

Next-Generation Wind Turbine Monitoring: Holistic CMS for Predictive Maintenance and Digital Twin Integration

Motivation

Modern wind turbines rely on multiple condition monitoring systems that in some cases operate independently and focus on individual components such as main bearings, pitch bearings, or rotor blades. Such fragmented approach limits the understanding of system-wide interactions and could lead to false alarms, misdiagnoses, and inefficient maintenance decisions. The holistic condition monitoring system addresses this gap by integrating mechanical, thermal, structural, and operational data into a unified monitoring framework. By combining high-frequency CMS data with SCADA signals and contextual information, the holistic CMS enables earlier fault detection, improved failure interpretation, and more reliable maintenance planning—especially critical for large offshore turbines where downtime and unplanned interventions could cause substantial cost and energy losses.

Results

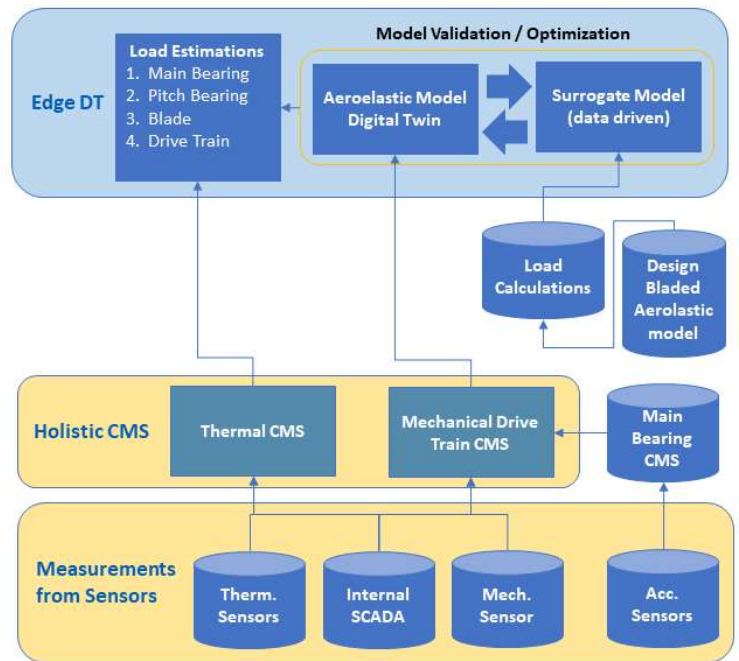
We developed and partially implemented a holistic condition monitoring system (CMS) for wind turbines that integrates thermal, mechanical, and structural monitoring into a unified platform. This system directly tackles key challenges in monitoring critical components such as main bearings, pitch bearings, and rotor blades.

In a case study, we used the adapted preInO tool to fuse and analyze diverse SCADA data streams, enabling continuous damage assessment through virtual sensors even during physical sensor outages. This approach enhances failure detection accuracy and reduces false alarms by providing richer context for evaluating component health.

By combining CMS outputs with edge and cloud computing and applying standardized data protocols, we ensure the system's interoperability and scalability. These advances create a robust, data-driven framework that extends turbine service life and lowers operational costs through improved condition monitoring.

Methodology

The holistic CMS is built by interlinking existing component-level CMS with standard SCADA and control data through a unified data integration and analytics framework. Data from sensors measuring vibrations, temperatures, loads, and structural responses are aggregated at the turbine edge and selectively transferred to cloud-based systems to respect bandwidth and storage constraints. The preInO tool is used as the central integration and analytics platform, enabling semantic data harmonisation, flexible preprocessing, and advanced diagnostic and predictive algorithms. In addition, virtual sensors are introduced to enhance data quality and compensate for missing or faulty physical sensors. This integrated setup prepares the data foundation required for advanced predictive maintenance and future Digital Twin applications.



Excerpt of the WP6 concept with focus on the holistic condition monitoring system

ReaLCoE's vision is to unleash the full potential of offshore wind energy

€35/MWh LCoE Goal, +12MW WEC Capacity, ~32 mio € Total Budget, 42 month project duration



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