drought Scenario

- Drought conditions chosen from U.S. Drought Monitor (1/27/09)
- Only powerplants using fresh water for cooling and located within areas with a drought intensity of moderate or worse were shutdown
- Plants within drought area were found in database developed by a companion Argonne study (Kimmell and Veil, 2009)
- Drought affected 5 plant sites in 4 states
- If affected plant was a combined cycle plant, steam turbine was shutdown; gas turbine portion could continue to operate
- Year with lowest hydro generation between 1980 and 2005 was chosen

Drought Conditions on January 27, 2009

Source: [http://drought.unl.edu/dm](http://drought.unl.edu/dm)
Impact of Drought on Generation Mix

- Hydropower dropped by 54 TWh or about 30%
- Coal generation dropped by 20.6 TWh in 2010 & 2015; by 15.6 TWh in 2020
- Fuel oil and renewables rose only slightly
- No increase in nuclear – capacity factor already at max in base scenario. In WECC, these plants do not rely on fresh surface water for cooling
- Natural gas rose by over 70 TWh in all 3 years – made up almost entire amount not generated by coal/hydro. Not fully utilized in base scenario – have lower capacity factor than coal
Impact of Drought on Generation Cost

- Production costs rose 25%, 22%, & 23% in 2010, 2015, and 2020
- Energy Not Served (ENS) rose by 3.5 times in 2010 & more than double in 2015 & 2020; Virtually all occurred in July & August, WECC’s peak load months
- Production costs and ENS decrease over time because new coal plants with cooling systems less vulnerable to drought displace natural gas plants

Cost Differences Between Base and Drought Scenarios

- Cost (billion$)
- Year

2010 2015 2020

Production Cost Difference
ENS Cost Difference
Impact of Drought on Electricity Price

- Average monthly system-wide prices shown in table.
- Price distribution between months varies greatly; much wider in August (summer peak) than January.
- 5 to 10% of time prices in August 2010 & 2015 will exceed $150/MWh; drops to 2% by 2020.

<table>
<thead>
<tr>
<th>Month</th>
<th>Average Price of Electricity ($/MWh)</th>
<th>Price Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>61.01 54.04 51.76</td>
<td>65.97 58.32 56.79</td>
</tr>
<tr>
<td>Feb</td>
<td>60.21 53.30 50.67</td>
<td>67.21 59.40 54.29</td>
</tr>
<tr>
<td>Mar</td>
<td>55.58 49.14 46.02</td>
<td>60.84 53.38 50.69</td>
</tr>
<tr>
<td>Apr</td>
<td>54.95 48.47 43.61</td>
<td>61.08 53.45 50.27</td>
</tr>
<tr>
<td>May</td>
<td>54.69 46.88 40.57</td>
<td>62.23 53.06 48.29</td>
</tr>
<tr>
<td>Jun</td>
<td>55.35 48.71 40.04</td>
<td>61.80 54.96 47.48</td>
</tr>
<tr>
<td>Jul</td>
<td>69.14 68.07 54.17</td>
<td>91.67 89.16 67.24</td>
</tr>
<tr>
<td>Aug</td>
<td>78.48 87.87 61.75</td>
<td>105.70 109.75 71.27</td>
</tr>
<tr>
<td>Sep</td>
<td>59.97 52.85 44.95</td>
<td>64.05 56.73 50.17</td>
</tr>
<tr>
<td>Oct</td>
<td>63.20 55.75 43.04</td>
<td>65.47 57.86 47.24</td>
</tr>
<tr>
<td>Nov</td>
<td>62.97 55.36 52.13</td>
<td>65.89 58.18 56.36</td>
</tr>
<tr>
<td>Dec</td>
<td>59.44 52.70 50.89</td>
<td>66.72 58.71 55.30</td>
</tr>
</tbody>
</table>

Price distribution between months varies greatly; much wider in August (summer peak) than January.

5 to 10% of time prices in August 2010 & 2015 will exceed $150/MWh; drops to 2% by 2020.
Impact of Drought on CO\textsubscript{2} Emissions

- CO\textsubscript{2} emissions from drought scenario higher by 20 million tons each year
- Overall, increase is small; 5.4% in 2010, 4.3% in 2015, and 3.8% in 2020
- Natural gas plants replaced virtually all generation lost due to drought
- CO\textsubscript{2} emissions are less than what might be expected because natural gas:
  - Produces less CO\textsubscript{2} per BTU than coal; emission factor is 44% less than coal
  - Units are generally more efficient; use less fuel for each unit of electricity produced

<table>
<thead>
<tr>
<th>Year</th>
<th>Base Scenario (10\textsuperscript{6} tons of CO\textsubscript{2})</th>
<th>Drought Scenario (10\textsuperscript{6} tons of CO\textsubscript{2})</th>
<th>Difference (10\textsuperscript{6} tons of CO\textsubscript{2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>408.4</td>
<td>430.5</td>
<td>22.1</td>
</tr>
<tr>
<td>2015</td>
<td>480.5</td>
<td>501.3</td>
<td>20.8</td>
</tr>
<tr>
<td>2020</td>
<td>548.1</td>
<td>569.1</td>
<td>21.0</td>
</tr>
</tbody>
</table>
Conclusions from Simulation - Generation Mix

- Natural gas plants heavily utilized during drought; are in best position because they are operated at lower capacity factors than coal plants.
- Electric systems without sufficient natural gas capacity may have difficulty generating needed energy in the short term during a drought. Would need to purchase power on the open market at prices driven higher due to drought.
- Electric systems relying heavily on coal would benefit in long term by constructing new coal plants with advanced cooling technologies. Coal started coming back by 2020 in WECC example.
- Nuclear may be a wild card in drought scenario:
  - Those with cooling systems that don’t use fresh surface water would be unaffected – as in WECC example.
  - Those with fresh water cooling systems would be subject to shutdown/curtailment – their loss could severely strain electric system.
  - Nuclear plants in other U.S. power systems rely more on fresh surface water cooling than in WECC.
Conclusions (cont’d) – Electricity Prices, Water Supplies, CO₂

- Increased generation by natural gas plants during drought would likely raise natural gas prices; consumers may be hit twice – high electricity prices and high domestic gas prices. Quantification beyond scope of this study.
- Generators have been trying to diversify coolant water supplies
  - Installing groundwater wells to supplement lake water
  - Piping groundwater from a distance
  - Using wastewater from nearby facilities, such as produced water from a coal bed natural gas project (proposed for 2 Wyoming power stations)
- Groundwater may not be an option in some areas because of competing water needs, such as drinking water
- CO₂ emissions may increase only slightly due to drought
Areas for Future Study

- Transmission constraints
  - Droughts can affect specific areas without affecting others
  - Under normal conditions, transmission lines may be at limit; heavy use and high ambient air temperature (which often accompanies drought) can further reduce operating limit

- Drought effects power plant operation other than low water intake levels
  - Often accompanied by very hot conditions
  - Power plant limits on water temperature discharge – power output reductions even though water intake levels may be sufficient
  - Effect of excessive heat on air intakes; especially gas turbines
Thank you for your attention

The full report is available at:

- NETL web site
  - Kimmell and Veil 2009 study also located on this page

- Argonne National Laboratory web site
Supplemental Slides Follow
Processing Historic Hourly Loads to Obtain Future Load Profile

Control Area Loads Are Separated into Power Pools & Aggregated Hourly

Hourly FERC Form-714 Data by Control Area for 1993-2006

- NWPP (I) Hourly Loads 1993-2006
- RMPA (II) Hourly Loads 1993-2006
- AZNM (III) Hourly Loads 1993-2006
- CAL (IV) Hourly Loads 1993-2006

Load Profile Selection

Load Shaping Algorithm

Selected Profile

Monthly Load Control Totals (Peak & Total Energy)

- Selected Profile

- Monthly Peak and Total Loads by Power Pool for 2006-2020

- NWPP (I) Hourly Loads 2007-2020
- RMPA (II) Hourly Loads 2007-2020
- AZNM (III) Hourly Loads 2007-2020
- CAL (IV) Hourly Loads 2007-2020

WECC Hourly Loads 2007-2020

NERC ES&D Data Files
WECC Coordinated Power Supply Programs
EIA Annual Energy Outlook
Creating a Thermal Unit Inventory

- Fuel Prices
  EIA-423

- Thermal Unit
  Inventory
  EIA-860

- Outages
  Rates
  GADS

- Heat Rates
  EIA-906

- Water Use
  Heat Rates &
  FGD EIA 767

- Variable O&M
  EIA AEO
Model was Calibrated to WECC 2006 Data

<table>
<thead>
<tr>
<th>Technology</th>
<th>Model Generation Mix (%)</th>
<th>Actual Generation Mix (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>31.5</td>
<td>31.2</td>
</tr>
<tr>
<td>Gas</td>
<td>26.2</td>
<td>25.6</td>
</tr>
<tr>
<td>Nuclear</td>
<td>10.4</td>
<td>9.4</td>
</tr>
<tr>
<td>Hydro</td>
<td>28.1</td>
<td>28.8</td>
</tr>
<tr>
<td>Wind</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Others</td>
<td>2.2</td>
<td>3.6</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Note: Actual generation mix is calculated based on AEO 2008.

2006 Model Calibration for Generation Mix

Model Calibration – Price Probability Distributions for April through June 2006