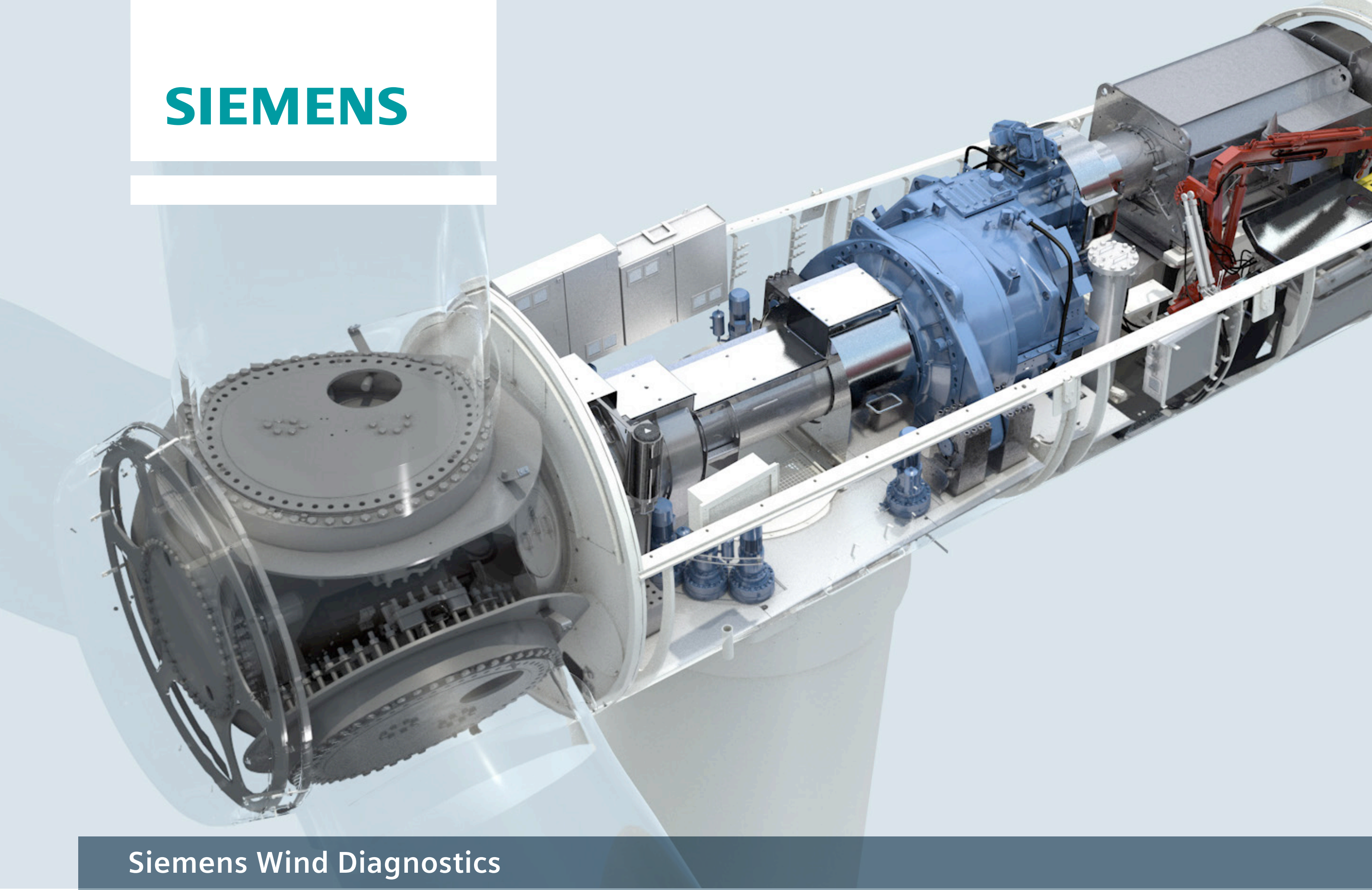
SIEMENS



Siemens Wind Diagnostics

Model Based Diagnostics

Helping to reduce production loss through early-stage detection of abnormal behavior. Recommending preventative remedial measures.

Positioning

- A vast amount of data collected from Siemens wind turbines over several years.
- The recent emergence of exciting new data analytic capabilities.
- And a massive knowledge base generated from developing and servicing wind turbines.

These facts have placed Siemens wind diagnostics in a very unique position, one that allows us to develop completely new types of tools and systems. Model Based Diagnostics (MBD) is one of these and is already completely and successfully implemented and generating measurable value for Siemens clients.

The importance of refining service for customer benefit.

A modern wind turbine is a complex and expensive machine. Profitability is crucial for the investment made by our customer, and achieving this depends on a turbine's performance and availability. As soon as the turbine is connected to the grid and the first kWh are generated, performance and availability rely on how service and maintenance are performed, and two important aspects make the difference.

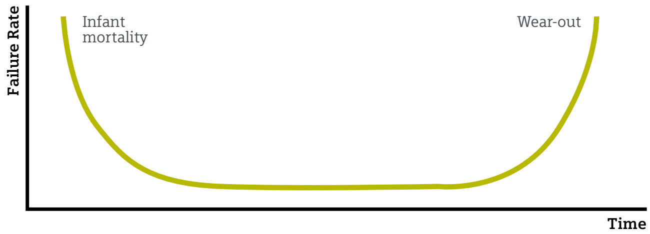
- Unplanned downtime and loss of production must be diminished.
- Planned service needs to be less frequent and as efficient as possible.

Model Based Diagnostics has a large impact on both of these aspects.

Unplanned service

MBD serves to detect the type of abnormal operational behavior, that if not addressed in due time, may become a more serious issue. Serious issues that can stop the turbines require repair, mobilization of a service team, spare parts, cause production loss and trigger travel costs that are particularly expensive when it comes to offshore turbines. With Model Based Diagnostics, service planners can be notified in advance of many issues, and prioritize and bundle remediation.

Modern wind turbines are designed to have an estimated lifetime of up to 25 years, when operated and maintained correctly. However, any internal system not performing satisfactorily may shorten the estimated design lifetime.



The Weibull failure rate distribution.
Also known as the Weibull Bathtub. Wear out failures are anticipated to occur outside the bathtub. However, incorrect operation may shift wear out failures into the bathtub, and cause breakdown before the expected end of a component or a turbine's estimated lifetime.

Planned Service

Scheduled service visits include a number of tests that need to be performed manually when inside the turbines. The need for these tests can be reduced by using a diagnostic model to verify the state of each system, simply by evaluating the data generated from the system. This can reduce the time spent on service and maintenance.

Servicing wind turbines is a hard and dangerous job.
Model Based Diagnostics reduces the time the technicians need to spend in the turbines, reducing the risk of personal injury accordingly.

The Siemens Turbine Condition Monitoring system (TCM) monitors vibrations from the main components such as the gearbox, main bearing, generator and so on.

This is different to Model Based Diagnostics, which uses almost all the sensors connected to the control system in the turbine.

How does Model Based Diagnostics work?

For the last several years, most Siemens wind turbines have been standard equipped with our state of the art vibration monitoring system, the Turbine Condition Monitoring (TCM) system. This system takes information from dedicated vibration sensors located on all larger mechanical components, such as the gearbox, main bearing, generator, and others.

Model Based Diagnostics is quite similar to this system, taking use of all the sensors located in the rest of the turbine, especially on ancillary systems like filtration, lubrication, hydraulics, cooling, yaw and pitch systems, and the power unit.

A Siemens turbine typically takes measurements from more than 1,000 sensors and interfaces, stores the high resolution data inside the turbine, and then replicates this data in a compressed format back to the Diagnostic Center of Siemens Wind Service, where data from turbines are stored in one central database. We call this database the Wind Farm Database.

Considering that as far back as 15 years ago Siemens had already begun to collect data from some turbines located in very different environmental conditions, like the arctic climate of Norway, the hot deserts of Texas, and in the high wind speeds in New Zealand, we now have at our disposal what corresponds to more than 50,000 years of operational experience to learn from. Given the development in data analytics over the last few years, this sets Siemens Wind Service in a very unique position.

Basically we use the data generated by the turbines to model and compare new data. The highly advanced and intelligent models that we operate can pre-calculate an expected value based on learning algorithms like neural networks, local outlier factor, linear regression and so on, and afterwards compare to the actual measured value. Any significant deviations will alert our experts, and a detailed technical advice and troubleshooting guide can then be created to assist the customer, or service technicians on site, to efficiently remedy the issue. This is done by automatically raising a ticket in the internal case management system. The ticket is forwarded to the responsible service planner, allowing the planner to assign a technician according to the predefined priority.

Four diagnostic model examples:

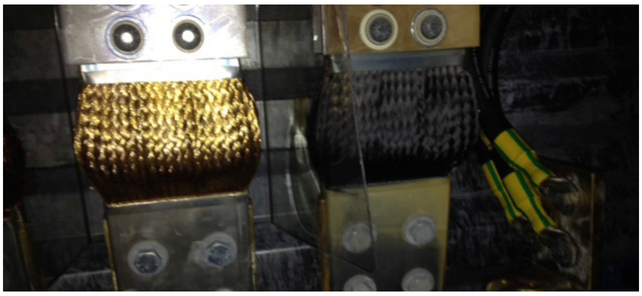
Hundreds of systems, components, and sensors inside Siemens turbines now have their own dedicated diagnostic model keeping track of their performance and condition.

Room temperature models

Based on intelligent learning from selected channels, a diagnostic model can pre-calculate the expected temperature in the internal grid-transformer room on offshore turbines.

Comparing this to the measured temperature, the model can help detect potential problems with the ventilation systems in the transformer room thus allowing for actions to be taken to help avoid damage to or stoppage of the turbine.

In addition, this model is also able to detect heat dissipation on junctions inside the transformer room and avoid serious damage to the grid transformer.



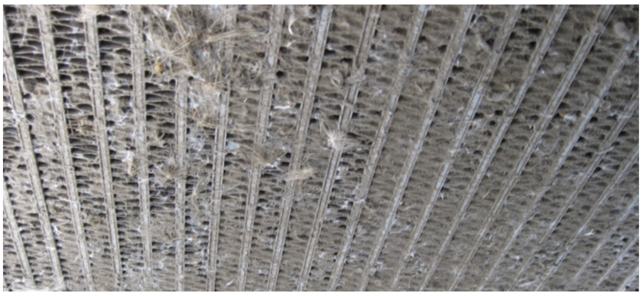
Accurate room temperature models can even help to detect overheated junctions

Radiator capacity models

Cooling systems uses the ambient air to evacuate heat from internal systems through radiators.

Sometimes the cooling effect is reduced as these radiators become contaminated.

Intelligent models trained on the relations between power production, airflow, and other factors, can now submit early warnings if the cooling capacity at a specific radiator is reduced



Debris from harvesting a nearby cotton field reduces the cooling effect. Diagnostic models can now detect this well in advance

Leak detection models

Pressurized systems like cooling systems are designed to hold the pressure constant, at least until the next scheduled service visit.

All pressurized systems lose pressure over time and even small and unseen leaks may cause a turbine to stop and create the need for an unplanned service visit.

Special diagnostic models trained on the relation between temperature and pressure can detect certain leaking systems, potentially allowing for repairs to be arranged before the turbine suffers from a low-pressure stop alarm.

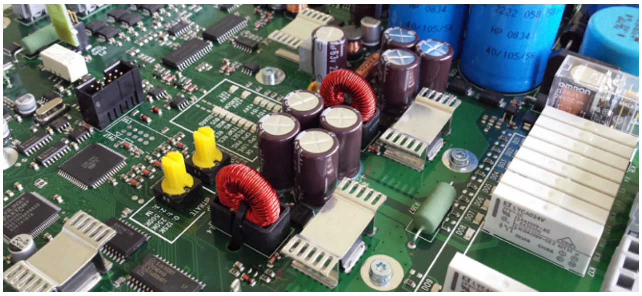
An almost invisible leak can cause a turbine stop over time. It can be detected by advance pressure models

Electronics environment models

Multiple self-learning models are trained on how temperatures inside controller cabinets are affected by outside temperature and other factors.

These models can detect deviations as low as 0.5 °C and helps protect the internal electronics from early wear out.

Raising the temperature by 7 °C on electronics statistically reduces expected turbine lifetime by 50 %. Electronic failures may cause turbine components or a turbine to stop and require repair. Failure modes can include seized ventilation fans, contaminated filters, and more issues.

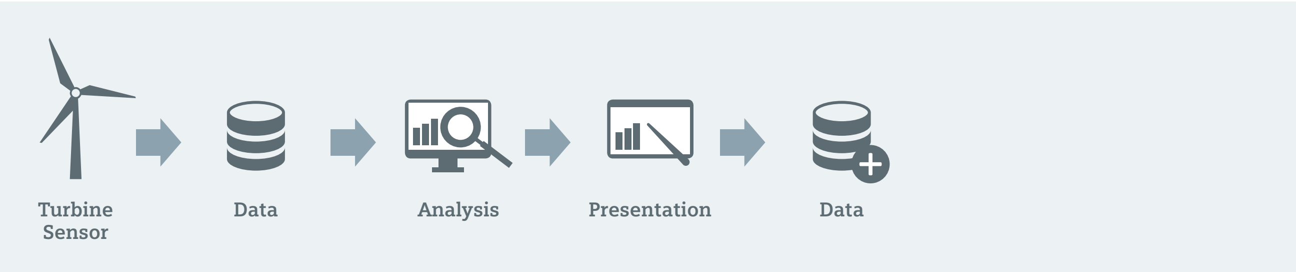


Electronic components can wear out prematurely when exposed to excessive heat over time

Integrating domain knowledge and expertise into digitalization.

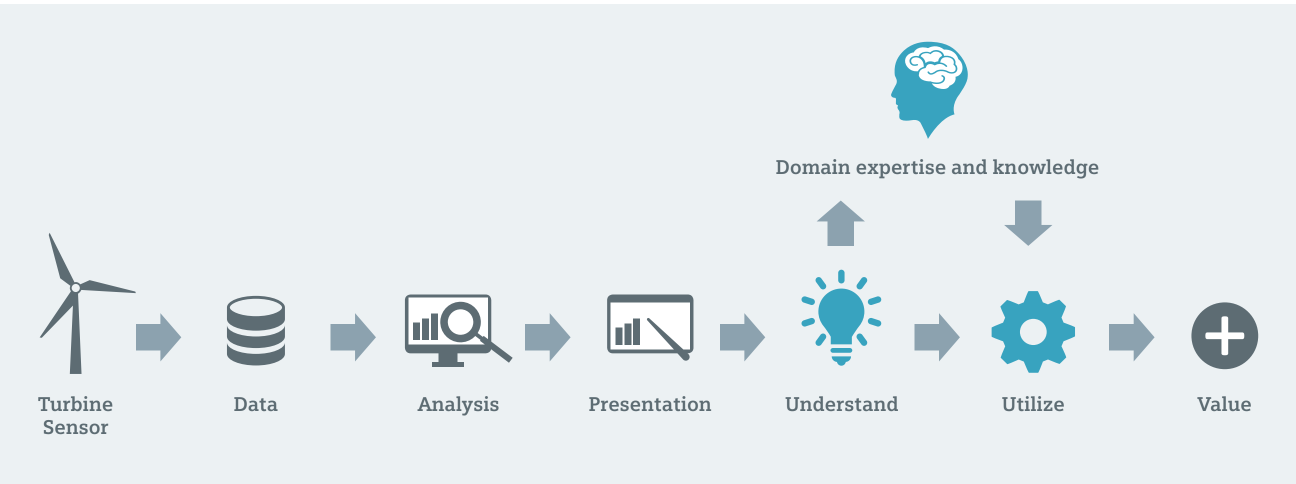
Digitalization is about collecting data, analyzing the data, gaining knowledge, and creating value from this knowledge. When it comes to wind turbine diagnostics, this starts at the sensors in the turbines and ends with proactive and preventive repairs.

A large number of new solutions and platforms for power plant owners and operators are now reaching the market, with the claim that they enable optimization of performance, operation, and service. The producers claim that most of these external tools achieve this by collecting data, and providing the opportunity to create customized dashboards for visualization. Some go further and offer the ability to set up limits and alerts.



Systematic data analysis generate data

However, the understanding that allows the utilization of this information into actual business value requires the integration of domain expertise and domain knowledge



Wind turbine data analysis only generates value when combined with wind turbine expertise

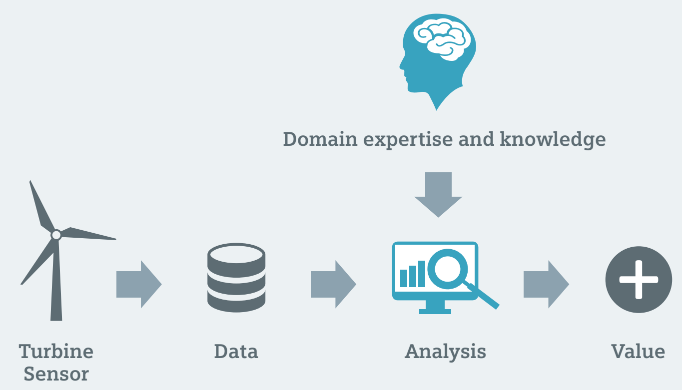
How is Model Based Diagnostics different from what else exists on the market?

Knowing what a potential problem actually looks like on a dashboard requires knowledge, understanding, and experience on every single wind turbine, including its current configuration. This does not come with an external tool, but needs to be joined and compared afterwards, most often as case by case investigations. When an insight is achieved, a further action plan then needs to be decided on.

What really sets Model Based Diagnostics apart from external tools is a new approach in the Model Based Diagnostic system.

This new approach makes it possible to integrate this knowledge and experience on wind turbines and their internal systems and configuration, directly into each diagnostic model before any result appears on the dashboard.

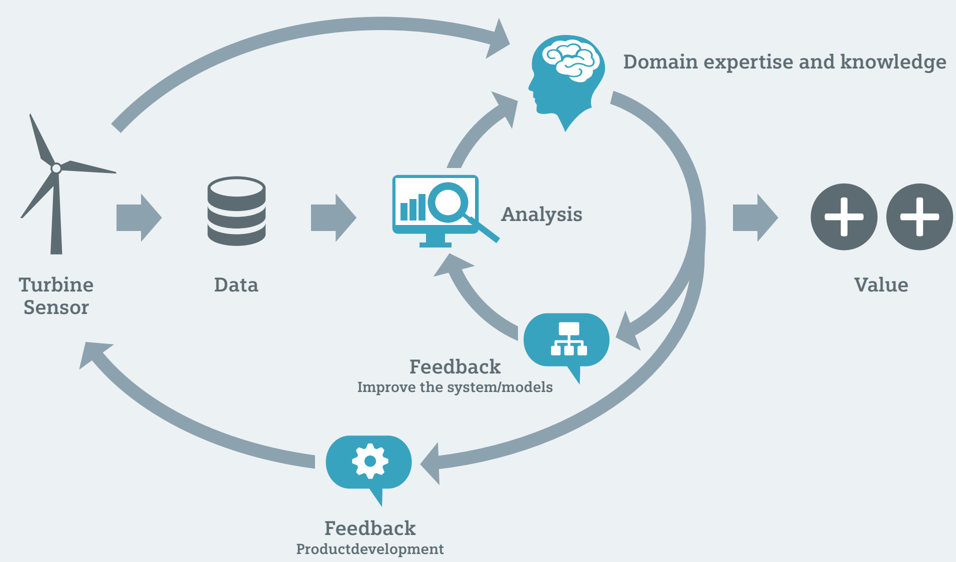
This enables Model Based Diagnostics to make precise decisions on the nature of each potential problem and even create the action plan, automatically completing the remaining two steps without any manual intervention.



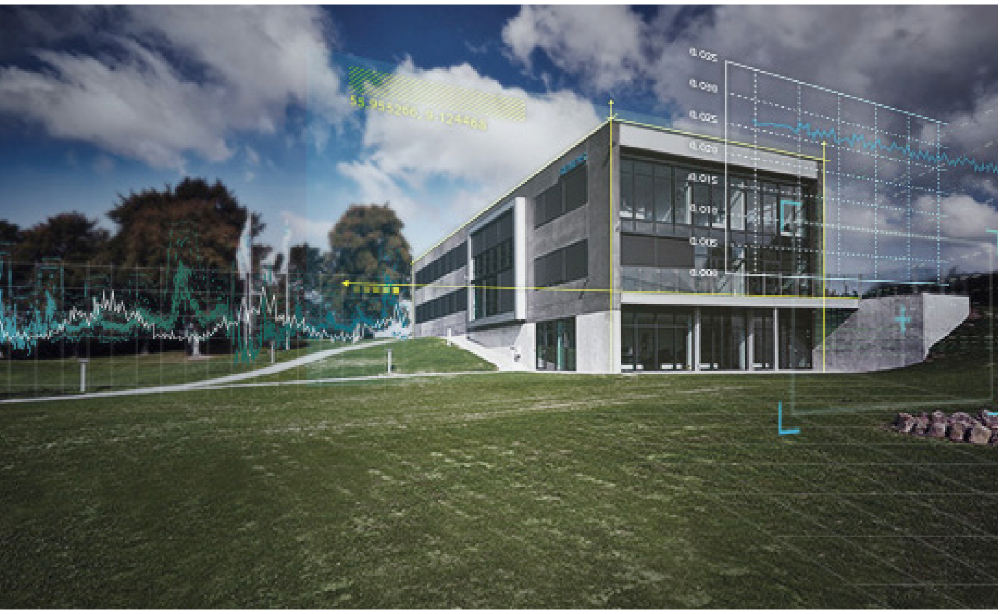
By already introducing turbine experience into the analytic engine, the MBD system generates the business value as a direct output.

The complete circle

Model Based Diagnostics goes even one step further and completes the circle, by joining experience and feedback from these repairs back into the models for further improvement. When followed by a service technician in the field, the technical advice created by our model proves accurate 97 % of the time. Providing tangible benefit to the customer and the industry.



Based on feedback from service technicians, models are constantly being improved Performance feedback is additionally used for product improvements.



The diagnostic center in Brande, Denmark, brings together data analytics skills with decades of wind turbine service experience.

Into the future: moving forward with Model Based Diagnostics.

The developers of Model Based Diagnostics are located in the Siemens Wind Service's new diagnostic center in Denmark, together with domain experts and experienced service technicians. This has created the optimal environment for merging the domain knowledge into diagnostic models.

Our development teams in the diagnostic center are constantly evaluating new opportunities and seeking new ways to improve the energy production of the large fleet of Siemens wind turbines owned by our customers.

The basic ideas now implemented through Model Based Diagnostics enable the development of solutions that change the way wind turbines are serviced and maintained.

We look forward to a bright future where many new solutions will decrease the costs associated with generating environmentally-friendly energy.

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