Controlling Energy Capture from Wind

Wind energy is currently the fastest growing power-generation technology worldwide, reaching a 30% annual growth rate and an installed capacity of 300 GW. To realize these achievements, wind turbine designs have overcome multiple technical challenges to be competitive with predominant energy sources. Control technology has played a crucial role in this quest. The control system dynamically adapts to a wide range of wind conditions and maintains structural integrity while maximizing energy production. In addition, the controller must manage weather conditions, abnormal wind disturbances, and fault scenarios that may occur unexpectedly during the life span of the turbine.

Leveraging the experience of more than 22,000 units installed worldwide, General Electric has developed a comprehensive model-based control system for wind energy that includes algorithms to adapt to variable wind conditions, fault-tolerant strategies to accommodate failures and extreme disturbances, and a supervisory system that manages both the turbine and farm-level fully automated operations.

Challenges of Controlling Wind Turbines

Wind turbines are rather complex systems, with multiple flexible structures coupled through highly nonlinear dynamics and subject to varied wind disturbances. Their designs need to satisfy stringent requirements to ensure safe and reliable operation for a 20-year or longer life span. Indeed, international standards such as IEC 61400 require extensive numerical simulations to ensure survival in conditions ranging from normal operation under turbulent wind to a multiplicity of fault events combined with abnormal wind or weather scenarios. An example requirement is to consider the most likely sudden failures of the blade pitch system or storm conditions and show that the turbine can shut down without overstressing the blades, the tower, or the drive train. Maximizing energy production under these requirements is achieved with only a limited set of actuators that command blade pitch, rotor yaw, generator torque, and brakes to stop the rotor. In addition, to avoid the cost of on-site manual maintenance, the turbine controller includes extensive logic to perform automatic calibration procedures, self-diagnostics, and supervisory functions.

Contributor: Fernando D'Amato, GE Global Research, USA

Solution Approach

The control system for GE wind turbines includes:

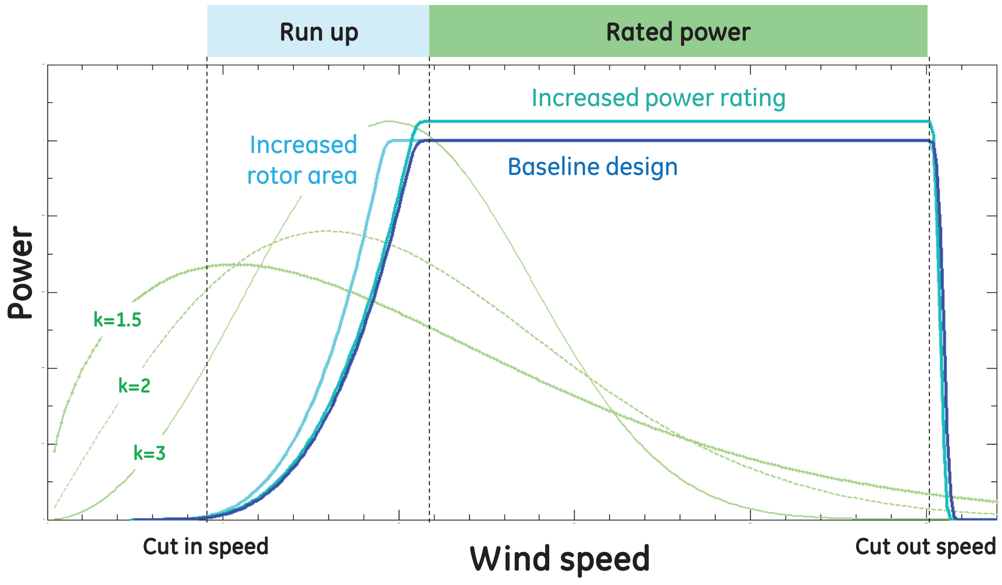
- Turbine control algorithms that adapt operation to each wind condition
- Supervisory controls to handle failures and braking procedures
- Farm-level control to maximize energy capture and manage grid integration

Wind turbine controls rely heavily on model-based technology at every layer of implementation. Namely, the basic dynamic equations of the drivetrain, tower, and rotor are included as an integral part of controller algorithms. Model-based estimation is used to learn the state of the wind and structural components. The main turbine controller uses this model to achieve consistent disturbance rejection response across the operating range. In addition, first-principle concepts of dissipative systems theory are implemented to ensure safe braking and shutdown procedures. Finally, optimization algorithms based on wind models are used to generate the turbine control setpoints to maximize energy capture and minimize noise at the farm level.

Results and Benefits

The limiting loads of wind turbine components are highly dependent on the ability of the control system to cope with all design requirements. Decreasing the maximum load of components directly translates into cost reduction or increased performance. For example, improvements in the control system for 1.6-MW turbines enabled use of larger blades, resulting in a 20% increase in annual energy capture. For turbines in the range of 2.5 MW, development of fault-tolerant controls to handle extreme wind events reduced component loads by up to 30% in several turbine components.

In the foreseeable future, control design improvements will continue to increase operating efficiency and reliability and reduce turbine costs. Advances in controls are crucial for more competitive wind power generation!



By effectively managing structural loads, control technology enables significantly higher power to be captured from wind resources, as shown by these power curves. Lower loads allow using generators with increased power rating or increased rotor area (i.e., longer blades) than the baseline design. The three green lines show typical wind site characteristics and represent the proportion of time expected for prevailing wind speeds. Each characteristic is approximated by a Weibull distribution with different shape parameter k.

For more information: visit http://www.ge-energy.com/products_and_services/products/wind_turbines/ges_2.5_120_wind_turbine.jsp.