Improved Emission Functions for Generators, and How They Help Resolve a Controversy About the Emission Effects of Wind Power

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(1) Overview

We demonstrate a method for estimating emission and fuel use functions for most of the fuel-burning electric generation units in the United States, and use it to address a controversy about the emission effects of wind power.

Prior simulations have shown that 20 to 30 percent renewables penetration in Western Electricity Coordinating Council (WECC) would result in a significant increase in the ramping up and ramping down of fuel-burning electricity generation units (GE Energy, 2010, Western Wind and Solar Integration Study). This increase in ramping may impact emissions, and past studies of the effect of wind power on emissions arrive at vastly different results. Two studies have found that wind power increases a regional power system's emissions of sulfur dioxide (SO2) and nitrogen oxides (NOX) because of the emission effects of increased start-ups and ramping by fuel-burning generation units that adjust to varying wind farm output (Bentek Energy, LLC, 2010, "How Less Became More…"; Katzenstein & Apt, 2009, Env Sci & Tech 43). Other research has found that wind and solar power reduce emissions almost as much as they reduce generation by fuel-burning generation units (Fripp, 2011, Env Sci & Tech 45; Lew, Brinkman, Kumar, Besuner, Agan, & Lefton, Impacts of Wind and Solar on Emissions, undated).

We estimate the actual SO2, NOX, and CO2 emission functions of each fuel-burning generation unit with a capacity over 25 MW in the Texas power grid, accounting for startups, ramping, and non-linear relationships between electricity output rate ("GLOAD") and emission output rate ("E"). Accounting for the effects of ramping and start-ups on emissions and heat rates is particularly important for predicting the effects of scenarios that may significantly change the frequency of ramping or start-ups, such as scenarios with differing market penetrations of wind power. We then apply these functions to two simulated scenarios from the Texas grid operator. One is a "low-wind penetration" scenario with 11,000 MW capacity of wind, and the other a "high-wind penetration" scenario with 18,000 MW capacity of wind. Applying our emission functions, we produce estimates of emissions under the two scenarios.

(2) Methods

We estimate the following ARMAX model for each generator i and emission type e, with p, q, u, r, and s lag lengths. The symbol t is an index of time measured in hours. "Upramp" is the increase in generation from the last hour, if any. "Downramp" is the decrease, if any. "Startup" is a binary variable that takes the value 1 only in an hour in which the unit changed from not generating to generating.

$$E_{iet} = \mu + \sum_{n=1}^{p} \phi_m E_{ie(t-n)} + \theta_1 \epsilon_t + \sum_{m=0}^{q} \theta_{m+1} \epsilon_{t-m} + \alpha_1 GLOAD_{it} + \alpha_2 GLOAD_{it}^2 + \sum_{k=0}^{u} \beta_k Upramp_{i(t-k)} + \sum_{j=0}^{r} \lambda_j Downramp_{i(t-j)} + \sum_{h=0}^{s} \gamma_h Startup_{i(t-h)}.$$

(3) Results

COAL SIMULATION RESULTS

	Low Wind Penetration	High Wind Penetration	Percent Change
Wind Capacity	11,000 MW	18,000 MW	63.6%
Coal Generation	127,773,413 MWh	123,714,479 MWh	-3.2%
Coal Startups/GWh from coal	0.00325	0.00340	4.4%
Coal Ramp Incidents/GWh from coal	0.154	0.284	84.4%
Average Coal Ramp	125.71 MW/hr	94.4 MW/hr	-24.9%
Standard Deviation of Coal Ramps	88.65 MW	70.99 MW	-19.9%
Coal NO_x Emissions	157,003,520 lbs	151,001,544 lbs	-4.0%
Coal SO_2 Emissions	655,989,596 lbs	632,268,091 lbs	-3.6%

NATURAL GAS SIMULATION RESULTS

	Low Wind Penetration	High Wind Penetration	Percent Change
Wind Capacity	11,000 MW	18,000 MW	63.6%
Gas Generation	115,223,385 MWh	93,657,898 MWh	-18.7%
Gas startups/GWh from gas	0.101	0.114	13%
Gas Ramp Incidents/GWh from gas	0.86	0.95	10.5%
Average Gas Ramp	78.32 MW/hr	78.77 MW/hr	1.01%
Standard Deviation of Gas Ramps	31.3 MW	31.1 MW	-0.64%
Gas NO_x Emissions	438962830.69 lbs	268648138.43 lbs	-38.8%

COMPARING TOTAL EMISSIONS

	Low Wind Penetration	High Wind Penetration	Percent Change
Wind Generation	35,430,595 MW	63,214,866 MW	78.42%
Fuel-Fired Generation	285,488,976 MWh	259,854,011 MWh	-8.98%
Total SO_2 Emissions	665,204,116 lbs	641,394,291 lbs	-3.6%
Total NO_X Emissions	596,694,675 lbs	420,389,134 lbs	-29.5%

(4) Conclusions

Increases in wind penetration do increase the number of startups and ramping incidents per GWh. However, for both coal and gas, emissions decrease more than generation. Finally, wind displaces gas generation more than coal generation, with the result that sulfur dioxide emissions decrease less than does thermal generation, but nitrogen oxide emissions decrease more than does thermal generation. The latter result occurs because wind disproportionately displaces highly emitting gas-fired generators. It does so because those generators also tend to be less fuel efficient and hence more expensive to use. We will add carbon dioxide emissions for Texas, and all three emission types for the state of New York, before August.