Control for Wind Power

Recent experimental assessments show that wind power has the potential to satisfy the global primary energy need. Today, wind power accounts for the largest share of renewable energy generation after hydropower, with 30% global annual growth. Moreover, in the last few years, innovative technologies are being investigated to tap the astonishing power of high-altitude wind using tethered controlled aircraft/kites, with the promise of wind energy at lower cost than fossil sources. Common to both traditional and innovative wind energy concepts are challenging modeling and control design problems. Advances in wind power control will be essential for increasing the penetration of renewable generation and thereby reducing the planet's dependence on fossil sources—a global imperative.

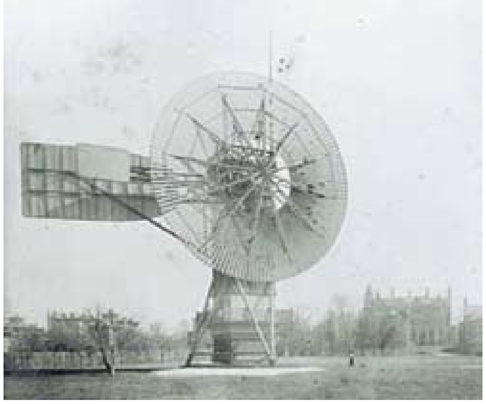
Efficiency Improvement with Control Theory

Today's wind power technology is the result of decades of incremental innovations of wind turbine systems, yet some aspects still require enhanced solutions.

Wind turbines are complex nonlinear systems operating in strong noisy environments with severe constraints on admissible loads. Recent advances developed by the control community in nonlinear modeling, filtering, and control can help realize significant, cost-effective, and safe energy generation improvements.

Adaptive and fast model-predictive control techniques appear to be well suited for the two most critical control problems for wind turbines: blade pitch control and generator torque control. However, the modeling codes available are of questionable accuracy for use in such control design. Data-driven nonlinear modeling and identification approaches could be employed to increase the accuracy of wind tower models. Furthermore, more complex algorithms for blade pitch control based on accurate short-term prediction of wind speed will be fundamental to reducing loads, thus improving reliability and saving material. Finally, distributed control on rotors, using a series of actuators and sensors along each blade, could further reduce loads on the blade, the drive train, and the tower. Such improvements will be even more important for the development of larger offshore wind turbines.

Left: High-altitude wind technology
Right: Wind turbine technology



Wind Energy and Control—The Early Days

The world's first automatically operating wind turbine for electricity generation is attributed to Charles F. Brush, who designed and erected a turbine in Cleveland, Ohio, in 1887. Its peak power production was 12 kW, and it operated for 20 years. Control was critical even then—an automatic control system ensured that the turbine achieved effective action at 330 rpm and that the dc voltage was kept between 70 and 90 V.

Another milestone in wind energy was the 1.25-MW wind turbine developed by Palmer Putnam, also in the U.S., in 1939-1945. This was a giant wind turbine, 53 m in diameter. A hydraulic pitch control system was used for its two blades.

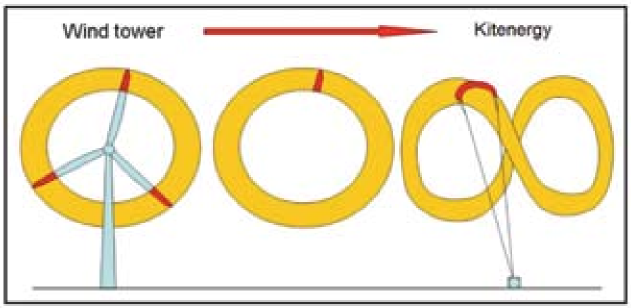
Left: Charles F. Brush's wind turbine, c. 1887

Contributors: Lorenzo Fagiano and Mario Milanese, Politecnico di Torino, Italy

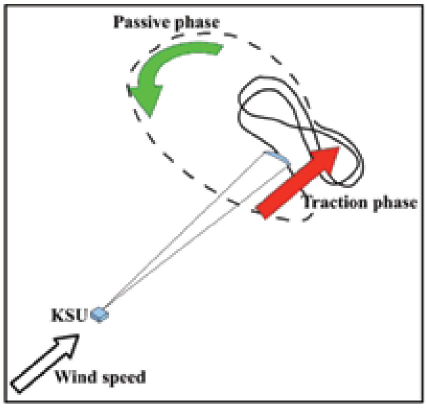
Radical Innovation with Control Theory: High-Altitude Wind Power Systems

In recent years, several university researchers and high-technology companies have been actively working to develop innovative high-altitude wind (HAW) generators. HAW generators aim to harvest wind power at higher altitudes than those reachable by wind turbines, that is, at over 200 m. At these altitudes, stronger and more constant wind can be found almost everywhere.

In all proposed HAW generator concepts, whether rigid wings, kites, rotorcraft, balloons, or other aircraft, control is a key technology. The control system has to maximize the generated energy and satisfy operational constraints while coping with the nonlinear dynamics of the system, the presence of turbulence, and changes in wind speed and direction. Advanced model-predictive control, nonlinear experimental modeling methods, filtering, and sensor fusion techniques will all be important. Furthermore, distributed control strategies will be highly important for the operation of high-altitude wind energy farms, composed of several HAW generators operating in the same site, to avoid interference among the aircraft and to maximize the overall power output.



Example: Kitenergy



One example is a technology developed at Politecnico di Torino called the "Kitenergy" system. The concept is based on wings (for example, power kites like the ones used for surfing or sailing) linked to a kite steering unit (KSU) on the ground. Two lines serve both to control the kite's flight and to convert the aerodynamic forces into electrical power by using suitable rotating mechanisms and electric drives kept on the ground. In one possible configuration, energy is generated by continuously repeating a two-phase cycle. In the traction phase, the kite exploits wind power to unroll the lines, and the electric drives act as generators, driven by the rotation of the drums. The kite is controlled so as to fly fast in the crosswind direction and to generate the maximum amount of power. When the maximal line length is reached, the passive phase begins and the kite is driven in such a way that its aerodynamic lift force collapses; this way, the energy spent to rewind the cables is a fraction (less than 10%) of the amount generated in the traction phase. Theoretical studies, numerical analyses, and experimental results obtained from a KSU prototype show that Kitenergy could bring forth a radical innovation in wind energy, providing large quantities of renewable energy at lower cost than fossil energy (see the table below).

Power Source	*Min. Cost ($/MWh)*	*Max. Cost ($/MWh)*	*Avg. Cost ($/MWh)*
Coal	25	50	34
Gas	37	60	47
Wind turbines	35	95	57
Solar	180	500	325
Kitenergy	**15**	**48**	**20**

Sources for data: "Projected Cost of Generating Energy," IEA Publications, 2008; L. Fagiano et al. IEEE Trans. on Energy Conversion, vol. 25, 2010.