GAS TURBINE DEVELOPMENTS NEEDED TO AID WIND POWER INTEGRATION

WARREN KATZENSTEIN, THE BRATTLE GROUP

Gas turbines are almost an ideal technology to compensate for wind power variability. They can be quickly started (some gas turbines have cold startup times of less than 5 minutes) and can ramp up and ramp down their power levels faster than coal, steam, and nuclear plants can. The strong growth in wind power and the lack of cost-effective storage solutions means systems will rely heavily on gas turbines to compensate wind power variability. Even in regions with significant amounts of hydropower (a better technology to compensate for wind power variability), gas turbines will still be required to backup wind power because environmental regulations limit the minimum and maximum amount of water a hydroelectric dam can release (termed run of river constraints).

Gas turbines operate best at full-power steady state conditions where they are at their highest fuel and emissions efficiencies. Deviations away from this tuned set point result in significant inefficiencies (particularly with NO_x emissions) and increased operational costs. Katzenstein and Apt found that wind power variability reduces the amount of CO_2 emissions wind power can displace by 25%.[1] More alarming, NO_x emissions for the majority of the cases studied were not reduced and in some instances increased substantially.

New regulations, like EPA's Clean Air Interstate Rule (CAIR) and its eventual successor (currently EPA's proposed Transport Rule), continue to ratchet down the limits on NO_x and SO_x emissions. Given Katzenstein and Apt's conclusions, stricter emissions caps could restrict gas turbines from compensating wind power variability in a similar way that run of river constraints have restricted the ability of hydropower to mitigate wind power variability in the Northwest.

As a result, the opportunity exists for manufacturers to develop gas turbines specifically tuned to compensate wind power variability. Ideally, manufacturers would focus on minimizing the emissions of their gas turbines over a wider range of power levels and ramp rates. Carbon dioxide emissions need the least amount of focus because a wind + gas baseload plant is able to achieve at least 75% of the maximum reductions available in CO_2 emissions. And using multiple turbines to compensate for wind power variability increases the amount of CO_2 emissions wind power displaces (although it is not possible to achieve 100% displacement of CO_2 emissions). Sulfur dioxide emissions depend on the sulfur content of the fuel used; therefore SO_x emissions are primarily a concern when coal plants are used to mitigate wind power variability.

Reducing NO_x emissions should be the primary focus for manufacturers when developing wind power friendly gas turbines. Gas turbine NO_x emissions depend on the type of gas turbine and the technology employed to mitigate NO_x emissions. Simple first steps can be taken for gas turbines that use dry low NO_x technology by utilizing, if available, gas turbine firing modes that originally were intended for

[1] Katzenstein and Apt's results are for wind + gas baseload plants. In other words, the turbine whose emissions are displaced is the same turbine that provides compensating power. Reference: Katzenstein, W., Apt, J. Air Emissions Due to Wind and Solar Power. *Env. Sci. Technol.*, **2009**, *43* (2), pp 253–258.

transitioning from diffusion flame combustion to lean burn combustion. Doing so would extend the transition point, where the turbine produces low NO_x emissions to where it produces high NO_x emissions: from 50% of its nameplate capacity to ~35 to 40% of its nameplate capacity. Manufacturers of gas turbines that use water and steam injection NO_x mitigation systems will need to focus on minimizing emissions during low-power, positive ramping events. Finally, the performance of selective catalytic reduction (SCR) and non-selective catalytic reduction (NSCR) systems in reducing the NO_x emissions of heavily-cycled gas turbines should be analyzed. The control strategies of SCRs and NSCRs will need to be revised if the systems cannot effectively mitigate the NO_x emissions of a wind + gas plant.

Finally, system operators and participants need to identify the additional costs incurred by generators when compensating for wind variability and electricity markets need to ensure adequate market mechanisms are present to allow gas generators to recover these costs. Using gas generators to mitigate wind power variability increases the variable costs of generators. For example, gas generators will have to spend more to obtain emissions permits to produce a MWh of electricity and spend more on maintenance because the maintenance schedule of a gas turbine depends on how much it cycled over its power range. System operators will need to ensure gas generators can recover these expenses. Finally, compensating for wind power reduces the revenue stream of a gas generator because of the lost opportunity cost of operating at its maximum capacity. System operators will need to provide gas generators with a method to recover a portion of their lost opportunity costs in order to ensure enough gas generators are financially viable and will remain in the market to support the integration of wind power.