Wind-Energy Science, Technology and Research (WindSTAR)

University of Massachusetts Lowell, Christopher Niezrecki, 978-934-2963, Christopher_Niezrecki@uml.edu
University of Texas at Dallas, Stefano Leonardi, 972 883-3564, stefano.leonardi@utdallas.edu

Extremum Seeking Control for Maximizing of Wind Turbine Power Output

Wind power is a primary renewable energy source. Wind turbines are operated across a range of wind speeds. For a majority of the time, wind turbines operate below the rated wind speed; the so-called Region-2 operation. The primary objective of Region-2 wind turbine control is to maximize the power output by adjusting generator torque and/or blade pitch angle.

In field operation, WINDStar ESC Region-2 control strategy and wind turbine control systems face two major challenges. The first is coping with the not insignificant uncertainties and changes in turbine characteristics. These uncertainties and changes are due to the complexities of wind field and turbine aerodynamics, manufacturing variability, blade wear and the accumulation of foreign materials such as snow, ice, bugs and dirt. The second challenge relates to the fact that typical anemometers (air speed gauges) on commercial turbines do not provide the needed wind measurement accuracy and reliability that is necessary for optimal energy capture. This is due to the accumulation of snow and ice, wear, blockage and a phenomenon known as the near wake effect.

A wind turbine. Credit: Wind Energy Development Programmatic Environmental Impact Statement (EIS)

The major impact of this breakthrough WINDStar technology is increased energy yield without significantly increased cost. Referred to as Extremum Seeking Control (ESC), it has the ability to address these challenges because: 1) it is a model-free control strategy (that is, it is not sensitive to modeling uncertainty), and; 2) it does not require wind measurements. ESC is a self-learning algorithm that uses a probing signal (dither) to determine how to adjust the generator torque gain and/or blade pitch angle for maximizing power production in Region 2 wind turbine applications.

Currently available wind turbine controllers for Region 2 applications are usually based on pre-determined models, curves, or lookup tables; precise wind measurement is required. During field operation such strategies cannot optimize energy capture because of changing turbine characteristics and inaccurate wind measurements. Recently proposed adaptive control schemes alleviate the need for models, but may not be capable of decoupling the changes in wind input from that of the tuning of control inputs. This leads to excessively long times to achieve best performance. This implies that wind turbine owners would lose energy and the revenue it provides due to an inherent inability to track the point of maximal power production with adequate reaction times.

The WINDStar Center's ESC Region-2 control strategy uses an innovatively designed dither signal that serves as carrier for the information required to maximize power. This process is similar to the process used in AM radio transmission, wherein a properly designed carrier transmits useful information. In the ESC for power maximization, the most useful information is the "slope of the power curve," which allows the algorithm to decide how to climb this curve to its maximum. Thus, by demodulating from the carrier signal the slope of the power curve, power maximization is achieved despite wind fluctuations. As a consequence, the convergence time of the control parameters is greatly reduced.

The breakthrough WINDStar ESC Region-2 control strategy can be implemented in both new and existing wind turbines because the technology features a simple control structure and makes use of control inputs and measurements readily available on commercial turbines.

Economic impact: The procedure for ESC algorithm tuning is relatively simple. This makes relatively straightforward field commissioning possible. Wind turbine operators using ESC for power maximization will benefit through higher energy capture without significant increases in maintenance cost. As a result of this breakthrough the overall levelized cost of energy (LCOE) for wind power generation can be reduced, thereby increasing the value proposition for wind power.

Field evaluation of ESC at NREL's CART3 600 kW turbine has shown an impressive 12 to 17% increase in energy capture relative to common controllers without substantive increases in structural load. The economic impacts on energy producers and consumers should therefore be substantial. Based on the NREL test results, WindSTAR's industry members estimate increased energy output of at least 1-3% for actual field deployments of the technology. For a typical commercial scale wind turbine, a 1% increase in annual energy results in an extra $3,000-5,000 per year per turbine. That is, a 3% increase in energy capture made possible by this technology will likely result in $470-780 million increases in the annual revenue for the U.S. wind power industry even considering the currently installed capacity. This is a huge opportunity for any entity that operate turbines and should be very attractive to wind farm owners.

For more information, contact Yaoyu Li at the University of Texas at Dallas, yaoyu.li@utdallas.edu, Bio http://me.utdallas.edu/people/li.html, 972.883.4698, and/or Mario Rotea, rotea@utdallas.edu, Bio http://me.utdallas.edu/people/rotea.html, 972.883.2720.