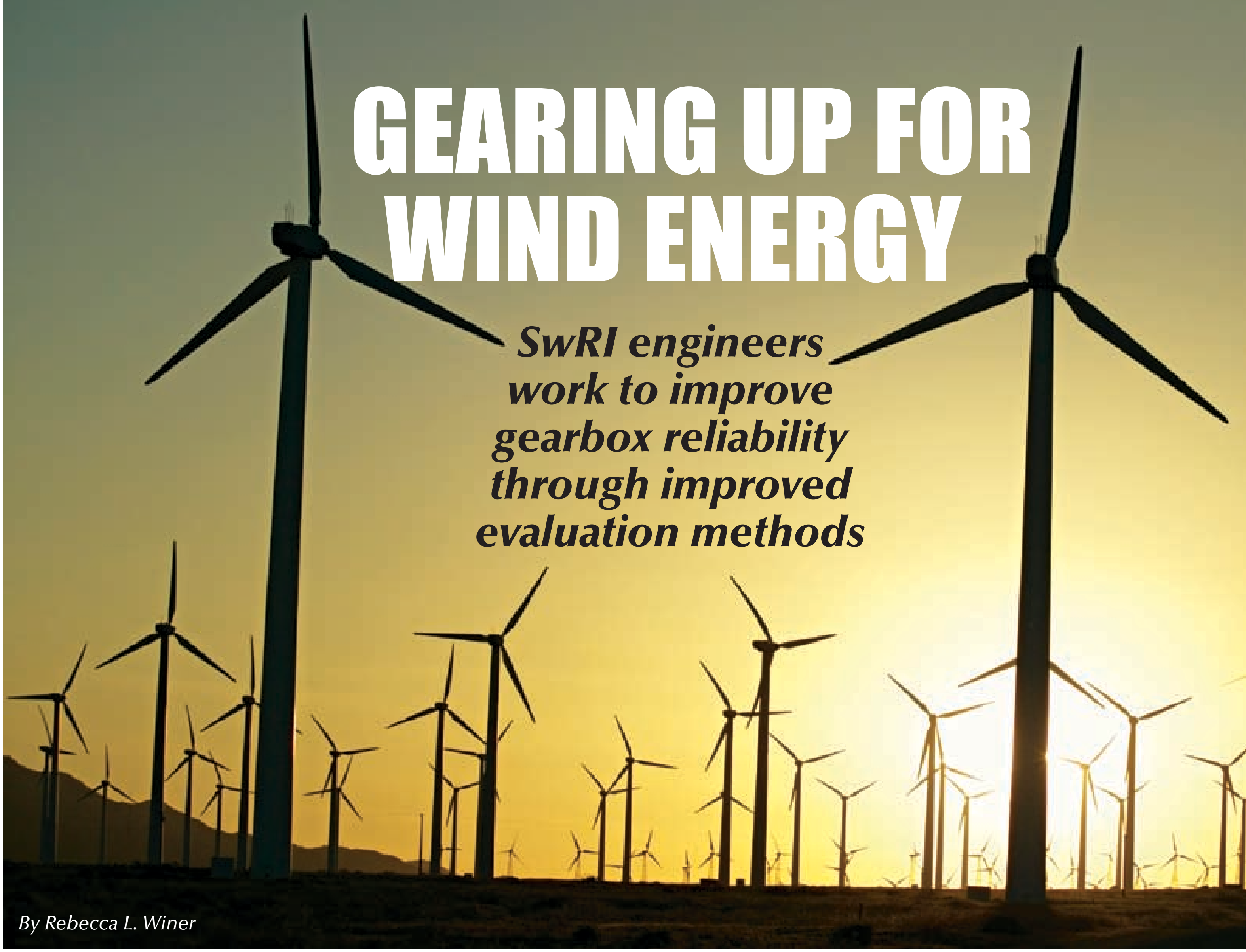

GEARING UP FOR WIND ENERGY

SwRI engineers work to improve gearbox reliability through improved evaluation methods

By Rebecca L. Winer

Those tall, graceful vanes slowly rotating in the breeze on electricity-generating wind farms give immediate notice that this is a new, alternative source of generating electric power for our nation. However, these 21st century windmills revolve around a familiar set of mechanical gearboxes and shafts.

Southwest Research Institute (SwRI) engineers have built specialized test stands and developed procedures needed for evaluating gearboxes for a wide range of industries over the past 50 years. This experience has ranged from hypoid gears used in axles on 18-wheel trucks to large multi-ratio gearboxes on farm tractors, to the gearboxes used in submarines and heavy-lift helicopters. SwRI engineers have helped identify causes and effects associated with gearbox failures and have developed solutions to specific failures involving excessive deflection, cracking, pitting and fatigue life of gear teeth. Throughout this process, rigorous testing has been employed to validate either the failure mode or its fix. Today, engineers are turning their attention to address the special requirements of wind turbine applications.

Growing role of wind power

Wind power as a source of alternative energy has had an exponential rise in popularity and use over the past decade and is expected to continue that trend for many years to come. In the 1990s, less than 2.5 gigawatts (GW) of wind energy capacity was installed in the United States. By 2002 that number had nearly doubled, and total capacity grew to more than 25 GW in 2009. Currently the U.S. produces enough power through wind energy to power more than seven million homes. As the world makes strides for "greener" forms of energy along with less consumption, many have looked to the wind as an answer. The U.S. Department of Energy (DOE) hopes to achieve 20 percent renewable energy by 2030, and wind energy is expected to be the base for the majority of that progress. In order to achieve it, wind capacity would have to increase to more than 300 GW by 2030. With the rapid growth in the industry, as well as the infancy of wind turbine technology, many factors are still unknown, which can inhibit the reliability of this new technology.

The major components of a wind turbine are its blades, input shaft and bearings, gearbox, generator and power electronics, all of which are installed atop a tall tower. The gearbox must increase the shaft's rotation speed from approximately 12 rpm provided by the wind, to 1,800 rpm, which is more efficient for a standard generator to produce electricity. The electricity is

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then routed onto the electrical grid to be used by consumers.

A wind turbine gearbox is similar in purpose to an automotive transmission. It takes an input speed and torque combination and outputs a more usable speed and torque through the other side. Unlike automotive transmissions, wind turbine gearboxes don’t need to shift gears. However, there are significant challenges in the form of speed multiplication and high torque exerted on the driveshaft. While automotive transmissions operate within a gear ratio of approximately 5:1 or less, a wind turbine’s gearbox operates in the 150:1 range. This extreme gear reduction takes a toll on gear teeth and bearings and also places high demands on the gearbox lubricant, which must be effective at both the low and high gear rotation speeds that occur in the input and output ends of the gearbox. Also, wind turbine gearboxes must meet significant reliability challenges associated with their extreme size amid weight limitations that combine to make manufacturing difficult as well as expensive.

Design reliability and field reliability

Wind turbines are intended to last 20-plus years in the field. However, many turbines are experiencing failures at closer to five years of service, and many of those failures are in the gearbox’s bearings and gears. A gearbox failure is one of the costliest repairs to make because of its location atop the tower, and also because of the high cost of its components. When a failure occurs, the entire gearbox must be removed for servicing. This involves getting a technician safely to the top of the tower, disconnecting the gearbox, and then using a large crane to bring it down to the ground. In today’s wind turbine designs, the gearbox may be mounted up to 350 feet above the ground, and even taller installations are contemplated for offshore wind turbines. Besides the equipment and time required to remove and re-install the gearboxes, there is also a significant cost for new gears and bearings, making a gearbox failure extremely time-intensive as well as expensive.

Large land-based wind turbines range between 1.5 and 3 MW in power-generating capacity. For offshore wind turbines, generation capacity is expected to reach up to 15 MW each. The larger applications involve much larger components and therefore result in much higher manufacturing and development costs.

The most logical way to analyze a gearbox is to install an electric motor and speed-reducing gears at the input shaft of the gearbox, and an electrical generator at the output shaft to make an electrically regenerative system. By electrically connecting the motor and generator, the system only requires the amount of power needed to overcome parasitic losses, the losses due to inefficiencies in gear meshes and windage and churning

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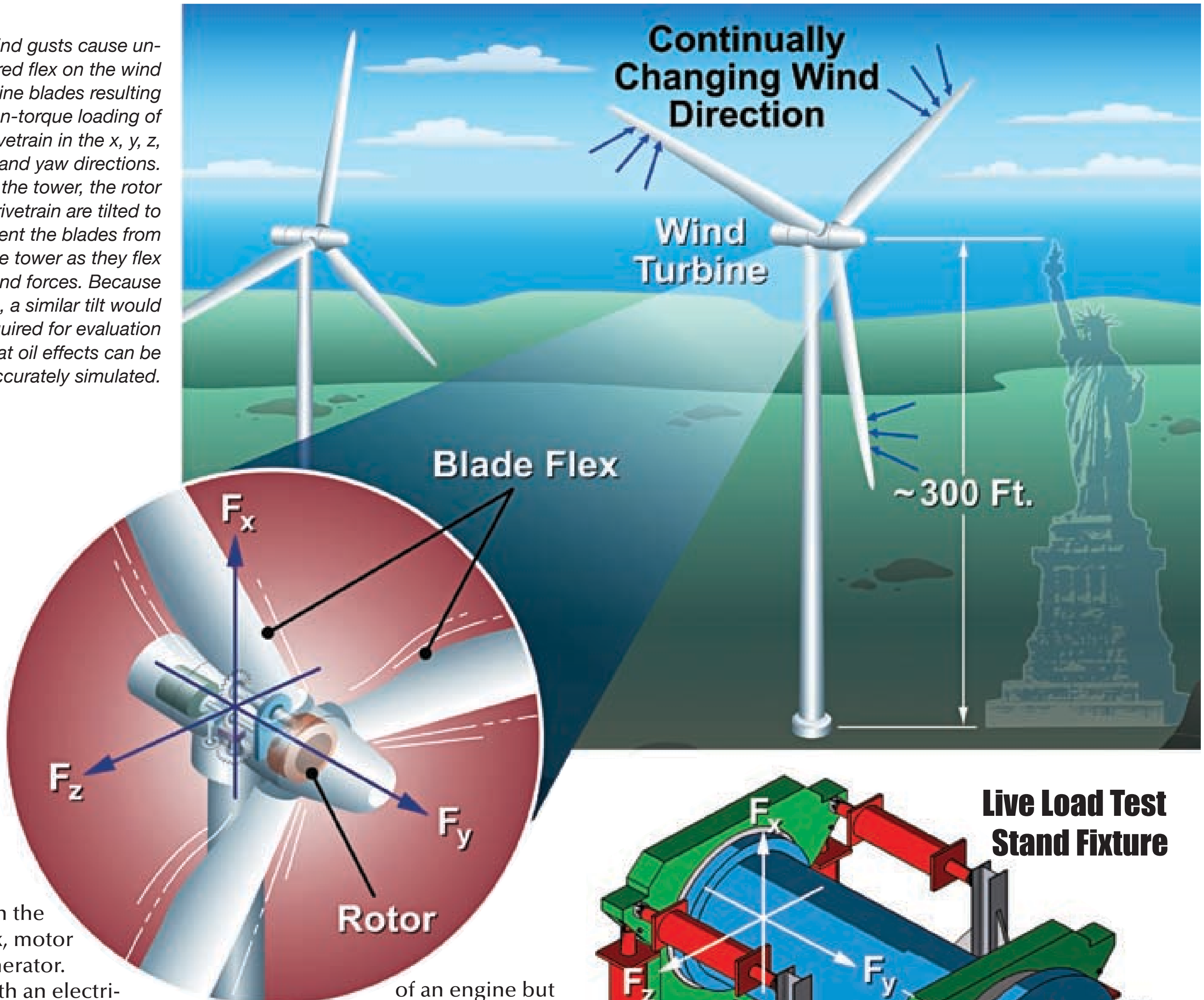
Installed wind-power capacity as of January 2009 already exceeds the 25 GW projected for that year en route to a 2030 goal of meeting 20 percent of total U.S. demand with renewable energy. The growth curve climbs even more steeply with the addition of offshore capacity, shown in blue, to reach the 300 MW goal.



Wind gusts cause undesired flex on the wind turbine blades resulting in non-torque loading of the drivetrain in the x, y, z, pitch and yaw directions. On the tower, the rotor and drivetrain are tilted to prevent the blades from hitting the tower as they flex under wind forces. Because of this, a similar tilt would be required for evaluation so that oil effects can be accurately simulated.

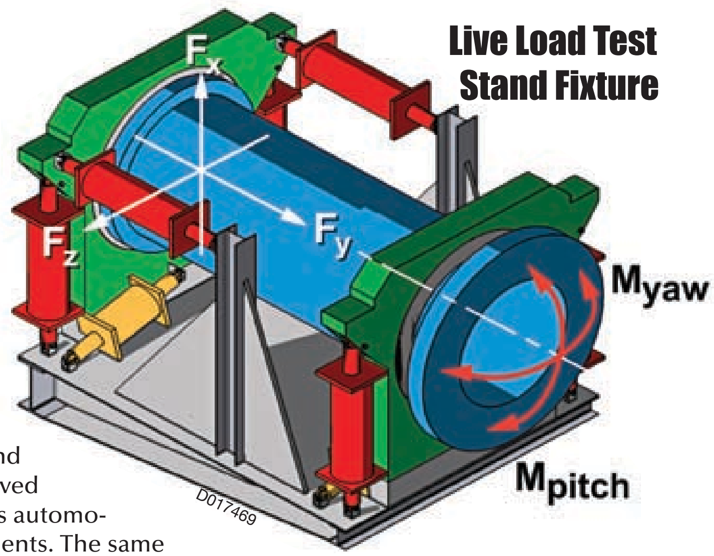
losses in the gearbox, motor and generator. Even with an electrically regenerative system, the electricity required for such motors is greater than many facilities can supply.

Meanwhile, these gearboxes generate up to 3 million foot-pounds of torque, which can be difficult to duplicate and measure accurately. Start-up expenses, combined with such daunting torque and power requirements, have prevented many laboratories from entering the wind turbine testing field. The National Renewable Energy Lab (NREL) in Colorado is the only independent DOE lab that tests wind turbine drivetrains, and NREL currently has only one test stand available.

Hardware and software in the loop

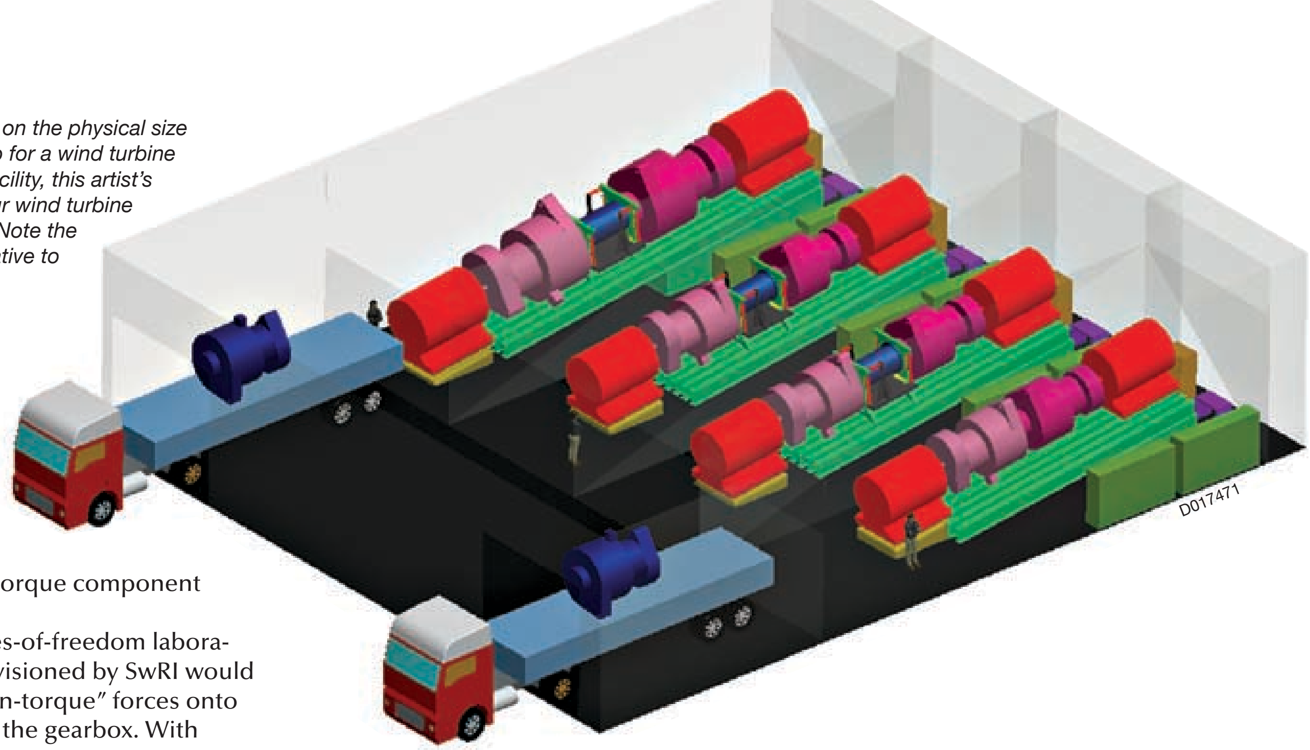
Through SwRI's work in the automotive industry over the past 60 years, much effort has been spent on creating capabilities that accurately simulate real-world conditions. Test stands have been designed to simulate not only the firing of an engine but also the road load and rolling resistance a vehicle experiences. This hardware-in-the-loop (HIL) approach has revolutionized the automotive industry and has significantly improved the reliability of today's automotive drivetrain components. The same HIL philosophy can be applied to wind turbine gearboxes, specifically because the nature of wind is highly transient and non-linear. As the wind blows, it not only turns the blades that apply torque to the gearbox, but it also imparts forces on the blades in the horizontal, vertical, pitch, yaw and thrust directions.

Blade lengths currently reach 170 feet or more, and lengths could more than double in the future. As the wind blows, it forces the tip of each blade not just to rotate but also to flex in five different directions or degrees of freedom.



The live load test stand fixture designed by SwRI will impart x, y, z, pitch and yaw forces on the input shaft of the wind turbine gearbox to properly simulate the winds effects on the drive system.

The leverage moment imparted by this motion, across such a long span to the relatively small rotor, is magnified to a point at which even a small gust can create a significant force. Despite this, current procedures

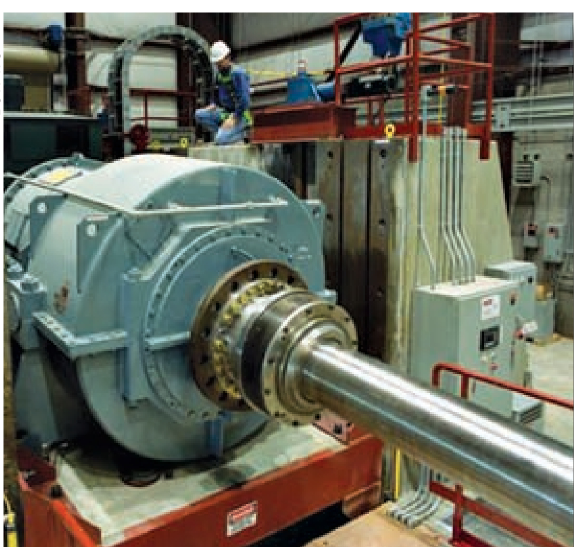


To give a perspective on the physical size of a possible scenario for a wind turbine gearbox evaluation facility, this artist's rendition contains four wind turbine gearbox test stands. Note the size of the stands relative to the operators.

only evaluate gearboxes' ability to withstand the torque component of wind force.

A five-degrees-of-freedom laboratory fixture as envisioned by SwRI would impart all the "non-torque" forces onto the input shaft of the gearbox. With many wind turbines in commission today, simple measurements can be taken to map the forces applied to the input shaft by the wind. These same forces will then be generated by the five-degrees-of-freedom fixture. Fast-acting hydraulic cylinders apply forces to the gearbox input in all directions. With a mathematical model of wind, the fixture can accurately simulate the influence of wind forces on the input to the gearbox.

Along with the new fixture, SwRI engineers can use current variable-frequency drive technology to simulate the non-linear nature of wind gusts by applying variable, rather than steady-state torque levels to the gearbox.



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Courtesy DOE/NREL, Warren Gretz

The Department of Energy's National Renewable Energy Laboratory's 2.5 MW test stand includes an input motor, speed reducing gearbox and input shaft.

Through this system, the motor can simulate cut-in wind speed, partial-load wind speed, rated wind speed, full-load wind speed and cut-out wind speed. This additional variation in torque more accurately portrays the type of loading that gears and bearings are experiencing in the field, leading to early failures. In addition to the forces seen on the input side of the gearbox, SwRI engineers can simulate the effects of grid surges and variations of supply voltage on a wind turbine's generator. These surges and variations can cause back-driving from the output side of the generator, and its effects on the gearbox can be tested alongside the input conditions. HIL systems enable gearbox manufacturers to evaluate their gearboxes more accurately and can also help designers prevent premature failures.

Alongside their HIL experience, SwRI engineers have performed extensive work in software-in-the-loop evaluation. This uses SwRI-designed mathematical models of all the components under study and can apply conditions to the mathematical models to see how they will react. This can prevent many unnecessary failures of extremely expensive components during hardware evaluation and also allows for much more rapid analysis in advance of hardware evaluation.

Future trends

As wind energy continues to grow, strides are being made to make wind turbines more reliable, cheaper to manufacture and more efficient. The lighter the weight of the gearbox, generally the less expensive its components, and the less expensive it is to assemble the gearbox and install it atop the tower. If each of these costs can be decreased just a little, the cost to the owner is decreased significantly, thereby improving profitability and likely attracting more investment in wind turbine farms. In contrast, the occurrence of gearbox failures forces manufacturers to increase the weight of the mechanism, thereby negating some of the advantages of a lightweight system.

With more accurate capabilities for evaluation, manufacturers can pinpoint where failures are occurring in a certain design and make changes and improvements before the turbine is released for production. These types of improvements are vital to the industry's longevity. Otherwise, wind energy could become the victim of a boom-and-bust cycle and a diminished role as a viable, large-scale power source. As the world strives for greener forms of energy, wind power has the capability to fill a portion of our power requirements, while also becoming a self-sustaining industry whose economies can help it outgrow the need for government subsidy. ❖

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