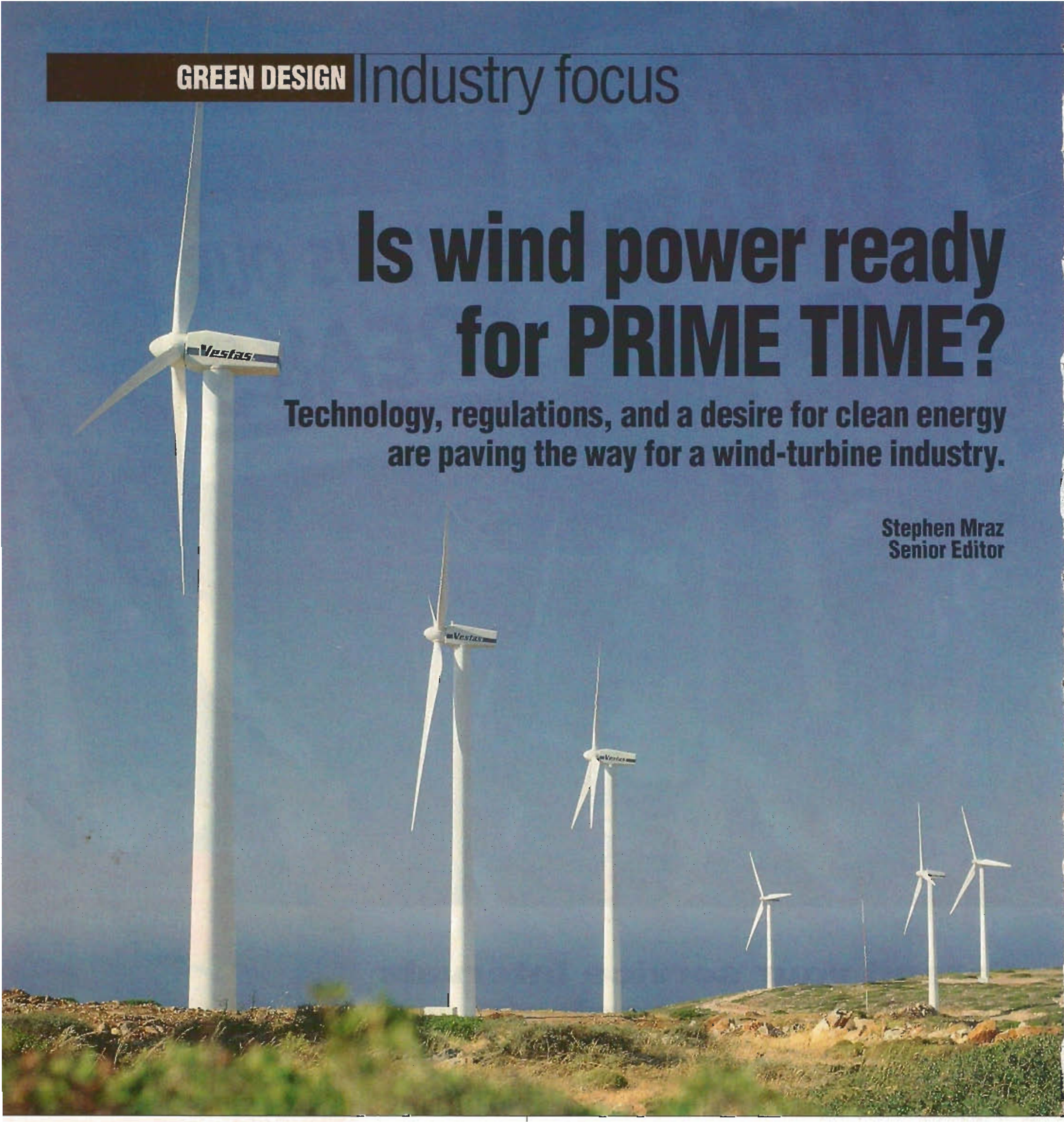


Is wind power ready for PRIME TIME?

Technology, regulations, and a desire for clean energy are paving the way for a wind-turbine industry.

Stephen Mraz
Senior Editor

No question there is a case to be made for drawing **electrical power from the wind. Power** utilities say **they're eager to generate electricity using** a clean fuel **with little environmental impact, and they** have customers **lined up and waiting. Turbine and** blade manufacturers, **most based in Europe,** are also eager for **the opportunity to serve 300 million** U.S. consumers.

But most important, the U.S. government is **greasing the skids for wind power,** making all this **possible with healthy subsidies** and mandates **that power companies adjust** generation portfolios **so about 15% comes from "al**ternative" energy sources. Wind-power proponents say it would be feasible for the U.S. to get 20% of its power from wind by 2020. The current figure is only 0.8%.

But this hardly means we should throw caution to the wind.

ONLY WHEN THE WIND BLOWS

Needless to say, wind turbines only generate electricity when the wind is blowing. This translates into an average output equaling roughly 30% of total rated capacity. Thus for customers such as hospitals and Internet companies who need uninter-

Wind farmers, like this one made up of Vestas' 850-kW wind turbines in Crete, Greece, could become a common sight in the U.S.

rupted service, every megawatt of power created by a wind turbine must be backed up by an equal amount of power from more reliable sources, such as a nuclear or coal-burning plant. But it is inefficient to run power plants at less than 50% of capacity. So wind power may make most sense as a means of avoiding brownouts rather than as a competitor for conventional power facilities.

Researchers have also proposed several ways to overcome wind's intermittence. Most involve storing wind-generated energy either by cracking water into hydrogen or pumping water into reservoirs, reclaiming potential energy as water passes through a hydroelectric dam. Other schemes involve charging batteries. One of the more ambitious ideas is to carefully monitor utility-power demand and real-time wind conditions, then balance the two by bringing turbines on and off the power grid. And even this might not be possible without new, more efficient transmission lines.

BUYING WINDMILLS

Most windmill manufacturers are European and the euro is currently at record highs against the dollar. So it's pricey to import wind-turbine capital equipment like 50-m pylons, 30-m blades, and large generators. Some wind-industry experts predict prices will continue to climb by about 1.5% annually. Economists see this as potentially good news for the U.S., believing it will spur development of homegrown wind-turbine companies. They estimate that a continuing interest in wind power could create 3.7 million jobs.

There's also debate among wind-industry leaders about the best way to site wind farms. Where wind condition are best, demand tends to be weak. And close to urban centers, wind conditions aren't always that great. Of course, breakthroughs in transmission or energy storage could render such questions moot.

KEEPING IT GREEN

The biggest factor in wind power's favor is its portrayal as a 100% clean source of renewable energy. But wind has its detractors. Some upscale residents of Martha's Vineyard and Cape Cod, Mass., for example, oppose a wind farm there. The Cape Wind project would consist of 130 spinning wind turbines covering 25 square miles. Though the site would be more than 6 miles from shore, residents fear it would spoil the scenery and kill fish and birds. The environmental activists group Greenpeace, however, insists that offshore windmills pose no threat to marine or avian life.

Those living near wind turbines sometimes complain about the noise the spinning blades create. They say it's unbearably loud, almost like a jet airplane. But wind-turbine makers say the noise issue is all but resolved. Newer blade technologies limit noise, and zoning ordinances can be written to regulate it.

Finally, there is the issue of energy use. Though wind turbines don't consume fuel, it takes at least 150,000 lb of steel, concrete, and fiberglass to build a single 3-MW turbine. Thus, turbines have a carbon footprint that is laid down before they ever generate a single kilowatt. And detractors point out that steel and concrete are both energy intensive, carbon-emitting industries. There are also networks of roads needed to service wind farms. And wind turbines take land, somewhere between 60 and 300 acres/MW. (For comparison, nuclear and coal plants generate about 1,000 MW/acre).

There are several European countries with significant wind-power experience. They offer lessons about what works and what doesn't. For example, Denmark is the country getting the largest percentage of its electricity from wind turbines. But Danes also pay more for electricity than anyone else. The average Dane pays 34¢/kw-hr, according to Eurostat, the statistical office of the EU. In the U.S., that rate varies from 5¢ (Ohio) to 15¢ (Calif.) per kw-hr. And if today's warnings over global warming eventually turn out to be false alarms, the limits on economic growth imposed by higher electrical costs may seem like a bad bargain. **MD**

MAKE CONTACT

American Wind Energy Assoc., ***www.awea.org***

Giant fans of *wind energy*

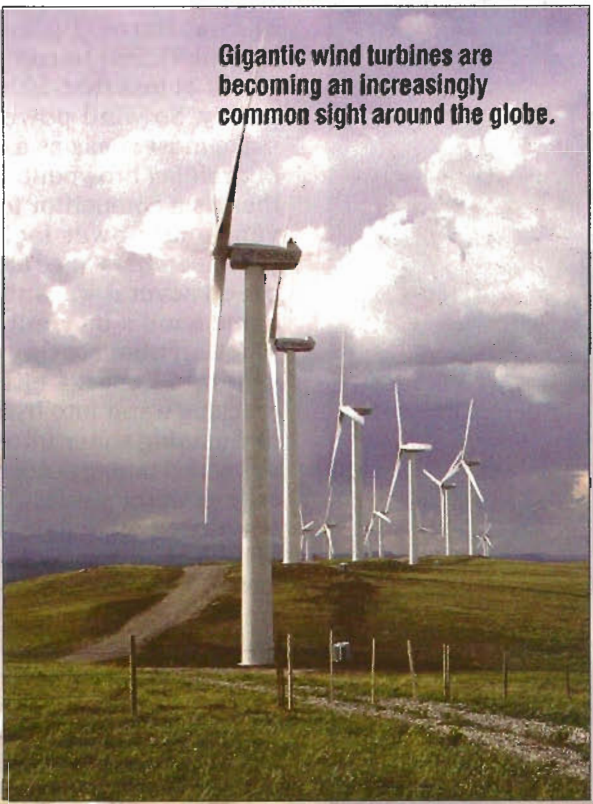
Windmills aren't what they used to be but then neither is the search for renewable energy sources.

Patrick Mahoney
Associate Editor

In an effort to develop renewable energy sources, engineers are looking for ways to build a better mousetrap. Or, in this case, windmill. As manufacturers continue to lower the cost of wind turbines and components, wind energy may soon compete cost-wise with conventional energy sources. Thanks largely to virtual prototyping and physical prototype testing, engineers are moving closer to that goal.

But there's a problem when it comes to simulating wind turbines. Complex aerodynamic effects and large deflections are at work. And the electrical systems are sophisticated and difficult to model. Physical prototype testing is no walk in the park either. The source of the power for field tests is, of course, the wind, which can't be controlled. Also, modern wind turbines are huge, which means facilities for full-scale testing must be supersized, too.

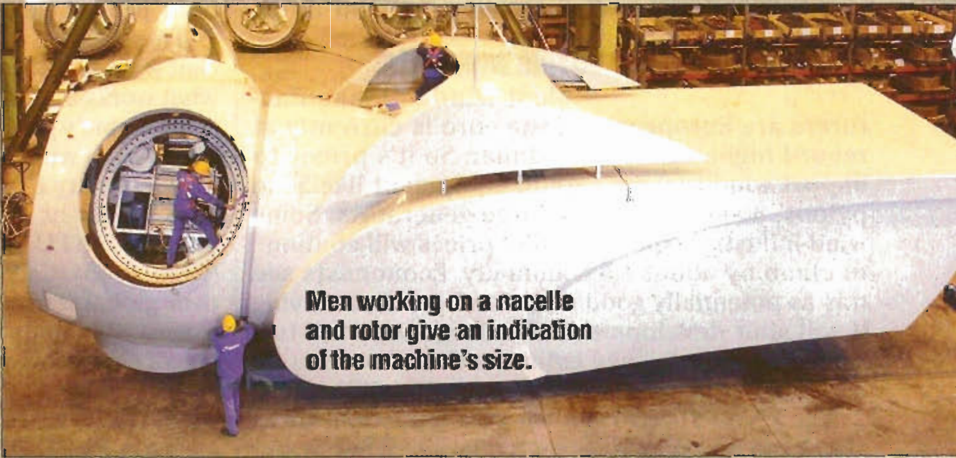
To overcome these obstacles, other countries have developed strategies that could serve as blueprints to help the U.S. Spain, for example, is a global leader in installed capacity and wind-turbine manufacturing. The Spanish Centre for Renewable Energy (Cener) is currently building an innovative test center dedicated to developing wind energy.



Gigantic wind turbines are becoming an increasingly common sight around the globe.

The publicly funded facility will have testing laboratories and an experimental wind farm. A blade-testing facility will house two rigs to conduct extreme and fatigue-load tests as well as physical-properties testing. It will handle turbine blades up to 75-m long. One rig, able to withstand bending moments up to 100,000 kNm, could test blades as long as 90 m, after a portion of the blade is removed.

The Spanish lab will develop processes and materials to reduce costs or improve performance, mainly in the area



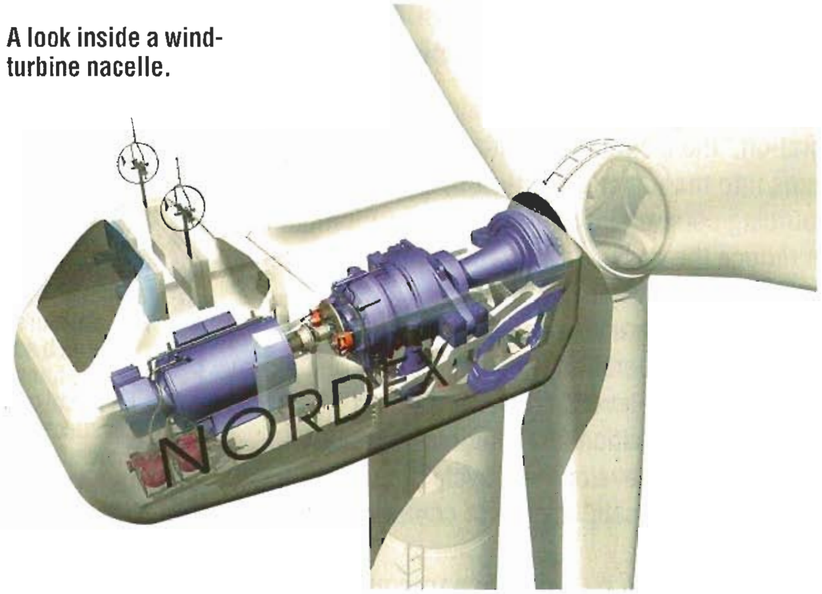
Men working on a nacelle and rotor give an indication of the machine's size.

of composites. An experimental manufacturing workshop will test new processes, and a material-characterization laboratory will study physical, chemical, and mechanical properties. The center will also conduct testing (power curve, mechanical loads, noise, and power quality) at its own experimental wind farm.

A wind tunnel, with a test section of 1.5 × 3 m, can reach Reynold numbers of 9×10^6 for aerodynamic and aeroacoustic airfoil tests. Specially designed dynos will simulate real-life wind-turbine loads. Most dynos are good at applying torque, but little else. The drivetrains in wind turbines, however, see a variety of asymmetrical loading scenarios as winds gain force, die down, and change direction. These dynos will handle turbines up to 5 MW.

The drivetrain test rig will perform functional and mechanical (fatigue and extreme load) tests. An 8-MW electrical motor, gearbox, and hydraulic actuators will introduce forces and moments on the shaft in three directions.

An electrical-system test rig will produce voltage dips and other electrical faults. Another test rig will perform functional tests on all of the elements in the nacelle. With all this technology, the Spanish wind-turbine laboratory will be one of the largest exclusively dedicated facilities anywhere.



A look inside a wind-turbine nacelle.

HOW DO WIND TURBINES WORK?

Modern wind turbines consist of four main components: a foundation unit, a tower, a nacelle (turbine housing), and a rotor. The typical foundation is a giant concrete block buried in the earth. The nacelle sits at the top of the tower, and the rotor is attached to the front of the nacelle. The tower raises the nacelle high into the air, and electrical cables run from the nacelle to the ground. The nacelle contains primary components such as the main axle, gearbox, generator, transformer, control system, and electrical cabinet. The rotor consists of a hub, usually with three blades attached.

When there's light wind, many turbines adjust the blades to a 45° angle, the position in which the turbine can draw as much energy as possible. The blades begin to turn very slowly, without generating energy. This is known as idling.

When there is enough wind to start generating energy — about 4 m/sec — the blades gradually start to rotate longitudinally, towards an angle of 0°, which means the broad surface of the blade is facing into the wind. Wind striking the blade creates a difference in pressure that turns the rotor.

Wind turbines typically generate energy at wind speeds of 4 to 25 m/sec. The rotor speed will range from 9 to 19 rpm, depending on wind speed and turbine type. At maximum speed, blade tips can reach a speed of 250 km/hr.

Rotating mechanical energy channels to a gearbox in the nacelle. The gearbox converts the slow rotation of the blades to a speed high enough to power the generator. The conversion is typically about 1:100. The electrical control system sends the electricity generated by the turbine through a high-voltage transformer, then to the utility power grid.

Wind-turbine rotors always face into the wind, thanks to a wind vane on top of the nacelle. When the wind shifts, a contact in the wind vane starts motors that turn the rotors into the wind.

The amount of energy a wind turbine can generate depends on the size of the generator, the dimensions of the rotor, and the strength of the wind. For example, the V90 turbine from **Vestas**, Portland, Oreg., which has a rotor diameter of 90 m, reaches maximum power output (3 MW) at 15 m/sec. When wind speed reaches 4 m/sec, the angle of the blades are 0° to ensure the turbine draws as much energy as possible. When wind speed reaches 10 to 12 m/sec, the blades

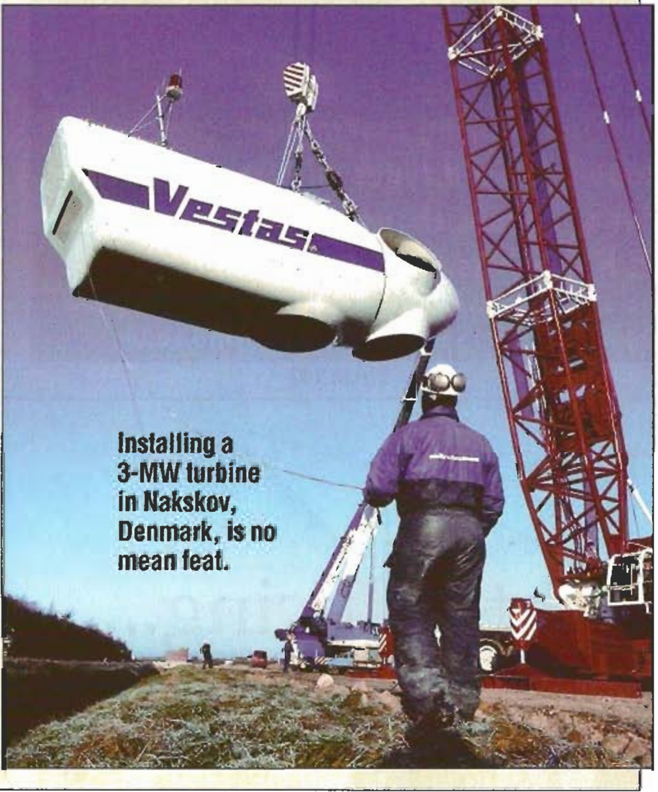
Fatigue data for wind-turbine-blade materials

Ongoing research by industry and universities has done much to improve wind-turbine blade design. These gigantic appendages are subject to great stress. A paper by researchers at the University of Montana examines static and fatigue results in four distinct areas: very high cyclic tension fatigue; refinements to the Goodman Diagram in the low amplitude tension regime; effects of fiber waviness on compression properties; and large tow carbon laminates.

In the course of a 20-to-30-year lifespan, composite wind-turbine-blade materials can experience between 10^8 to 10^9 significant fatigue cycles, the researchers say. However, due to a lack of data beyond 10^7 or 10^8 cycles, wind-turbine design has required extrapolations from experimental data.

An early spectrum-fatigue investigation showed two interesting features relating to high cycles. First, there was significant sensitivity to the fatigue model assumed in fitting the constant amplitude data. And second, many of the stresses in the spectrum for overall lifetimes of 10^6 to 10^7 cycles were in the low stress range where no fatigue data exist. As a result, assigning the damage contribution of the low stress cycles requires extrapolation of the S-N data.

To be practical, testing to high cycles requires high frequencies, and high frequencies can only be used for very small specimens to avoid hysteretic heating and thermal failure of the polymer-based composite. This study involved very-small-diameter impregnated strands with only enough fibers to represent the behavior of larger specimens (when tested at moderate cycles). There have also been limitations on testing equipment. Standard servohydraulic machines are limited in frequency, and the actuator rod assembly has wearing problems; piezoelectric actuators have displacement and thermal limitations; and standard vibration-table equipment can be costly. To determine the high-cycle behavior of impregnated glass strands, the researchers had to build a unique low-cost testing apparatus with several test stations.



Installing a 3-MW turbine in Nakskov, Denmark, is no mean feat.

rotate longitudinally, slightly away from the wind, to prevent the turbine from generating more energy than its components are designed to handle. This is called output regulation.

There are three ways to regulate output. The first is the passive stall in which the turbine operates at a constant speed of revolution with nonadjustable blades. Aerodynamics will force the blade profile to stall at wind speeds in excess of 12 to 15 m/sec, depending on turbine type.

Next is the active stall. Here, too, the turbine operates with a constant speed of revolution, but with adjustable blades. The turbine regulates output by turning the rear edge of the blades into the wind to produce a stall effect in wind exceeding 12 to 15 m/sec.

Finally, there are two types of pitch-based output regulation: pitch and variable-speed pitch. In pitch, the turbine operates with constant revolution speed and has adjustable blades. The leading edge of the blade turns into the wind to reduce uplift. In variable-speed pitch, the turbine operates with variable revolution speed and has adjustable blades. Again, the leading edge of the blade turns into the wind to reduce uplift.

When wind speeds exceed 25 m/sec, the turbine stops to avoid straining the components. However, wind speeds in most locales rarely exceed the stop limit, so there is little need to generate electricity from such winds. Besides, it would be prohibitively expensive to design a model that could handle such high winds. Instead, when wind speeds hit 25 m/sec, the blades pitch to 90° so the leading or rear edges of the blades point directly into the wind. This way the blades function as giant air brakes to slow the turbine.

How high is too high?

Wind turbines are reaching ever higher. Wind quality improves with height, especially inland where obstacles on the ground produce turbulence. But it costs more to put up taller towers, and hub height is limited by law. Typical height limits are between 80 and 100 m in the U.S., but some German installations are reaching hub heights of more than 100 m. Towers of 80 m have a rotor sweep of 35 to 125 m; 100-m towers have a rotor sweep of 55 to 145 m. Experts say 100-m towers are better for inland locations while 80-m towers work better on the coast.

According to the Global Wind Energy Council, global wind-power capacity has been rising by at least 20% annually since 2000. Modern wind turbines produce 200× more power than equivalent turbines of two decades ago. Today, there are more than 50,000 MW of installed wind-power capacity around the world, up from only 17,000 MW a decade ago. The world, you might say, is becoming a big fan of wind energy.

Despite unresolved variability, grid, control center, and meteorological issues, wind power still supplies 6% of Spain's power needs. And on certain windy days, it meets close to one-fourth of total demand.

Software, such as that from Danish wind-turbine maker **Nordex,** continuously evaluates all operating and climatic data. Two measuring instruments record wind speed and direction. The first is used for control while the second monitors the first unit. If one of the measuring instruments breaks down, the other takes over.

When there is no wind, the turbine remains at rest (energy-saving mode) and only the control computer works, collecting climatic data. The turbine switches on at cut-in wind speed (3 m/sec). At this point, all systems go through a quick operational check, and the nacelle aligns itself with the wind. Rotor blades move to the starting position to let the wind start turning the rotor.

EVOLUTION OF THE TURBINE

For two decades, turbine manufacturers have examined various ways of turning wind energy into power. The design that has proved most efficient and reliable is the three-bladed model. Recent models generate several megawatts versus a few hundred kilowatts for early versions. And wind turbines are taller, to access stronger, more stable winds.

The standardized shape of wind turbines is evidence of the industry's relative maturity. Now, manufacturers set themselves apart by incremental developments such as reducing weight and boosting efficiency. For example, **Gamesa Eólica**, a Spanish turbine builder, focuses on pitch technology. **MD**