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Cheaper Wind Equals More Wind

As wind power becomes more affordable and cost effective, its reach across the U.S. widens — 41 states are now home to utility-scale wind farms.

By John Hensley

American wind energy continues to power forward to reach new heights. Today, it powers more U.S. families and businesses than ever before — the country now has enough installed wind capacity to power more than 28 million American homes. That means wind has become a key contributor to our electricity mix, and the days of wind occupying a niche space are long gone.

Wind continues to expand to new areas, as 41 states now have utility-scale wind farms. Last year, wind surpassed conventional hydropower, and it is now the country's largest source of renewable energy capacity. It likely will not be long before wind surpasses hydropower in terms of generation as well. Utilities and Fortune 500 companies continue to buy ever increasing amounts of wind to meet their electricity needs, and that means more jobs and more opportunities for Americans in all 50 states.

What further developments can we expect to see in the years to come?

CHEAPER WIND MEANS MORE WIND

In each of the last three years, wind power has been one of the top three sources of new U.S. electric generating capacity. For this to happen, wind needs to win on cost, and in fact, wind is now the cheapest source of new electric generating capacity in many parts of the country. It's also cost-competitive in many more. Overall, wind's costs are down by two-thirds since 2009.

Several factors have made such dramatic declines possible. Technological advances help modern turbines access stronger, steadier winds. That means new projects can generate more electricity more of the time. It also expands the map of existing wind projects. In 2017, North Carolina's first utility-scale wind farm came online. This project would not have been possible without the advances of the past several years. Ground has also broken at Arkansas's first wind farm, and projects are under development in Virginia as well, meaning wind will continue its expansion into new frontiers.

Improved domestic manufacturing has also played a key role in driving wind's cost down. Today, more than 500 U.S. factories build many of the 8,000 parts in a typical wind turbine. Given the scale of certain wind components, transportation costs are lowered as more companies choose to locate new factories in the U.S. rather than importing from overseas. That has the added bonus of creating new opportunities for factory towns badly in need of them.

Recent wind deals demonstrate just how low these developments have driven wind's cost. Investment firm Lazard Inc. reported late last year that, "in some scenarios, the full-life-cycle costs of building and operating renewable-based projects have dropped below the operating costs alone of conventional generation technologies such as coal and nuclear. This is expected to lead to ongoing and significant deployment of alternative energy capacity."

Recent results from Xcel Energy's request for proposals (RFP) for

In each of the last three years, wind power has been one of the top three sources of new U.S. electric generating capacity. (Courtesy: AWEA)

new power in Colorado show how cost-competitive wind has become. Companies submitted more than 400 bids for new power projects, and wind energy led all technologies with the lowest median bid price: $18.10 per megawatt hour, a truly remarkable milestone. Nor was this result a one-off outlier — more than 100 wind projects were proposed, signifying these rock bottom prices are indicative of broad industry trends.

In reviewing these results, Vox energy and climate reporter Dave Roberts concluded, "Let's face it: In most areas of life, when you look past the hype at the real numbers, it's depressing. Renewable energy is one area where that typical dynamic is diverted. The closer you look, the better the news gets … It is the cheapest power available in more and more places, and by the time children born today enter college, it is likely to be the cheapest everywhere. That's a different world."

"These prices should have every policymaker, utility, and energy investor in the region reconsidering their thinking about how much renewable energy to purchase, and when," wrote

Kevin Steinberger and Noah Long of the Natural Resources Defense Council. "The short answer: as much as you can get, and now."

THE WIND-BELT LEADS THE WAY

Texas continued to be America's wind-power leader in 2017 with more new wind projects becoming operational than any other state. In fact, Texas has more than three times the installed wind capacity as second place Oklahoma. The Sooner State is no slouch, however, as it passed Iowa to claim second place in installed capacity last year. California and Kansas round out the top five, proving wind is popular in both red and blue states.

The wind development pipeline continues to be robust, too. More than 28,600 MW of new wind projects are under construction or in the advanced stages of development, a 34 percent year-over-year increase. That is enough new wind to power millions of additional American homes. Thirty percent of this activity is in the Midwest, 21 percent in Plains states, 20 percent in the Mountain West, and another 20 percent in Texas. This anticipated market growth, combined with existing capacity, positions wind to supply 10 percent of America's electricity by 2020, a visionary goal laid out in the Department of Energy's Wind Vision report.

CUSTOMERS REMAIN HUNGRY FOR MORE WIND POWER

Utilities, Fortune 500 companies, and other buyers all inked substantial wind deals in 2017 — overall power purchase agreements (PPAs) were up 29 percent from 2016. And the deal flow has not slowed. In just the first two months of 2018, more than 2,300 MW of new deals have been struck.

Fortune 500 companies continued the trend of powering more of their operations using wind. From Nike to Anheuser-Busch to Amazon and General Mills, businesses across the economic spectrum turned to wind in 2017. Significantly, Google achieved its 100 percent renewable energy goal in 2017, and wind supplied 95 percent of that electricity. On the municipal side, San Francisco's Bay Area Rapid Transit System inked a wind PPA that will supply a substantial portion of its energy.

Technological advances help modern turbines access stronger, steadier winds. (Courtesy: AWEA)

These buyers turn to wind for two reasons: because its costs are both low and they are fixed. Because the fuel cost of wind never changes, buyers know exactly what they will pay for electricity five, 10, or 15 years down the road — an attractive property that facilitates long-term planning.

"Our approach takes different business, social, and environmental benefits into account," Anheuser-Busch InBev said when announcing its 100 percent renewable target. "We do not expect our cost base to increase. Renewable electricity is competitive with or cheaper than traditional forms of electricity in many markets."

"Establishing a 100 percent renewable energy goal helps us better serve society by reducing environmental impact," said GM Chairman and CEO Mary Barra. "This pursuit of renewable energy benefits our customers and communities through cleaner air while strengthening our business through lower and more stable energy costs."

DEMAND FOR WIND MEANS AMERICAN JOBS

All of this new wind means jobs for American workers. They build turbines, construct wind farms, and keep projects running through skilled operations and maintenance. In fact, there are now more than 100,000 wind jobs across all 50 states. And wind-turbine technician, along with solar installer, is one of America's two fastest growing jobs, according to the U.S. Bureau of Labor Statistics.

"It just seems like this is the future. This is where we are headed, and where we should be headed," said Meredith Halfpenny, who has helped build about 400 wind turbines and climbed uptower an estimated 1,200 times. "Working in renewables, you feel good about it. A lot of people are drawn to it, and it resonates with people. Everyone comes together very quickly. You have a collective purpose for your jobs."

Once again, Texas is the country's job leader, followed by Iowa, Oklahoma, and Colorado. A recent report on Texas wind workers found:

"(They) include veterans and women, those leaning politically right and left, environmentalists and climate-change skeptics, the civically engaged and those who never vote. The clean energy component seems to be a bonus for some, but it was not the primary reason they chose this field. There is the laid-off gas worker who noticed all the wind turbines on the horizon and thought there must be an opportunity there. The English major who couldn't find a job and remembered how much she liked the outdoor work on her family's farm in the Texas panhandle. The two veterans who liked the element of risk and heights and the sweet spot of job independence and camaraderie."

BRINGING OPPORTUNITIES TO FARMING TOWNS

More than 99 percent of wind farms are built in rural areas — places that often need new investment. Wind farms frequently become the largest taxpayers in a county, so

WANZEK RENEWABLE SERVICES

We are an ISP specializing in comprehensive renewable power maintenance services utilizing our extensive crane fleet and a regional deployment strategy.

Our services include self-performed maintenance and repair services for wind turbines, electrical collection systems, substations and civil components.

these communities get substantial new revenues to fill out town budgets. That can help pay teacher salaries, fund fire departments, and fix roads while keeping local taxes low.

Sheldon, New York, for example, eliminated local taxes completely for eight years because wind revenue met its budgetary needs. In Van Wert County, Ohio, wind made it possible for the Lincolnview school district to provide every student in grades K through 12 with their own computer and fund the repair and replacement program.

"In pre-wind, our county taxable value was $500 million," said Ken Becker, executive director of the Sweetwater Economic Development Corp. in Texas. "In 2008 (after wind came to the area), it was $2.8 billion."

More than 98 percent of wind farms are also built on private land, and in exchange, landowners receive lease payments hosting turbines. This is guaranteed income that helps during the hard times, especially important in a thin margin business like agriculture. For many families, it makes the difference between continuing a multi-generation tradition and ending a way of life.

"Financially, it's a huge boost to us," says third generation Colorado farmer Richard Wilson. "And I know if we didn't have this wind farm, my sons wouldn't be able to keep this. I might have been able to, but they could not — there's no question."

More than 28,600 MW of new wind projects are under construction or in the advanced stages of development, a 34 percent year-over-year increase. (Courtesy: AWEA)

TAPPING INTO A NEW OCEAN ENERGY RESOURCE

U.S. land-based wind has been growing since the 1980s, and to date, there are nearly 54,000 wind turbines spread across 41 states. But it wasn't until last year that five offshore turbines made their way to U.S. shores with the completion of the Block Island Wind Farm.

Now, 14 offshore projects are under development in U.S. waters, with particularly active areas along the coasts of Long Island, Maryland, and Massachusetts. And companies are investing R&D money to cut offshore costs further, including $35 million in a South Carolina facility to test a 9.5-MW offshore wind turbine.

That continued development will create new supply chains and jobs in coastal cities up and down our seaboards.

The outlook for American wind power remains bright — we're adding new chapters to this American success story, and the good news should continue for years to come.

John Hensley is the senior director of research with the American Wind Energy Association. Hensley holds a Masters of International Economics and International Affairs from the Johns Hopkins School of Advanced International Relations.

The World of Turbine Bearings

Recent technological innovations show how far bearings have evolved in meeting operational demands and improving productivity and profitability.

By Dayananda Raju

The operational challenges for wind turbines can be daunting, whether related to increased turbine power and size, extreme weather conditions, heavy loads, and/or remote locations, among many others. In turn, significant advances in rolling bearing designs, materials, and engineering have helped to realize enhanced performance, reliability, and service life at all points in wind turbines.

Some of the recent innovations in bearing technologies serve to illustrate how far bearing technologies have evolved in meeting operational demands and improving the productivity and profitability of wind turbines, whether on land or offshore.

The combination of a spherical roller bearing (left) and CARB toroidal roller bearing (right) results in a self-aligning bearing system offering greater load capacity in a smaller and lighter housing for wind-turbine applications. (Courtesy: SKF)

HIGH ENDURANCE SLEWING BEARINGS

Slewing bearings historically have equipped a wide range of applications across industries, including wind turbines. These bearings consist of an inner ring and an outer ring, one of which usually incorporates a gear. Together with attachment holes in both rings, they enable optimized power transmission with a simple and quick connection between adjacent machine components. The bearing raceways, in conjunction with the rolling elements and cages or spacers, accommodate loads acting singly or in combination and in any direction.

Among typical turbine applications, slewing bearings will be used as pitch bearings to optimize blade position for different wind conditions or as yaw bearings to correctly position the nacelle during operation. A new generation of high endurance slewing bearings raises the bar for performance and reliability in service.

This class of bearings benefits from enhanced internal bearing geometry in the cages and raceways to reduce friction and increase turbine and pitch control performance. Reduced friction contributes to pitch system effectiveness and efficiency to maximize energy production.

As an added plus, a unique seal material, manufactured from polyurethane, provides better resistance to ozone, UV light, and salt water compared with conventional nitrile-based seals, thereby reducing wear and providing relatively longer service life. The seal design itself has been engineered to be less sensitive to ring deformation during operation for ideal seal function under high loads and reduced grease leakage and water ingress, which results in improved robustness and lower maintenance costs down the road.

SELF-ALIGNING BEARING SYSTEM

In typical industrial applications, a bearing system must accommodate misalignment, shaft deflections, and thermal expansion of shafts. To cope with misalignment and shaft deflections, design engineers conventionally use a bearing arrangement consisting of two self-aligning ball bearings or two spherical roller bearings. However, thermal expansion of a shaft is a more complex issue requiring one of the bearings to be a "locating" bearing and the other to be a "non-locating" bearing.

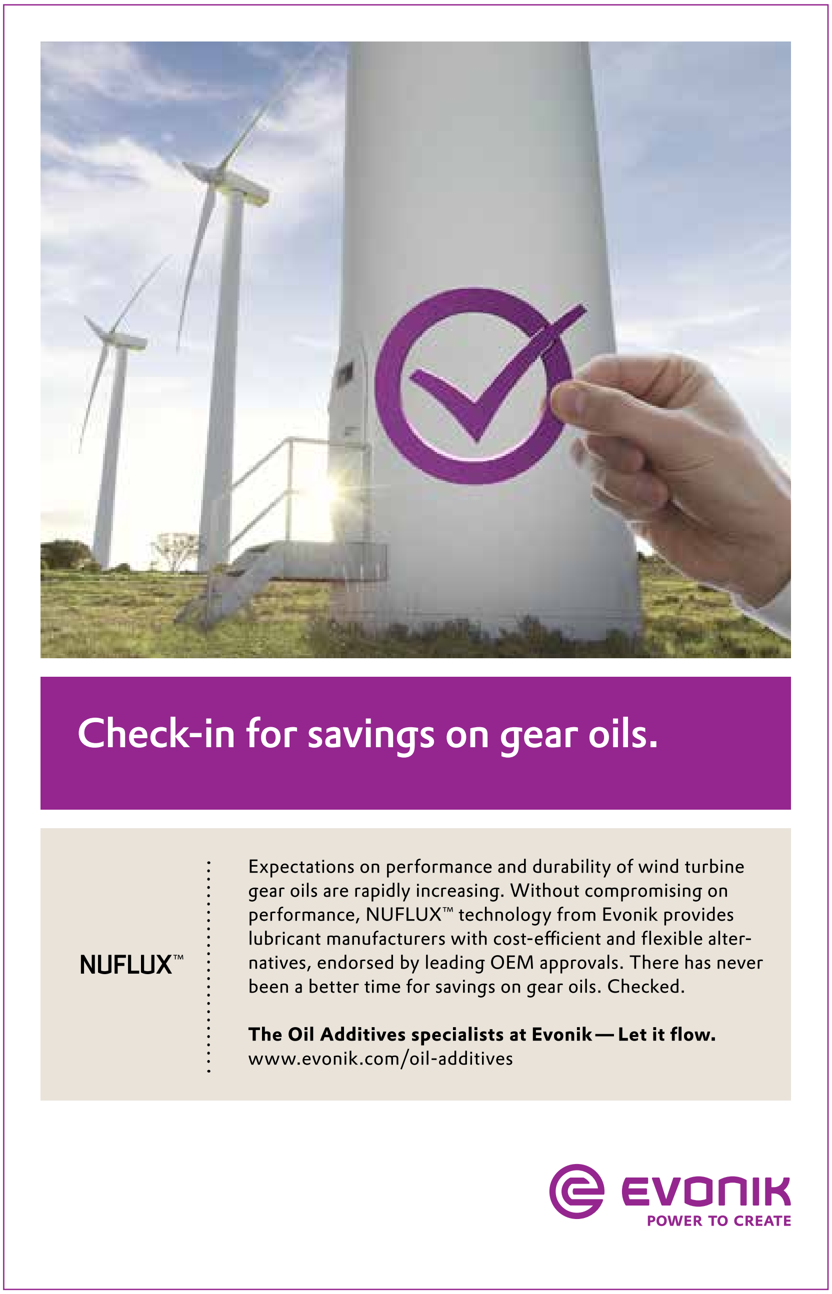
In most cases, the locating bearing must be secured in the housing and on the shaft. The non-locating bearing, in contrast, has to be able to move axially on its seat in the housing. To achieve this movement, the bearing's outer ring must be mounted with a loose fit and have enough room to move in the axial direction. The loose fit, however, under certain load conditions, can allow the bearing ring to creep and damage the housing seat. This accelerates wear, increases vibration, and provides less rigid shaft support in the radial direction.

In addition, when the non-locating bearing moves in the housing, the movement generates a considerable amount of friction, which then further induces vibration, axial forces in the bearing system, and heat — all threatening to reduce bearing service life.

An effective alternative to this conventional and problematic "locating/non-locating" bearing arrangement ideally suited for wind turbines is a system combining a self-aligning spherical roller bearing in the locating position and a CARB (compact aligning roller bearing) toroidal roller bearing in the non-locating position.

The CARB toroidal roller bearing is a self-aligning radial bearing able to accommodate both misalignment and axial displacement of the shaft inside the bearing at the same time. This helps to eliminate the risk of induced axial loads, improve reliability, and enable the cross-section of the bearing to be smaller than possible with standard types.

CARB bearings exhibit very high load-carrying capacity, high running accuracy, low friction, and resistance to wear resulting in reduced noise and vibration and promoting improved reliability and longer service life. They integrate design



A black oxide surface treatment for all types of critical bearings in wind-turbine systems can promote higher reliability as a defense against a range of conditions that can threaten bearing service life. (Courtesy: SKF)

gearless turbines (direct drive). Whereas turbines with gearboxes were once standard, the trend is toward direct drive turbines with permanent magnet technology, which are relatively lighter and more compact.

The portfolio of main shaft bearing solutions has been significantly expanded with the recent introduction of spherical roller bearings designed explicitly for wind-turbine main shafts. The heavy-duty bearings can significantly improve reliability and bearing life, in turn reducing the levelized cost of energy (LCOE).

Noteworthy features compared with standard spherical roller bearings include modified inner geometry with super-finished functional surfaces, optimized contact pressures, robust cast-iron cages, and significant total weight reduction. The resulting benefits: improved performance and enhanced reliability under typical wind-operating conditions and overall best-in-class ranking. Bearing boundary dimensions, in compliance with ISO standards, are compatible with existing arrangements, allowing for swap-out and upgrades.

These new bearings join a family of advanced stiff bearings (the Nautilus series in the case of SKF) providing high carrying capacity with minimum friction on turbine drive trains.

Designed to handle heavy and complex loads, this is a single bearing solution based on double row tapered roller bearings, arranged back-to-back. These two rows lock the unit axially and deliver extremely high stiffness. The

features from several conventional bearing types. They can accommodate misalignment (similar to a spherical roller bearing), adjust for axial expansion of a shaft (similar to a cylindrical roller bearing), and maximize load capacity due to long self-guiding rollers (similar to needle roller bearings).

A self-aligning bearing system combining spherical roller and CARB toroidal roller bearings can further contribute to a lighter, more compact wind turbine compared with conventional arrangements. Owners and operators can benefit from reduced tower and foundation weight and improved reliability, which can translate into reduced maintenance and operating costs.

MAIN SHAFT BEARINGS IN DRIVE TRAINS

Wind-turbine drive trains use one of three concepts: turbines with gearboxes, hybrid turbines, and compact bearing design helps reduce nacelle dimensions and weight and helps reduce production costs, in part, because tower and fundamental weight can be decreased.

The bearings, which can integrate a variety of options or otherwise be customized, have been designed overall to improve ease of installation, increase reliability and operational safety, enhance maintainability and reduce operating and maintenance cost, and increase turbine productivity, availability, and profitability.

Recent improvements include an enhanced segmented cage, a bolted inner ring, sealed and pre-greased units, and corrosion protection:

- The segmented cage technology consists of a single-pocket cage, which can operate in a flexible environment with the bearing being preloaded — a prerequisite for a stiff surrounding structure resulting in a stiff drive train. This new design makes it possible to increase the static and dynamic load-carrying capacity of the bearing, and the segmentation improves the roller guiding to deliver optimized load distribution among the rollers. The window-type cage further provides extremely low friction and makes the bearing less sensitive to inadequate lubrication conditions, resulting in less wear.
- A bolted inner ring allows the bearing to be attached directly to the rotor hub and mainframe, thus reducing bearing preload variations and resulting in higher operational reliability and safety, easier mounting, replacement and maintainability.
- Units can be supplied already sealed and pregreased with optimized grease fill, virtually eliminating any chance of contamination during manufacture and installation.
- Corrosion protection can be achieved with the application of a specialized corrosion-inhibiting coating, especially appealing for turbines in harsh offshore environments.

BLACK OXIDE BEARINGS

Wind-turbine bearings must endure widely varying temperatures, speeds, and loads, plus exposure to contaminants, including moisture and chemicals. These conditions can limit bearing service life and increase already high operation and maintenance expenses. An innovative black oxide surface treatment offers a viable line of defense for a variety of wind-turbine bearings.

The black oxide coating can be specified for all types of critical bearings in wind-turbine systems to help promote higher reliability against widely varying temperatures, speeds, and loads and to resist moisture and chemicals that otherwise could limit bearing lifecycles and increase costs of turbine operation and maintenance.

This surface treatment is applied to a bearing's rings and/or rollers. The process — involving a chemical reaction at the surface layer of the bearing steel — is performed in an alkaline aqueous salt solution at defined temperatures. Up to 15 different immersion steps create a thin, dark black surface layer delivering a significant performance upgrade for the broad range of bearing types and sizes in wind turbines (up to 2.2 meters in diameter and up to 1,000 kilograms per individual bearing component).

Black oxide bearings can increase turbine uptime by enhancing resistance to corrosion and smearing; improving performance in low-lubrication conditions; limiting risk of fretting, micropitting, and cracking; reducing potential damage from aggressive oil additives; and reducing the effects of friction and wear.

Suitable bearing types for the coating include tapered roller bearings, cylindrical roller bearings, spherical roller bearings, and CARB toroidal roller bearings, among others playing vital roles in wind-turbine systems.

Black oxide coated bearings can be specified for new installations or as replacements for conventional bearings of many types without encroaching on existing design envelopes.

All these examples of bearing innovations for wind-turbine applications individually and collectively can help support sustainable and ongoing success for wind-farm operations.

More innovations can be expected on the horizon as technology responds to the ever-present and emerging demands on the wind farm.

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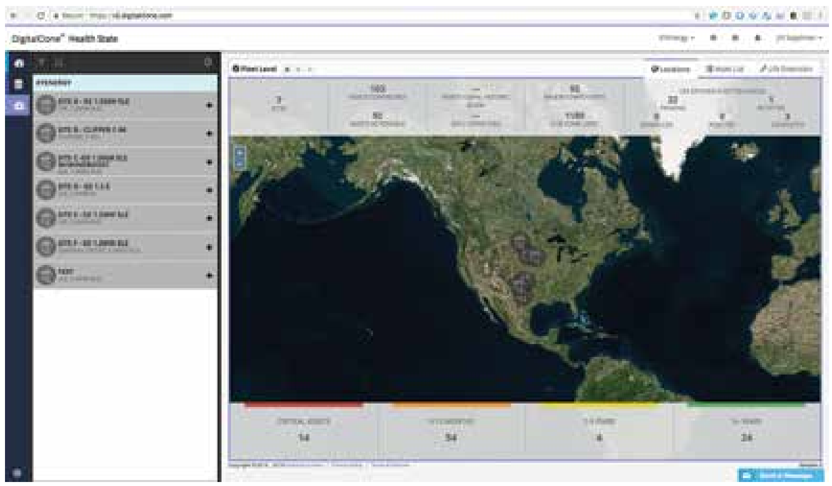
The Business Value of Digitalization

It goes beyond creating a digital model of a turbine for operations and maintenance.

By Karen J. Cassidy, Ph.D.

Digitalization may mean something different depending on who you are talking to in the wind industry. For some, digitalization is about getting ahead of unplanned failures and focusing on the operations and maintenance (O&M) problems that occur annually in a fleet. For others, it may be converting analog turbine data, like maintenance records, to digital data so they can be further analyzed. For others, it's making a digital model of an asset to reduce capital expenses through economies of scale. At Sentient Science, digitalization is converting the design, material, operational, and maintenance data into digital format, applying advanced analytics and providing the best prediction capabilities for life and health of assets and fleets. That information is then used by customers to make business decisions for cost reduction and better forecast planning.



DigitalClone provides a fleetwide view of the failure rate of each wind turbine in the field. (Courtesy: Sentient Science)

IRENA REPORT

According to the International Renewable Energy Agency (IRENA), wind-turbine cost reductions in the last two decades, for both onshore and offshore wind turbines, have been achieved already by economies of scale and learning effects as installed capacity has grown. LCOE of wind has been reduced further through increasing turbine height and rotor diameters.

The larger blades and hubs may mean higher torque and loading conditions on the critical components within the drivetrain. This shifts the digitalization strategy from increasing the installed capacity to improving the operational availability of the fielded turbines.

Gearboxes typically represent 13 percent to 15 percent of wind-turbine costs, according to the IRENA report. Some gearbox failure rates range between 4.5 percent to 8 percent in a fleet ahead of the gearbox's 20-year design life. That's because there is a major difference between physical testing of critical drivetrain components and the actual loading conditions seen in operation.

Sentient Science calculated a difference of as much as 68 percent between a physical test and live operational data.

The discovery was made by validating Sentient's materials science models against actual fielded maintenance reports.

The reason for the difference in life is because physical testing is limited in the number of data points that can be tested because of cost and time.

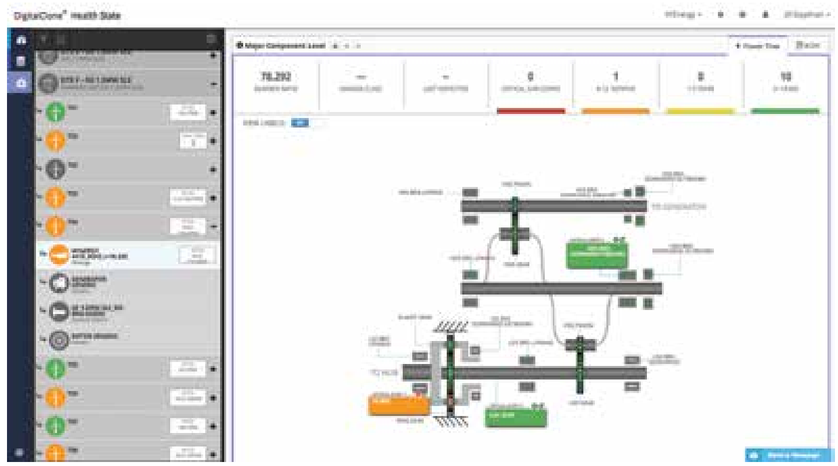
In addition, what happens in a laboratory under controlled parameters can be different from the unpredictable and harsh environments experienced in the field.

> Gearboxes typically represent 13 percent to 15 percent of wind-turbine costs.

BEYOND THE DIGITAL MODEL

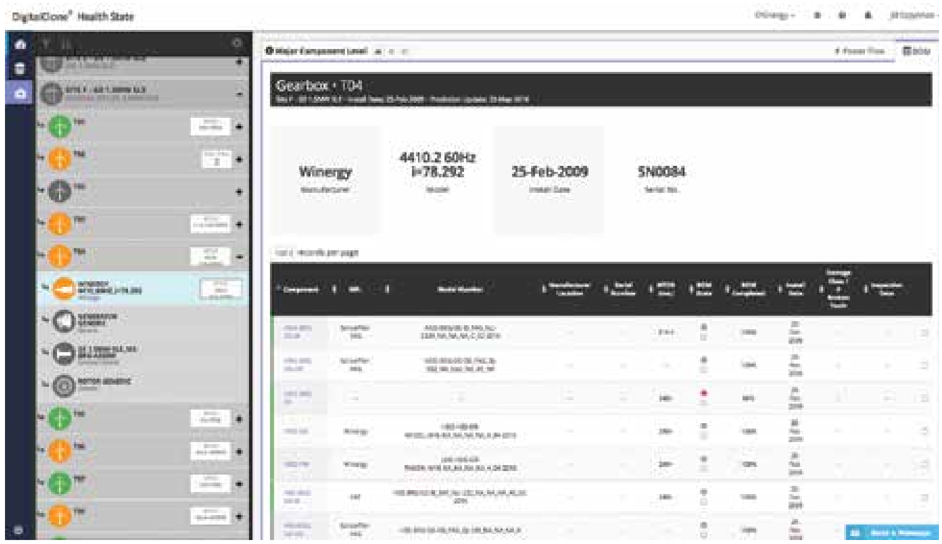
Therefore, digitalization goes beyond making a digital model of an asset for economies of scale, and it goes beyond using big data applications to catch impending failures in the field.

It involves simulating how the materials used in design respond to the actual operating conditions experienced in the field. This is done by converting the data into a digital format called a DigitalClone, applying materials science-based analytics to critical components of the drivetrain, and then measuring the true-life expectancy of the asset. By combining the materials model with the empirical data from the field, the behavior of the asset tells the operator a different story from the design and physical testing that was done before going to market.



When a damage class of 3 or 4 is flagged, a user can look at the Bill of Materials within the software to see where the failure is occurring, on which component, and look at the asset actions recommended to make a business decision on the best action to take for that asset.

It tells the operator how that asset will really perform in the field under a broad range of operating conditions. The same type of wind turbine, with the same type of gearbox, may perform vastly different depending on location and wind regimes. The combinations of major component OEMs within the turbines can vary, especially as assets are exchanged over time and different models used as replacement, furthering the variation.



A risk ranking of the components enables supplier purchasing decisions based on the life impact vs. just price and delivery. Sentient Science calls this Buy on Life.

For example, one wind farm with moderate wind conditions may experience far less failures in their fleet from another wind farm that lives in dynamic conditions with high turbulence and sheer rates. The same wind-turbine model by design and manufacturing process may have different failure rates. The bearings and gears selected for use in the gearbox contributes to the variation of failure rate.

When the operator understands the failure rates of their assets at the major system and component level, life extension actions can be taken to achieve savings of up to 13 percent of revenues. The data from merging materials science and data science enables informed decisions beyond O&M.

When looking at just short-term failure rates, a planning horizon is on average between one week and one month.

There is little life extension that can be gained in this timeframe; however, optimization of site resources can be achieved, including better visibility into the equipment and manpower needed for the job.

Medium- and long-term prognostics, ranging from one year to five years and five-plus years, respectively, can be used for asset management, risk reduction, and increased availability of field assets.

Consider looking at industries who have successfully integrated digitalization, such as Uber and Airbnb. They use digitized information to create new sources of revenue and cost reduction; sometimes a completely new way to look at how business gets transacted.

Uber and Airbnb transformed the taxi and hotel industries through economies of scale and enabling transactions in a platform, which may have implications in renewable energy.

Imagine connecting operators, OEMs, and suppliers in a platform with the needs and availability communicated almost seamlessly.

MULTIYEAR BUDGETING AND FORECASTING

Visibility to one- to five-year failure rates enables multiyear budgeting and forecasting for aftermarket parts to keep in stock. Inventory reduction has substantial value with the ability to shift to Just in Time planning.

This planning method is facilitated with knowledge of the failure rates of the major systems and critical components 12 months to five years in advance. Additionally, strategic partnerships with suppliers and other operators can be developed for maximum buying power that reduce capital expenses through economies of scale and accurate forecasting. It is also possible to correctly size insurance coverage and defend warranty and serial defect claims.

To gain significantly more savings from O&M optimization, operators have to look at applying digitalization to several areas of the business as a way to offer more substantial return on investment. For example, inventory carrying charge reductions and better terms and conditions with suppliers.

Sentient has calculated that a savings of up to 13 percent of revenue can be achieved when looking at the various business units that can benefit from using long term forecasting and budgeting to lower the cost of operations.

Karen J. Cassidy has a Ph.D. in Mechanical Engineering from Northwestern University. She has worked 12 years in the field of rotating machinery prognostics including president of GasTOPS Inc. and senior engineer for SmartSignal (now part of GE Intelligent Platforms). She is currently vice president of Customer Success for Sentient Science.