Wind Penetration Impacts: Costs, Fuel Used, and CO2 Emissions
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Why More Wind?
Although the nameplate capacity of wind power in today’s electric grid is a small portion of the total energy produced, wind power is creating an economic and operational challenge for today’s Balancing Authorities. ERCOT manages the largest nameplate capacity of wind power in the U.S., but how does the generation mixture of ERCOT compare with the national mixture?

Thermal Generation: Coal vs. Natural Gas
The average cost of natural gas during 2008 was 4.36 times as expensive as coal, with natural gas costs of $9.02/MMBtu and coal costs of $2.07/MMBtu. But, coal only produced 2.25 times as much energy during 2008 as natural gas, with coal producing 1.986×10⁹ GWh and natural gas producing 8.933×10⁸ GWh of energy.

Since nuclear generation construction has been stagnant over the last two decades, current emphasis on thermal generation mainly centers around coal and natural gas. These units play a crucial role in generation base loading (coal) and peaking (natural gas). Although coal is significantly cheaper to burn for electricity, a manageable generation source is needed to meet demand at any given time. Therefore, a premium is paid for the versatility needed by natural gas generation.

Energy storage systems such as pumped storage hydropower or batteries may be implemented once technology advancements are made, but for the meantime natural gas will play a key role in following demand and balancing wind for systems without a significant amount of hydroelectric generation.

Effects of Increased Levels of Wind Penetration
Introducing wind energy into the generation mix creates operational questions, but also economic questions as well. Unit commitment algorithms are used to find the economically optimal set of generators to commit for a given time period. Given a load profile and wind profile, perfect forecasting is assumed but the economic effects of increasing levels of wind penetration can be analyzed.

Using a generation mix that models ERCOT, various levels of wind penetration were applied and the results of the unit commitment algorithm are displayed below. Wind penetration levels applied were 5%, 10%, 20%, 30%, and 40%. This snapshot in time shows a 2-week period with significant levels of wind as well as limited amounts.

Although the national mixture of generation exploits the use of cheaper conventional units such as nuclear and coal, the ERCOT generation mixture accommodates the “free” energy created by wind. Thus, ERCOT profits exceed those of the national mixture at higher levels of wind energy because less wind must be curtailed. Natural gas is a form of generation that can quickly ramp to match variability of wind generation and the versatility of ERCOT’s large percentage of natural gas accommodates high levels of wind.

Cheaper to Curtail or Use the Wind?
Wind is a cheap, almost free resource but when is it cheapest to use this energy versus curtailing it? The unit commitment algorithm will attempt to find the cheapest feasible solution of generation mixture for its given forecast. As is expected, the unit commitment algorithm curtails less wind energy when the ERCOT mixture is used compared to the national mixture. This is due to the fact that the national mixture attempts to use base load generation rather than faster-ramping unit. But as the wind picks up or the load subsides, it must be curtailed while thermal generation attempts to accommodate the continuously changing wind.

The one inconsistency at 20% penetration is due to the unit commitment’s decision to keep all thermal generation on for the ERCOT mixture, while ramping both the nuclear and base coal units as quickly as possible. In the national mixture, the base coal unit is shut off while the natural gas units quickly ramp to balance the wind.

ERCOT’s Capability to Manage Large Amounts of Wind
The profitability of ERCOT’s generation mix compared to a mixture modeling that of the national mixture varies as wind penetration levels increase. The oscillation in profits is due to operational impacts that wind generation poses.

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Coal Consumption and CO2 Emissions
It is expected that as wind penetration levels increase, the use of fossil fuels will decrease because wind energy will displace the need for this fuel. Coal is usually used as a base load generating unit, meaning at low levels of wind penetration coal use will be relatively unaffected. But as wind energy picks up in the future, system operators will be faced with the question of economic optimality versus system reliability. The graph below demonstrates how at 30% wind levels, the coal units shut off for an extended period, but at 40% the coal used is larger. This is because at 40% penetration levels, the nuclear unit shuts off, reinitializing the need for coal.

Using data collected from the Energy Information Agency, CO2 emissions data from the electric power sector was extracted.

References
1. Energy Information Agency
   https://www.eia.gov/cneaf/electricity/epa/epates.html

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