

**THE UNIVERSITY OF VERMONT
SCHOOL OF ENGINEERING
PRESENTS:**

***The Character of Wind and Solar Power Variability and its
Effects on Fill-In Power***

Jay Apt (Carnegie Mellon University)

Executive Director, Carnegie Mellon Electricity Industry Center

Associate Research Professor, Tepper School of Business

Distinguished Service Professor in Engineering and Public Policy

Abstract

The power spectral density of the output of wind turbines and solar photovoltaic systems provides information on the character of fluctuations in turbine output. The spectrum defines the character of fill-in power that must be provided to compensate for wind's or solar's fluctuations when they are deployed at large scale. Installing enough linear ramp rate generation (such as a gas generator) to fill in fast fluctuations with amplitudes of 1% of the maximum fluctuation would oversize the fill-in generation capacity by a factor of two for slower fluctuations, greatly increasing capital costs.

Natural gas generators are often used to fill in the variable power output of wind or solar power to provide good power quality. Over a wide range of renewable penetration, we find CO₂ emissions from gas generators achieve less than 80% of the emissions reductions expected for a given amount of wind or solar if the power changes caused no additional emissions. Using steam injection, gas generators achieve only 30-50% of expected NO_x emissions reductions, and with dry control NO_x emissions increase substantially. We quantify the interaction between state RPSs and the NO_x Clean Air Interstate Rule, finding that improvements in NO_x controls on gas generators are required to achieve CAIR targets in states with a substantial RPS.

July 7, 2008

11:00 a.m., Perkins 101