# COMING: Wind turbines that **never fail**

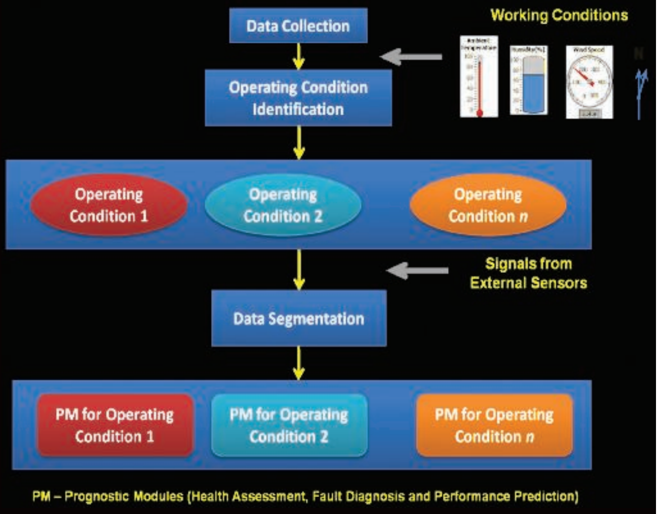
The idea of reducing breakdowns to nearly zero is unheard-of in the wind industry. But that's where a technique called "condition-based monitoring" could ultimately lead.

In these recessionary times, it's nice to know there is at least one industrial area seeing brisk growth: Estimates are that the wind-energy industry grew in the U. S. by a rate of 29% from 2002 to 2007. The U. S. became the world leader in wind-energy generation by the end of 2008. And the Global Wind Energy Council reports that the wind-energy generating capacity installed in the U. S. at the end of 2008 was approximately 21% of the total world generation. According to the **American Wind Energy Association** (AWEA), the total wind-power capacity operating in the U. S. as of first quarter of 2010 is over 35,600 MW, generating enough to power the equivalent of 9.7 million homes.

If we are to maintain this rapid pace, it is essential that wind turbines be reliable. Increasingly, the wind industry recognizes that better reliability can come from applying to wind-turbine components some fundamental research in what's called condition-based monitoring. Such research would be instrumental in determining the efficiency of power-generation schemes and in supporting the creation of advanced windmill designs.

The **Center for Intelligent Maintenance Systems** (IMS) is actively pursuing the idea that condition-based monitoring can enable wind turbines and wind-farm systems to reach and sustain near-zero breakdown performance. Such a feat would ultimately transform traditional wind-industry maintenance from "fail-and-fix" practices to "predict-and-prevent" operations. To this end, the Center is focused on cutting-edge technologies in embedded and remote prognostics and health management. In this

## Dividing operating data into regimes




**The modeling of a wind turbine for predictive maintenance starts with the collection of data, including those indicating real-time system-operating conditions, and using them to identify the system's regime of operation. With the operating regime identified, the data goes into the corresponding prognostics model that has either been established, or will have to be created for a newly learned operating regime.**

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**Key points:**

- Techniques originally aimed at predicting when factory-floor equipment would fail are now being applied on wind turbines.
- A toolbox of algorithms, collectively dubbed a Watchdog Agent, converts sensor data and operating conditions to useful information that eliminates the need for "fail-and-fix" maintenance in wind turbines.

**Resources:**

**IMS Center Web site,** *http://www.imscenter.net/*

***The Quest for Zero Downtime,*** *http://machinedesign.com/article/the-quest-for-zero-downtime-0607*

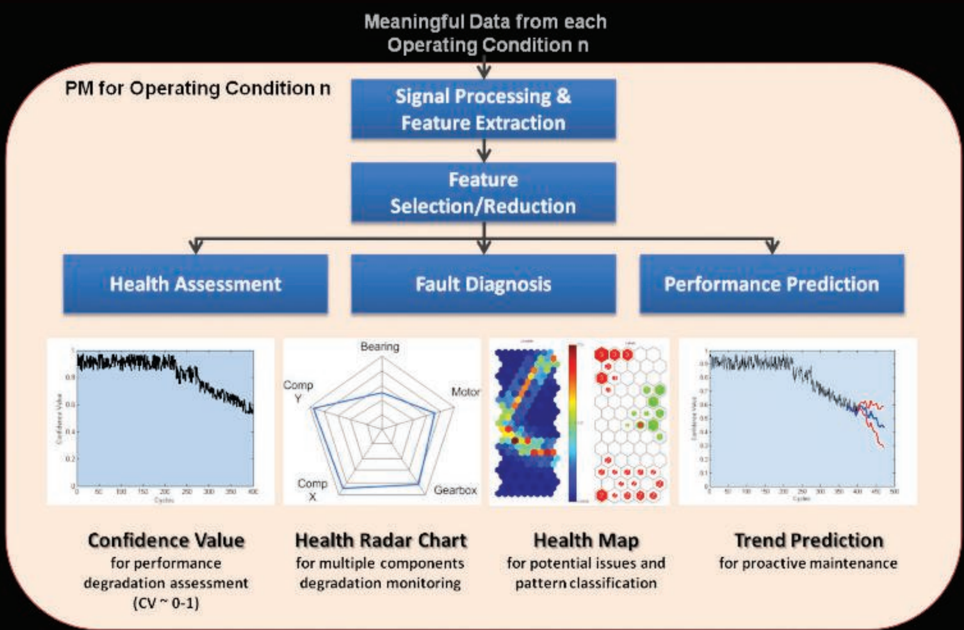
**Wind Turbine Prognostics and Health Management (WT-PHM) demonstration platform,** *http://www.imscenter.net/windturbinephm*

regard, it has also coined and trademarked the term Watchdog Agent prognostics tools and Device-to-Business (D2B) Infotronics platform for e-maintenance systems.

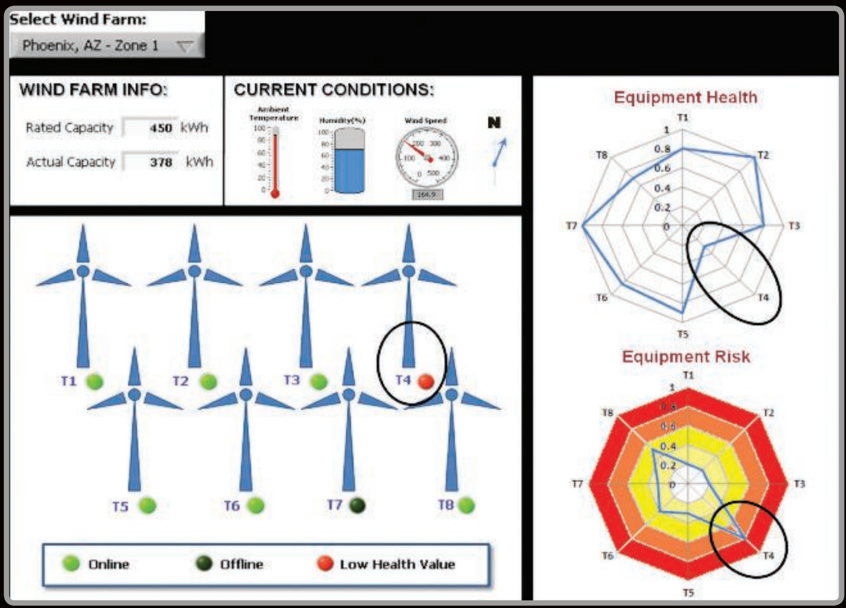
The Watchdog Agent is basically instrumentation capable of converting sensor data and operating conditions to actionable information. This information is indicative of a machine's level of performance and health. The Watchdog Agent monitors how fast components are degrading, then predicts the likelihood of failure and the health of a machine. This approach is called predictive maintenance, or prognostics.

Prognostics is a lot more than merely collecting the kind of data normally associated with

## Preparing wind-turbine data for visualization




**Wind-turbine behavioral tools may include routines for feature extraction, health assessment, and fault diagnostics, which have been studied and applied intensively by the IMS center for common rotary-machinery components, such as gearboxes and bearings. The results get displayed in visualization tools for degradation assessment and monitoring.**




Screen captures of the IMS Wind Turbine Demonstration Platform display illustrate status information for an entire wind farm (left) and for a single wind turbine (right).

statistical-process control. It truly is a paradigm shift. One thing it includes is "health-information intelligence." Health intelligence includes an awareness of what parts of the machine are functioning properly, performance prediction, failure prediction, and the ability to interact with functional intelligence. A machine is considered to have both functional and health intelligence if it is capable of reconfiguring itself, compensating for any degradation it notices, and performing some self-maintenance.

Prognostics also includes operations intelligence. It is relatively easy to make decisions about maintenance for a single machine that's clearly near failure. But the situation is less obvious when there are hundreds of machines. The ability to prioritize problems, optimize responses, and responsively schedule maintenance according to the developing situation is referred to as operations intelligence.

Finally, prognostics encompasses synchronization intelligence. This is the idea that machine health and maintenance data must automatically convert to information compatible with business systems.

## Unmet needs in wind turbines

Wind-turbine systems are growing ever-more complicated, and they must operate in highly dynamic and unpredictable environments. So it becomes ever-more-challenging to make such systems reliable.

The IMS Center has researched such critical wind-turbine components as gearboxes and rotor blades. However, wind-turbine systems are noteworthy in that prognostics and health-management tools and techniques must accommodate and factor in the dynamic operating conditions of the turbine systems. These factors include variable wind velocities and blade rotational speeds that continuously affect energy generation and the resulting turbine efficiency. Such complications necessitate that researchers develop a scientific understanding of the dynamic mechanisms at work in wind-turbine systems, how these factors affect the health of the turbine components, and the underlying relationship of component health on the efficiency with which a wind turbine generates energy.

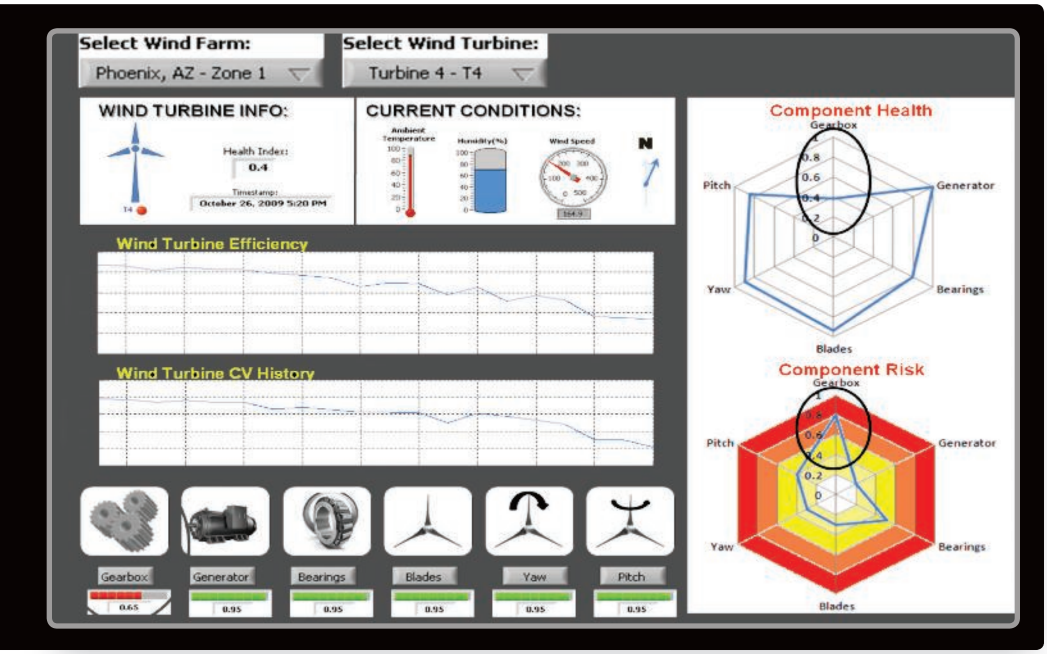
To handle such complexities, the Center for IMS has developed and implemented a special Watchdog Agent toolbox targeted specifically at wind turbines. These tools address three key challenges and unmet needs:

1.) Current wind-turbine systems can only collect data for basic monitoring. Of course, it takes much more than simple status information for wind turbines to predict when they're heading for failure. So the Center for IMS devised a toolbox of predictive analytic tools for this purpose. Employing such techniques as time and frequency domain analysis and wavelets, they offer a systematic way of extracting the critical components' state of health for wind-turbine systems.

2.) Rotary components of a wind turbine work under highly dynamic loads and are more susceptible to failure. So the Center for IMS developed innovative methods for extending traditional PHM techniques that allow for the dynamic behavior of these components.

3.) The degradation of critical wind-turbine components may reduce their power-generation efficiency. The Center for IMS is experimenting with new models that can relate the health of critical wind turbine components to the associated power efficiency or yield of the turbine.

In devising prognostics models for wind turbines, one must recognize that the turbine operates in constantly changing operating conditions: different wind speeds and directions, as well as slowly evolving environmental conditions such as temperature. This means the electrical and mechanical systems of a wind turbine actually operate under conditions that vary quite a lot. So the model must take what might




be called a multiregime approach. First, the collected data, including those indicating real-time system operating conditions, are used to identify the regime in which the system operates. Regime patterns are established for modeling and, if a new measurement cannot fit to any of the existing patterns, the prognostics system will automatically learn a new operating regime. Once the operating regime is identified, the data feeds into the corresponding prognostics model that has either been established, or will have to be created for a newly learned operating regime.

The prognostics models include a systematic framework with several subprocedures, including feature extraction, health assessment, fault diagnostics and future performance prediction. These areas all have been studied intensively by the IMS center for such common rotary machinery components as gearboxes and bearings. Finally, the health indices obtained from different operating regimes are fused together to form a continuous time series indicating system health. This data then is used for predicting the overall wind-turbine health.

The result of this work is displayed via a special human-user interface (HMI) dashboard. The display can be generated with four key visualization tools:

*A Confidence Value Chart for wind turbine component performance degradation monitoring* — A confidence value is defined as a health/performance value ranging from 0 to 1. If the value drops to a low level, a maintenance practitioner can track the historical confidence value curve to find the degradation trend. The confidence value curve shows the historical/current/predicted confidence value of the equipment. An alarm will trigger when the confidence value drops under a preset unacceptable threshold.

*A Radar Chart for multicomponent health monitoring* — Maintenance practitioners can look at this chart to get an overview of the health of different wind-turbine components (such as gearboxes, bearings, and rotor blades). Each axis on the chart shows the confidence value of a specific component.

*A Health Map for fault pattern classification* — This is used to determine the root causes of degradation or failure. This map displays different failure modes of the monitored components by presenting different failure modes in clusters, each indicated by a different color.

*A Risk Radar Chart for prioritized decision-making* — This is a visualization tool for system-level maintenance information management that displays risk values, indicating turbine-maintenance priorities. The risk value of a turbine (determined by the product of the degradation rate and the value of the corresponding cost function) indicates how important the turbine is to the maintenance process. The higher the risk value, the higher the priority given to that piece of equipment for requiring maintenance.

## Value and impact

All in all, the IMS work includes a multiregime prognostics approach to handle the wind turbine under various highly dynamic operating conditions. Via test equipment and software, the prognostics system can learn about operating conditions over time and provide a feasible solution for the scarcity of data that exists today. And the toolbox has been developed for different components and applications.

The result of this work is a better understanding of the relationships among dynamic operating conditions of wind turbines, the health of their underlying rotary components, as well as the resulting wind-turbine power efficiency. Currently, these developments are embodied on a Wind Turbine Prognostics and Health Management (WT-PHM) demonstration platform that can be accessed at *http://www.imscenter.net/windturbinephm*. It can be viewed through an animated demonstration on the Web site. The platform demonstrates how the systematic and analytic IMS methodology can be applied through a top-down approach, starting from the wind-farm level consisting of several turbines, and extending down to the root components of the wind turbine. So far, the WT-PHM platform has been implemented as a Watchdog Agent–based software platform. The hardware and instrumentation is obtained using existing hardware already installed by wind turbine makers. We typically find that wind turbines have all the necessary sensing (vibration and so forth) that the Watchdog Agent needs. So the platform simply taps into existing data. **MD**