Predictive maintenance for wind farms: Combining ML and physics-based modelling to reduce wind turbine asset downtime

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Wind energy is one of the leading (and fastest-growing) sources of renewable energy and represents a vital part towards the goal of realising a world powered by green energy. Despite their long history, the profitability of wind turbines is still highly dependent on their operational expenditure, notably the cost of asset maintenance. The asset downtime resulting from the failure of key turbine components, such as generators and gearboxes, means that a single fault can result in a significant reduction in energy production [1].

Traditionally, OEM-installed SCADA systems in wind turbines provide limited information about the current state of the various subsystems. The low frequency (typically every 10 minutes) and averaged nature of data acquisition is a prohibitive factor to the construction of intelligent models. The difficulty, and risk, of retrofitting legacy wind turbine assets with new, high-frequency, condition monitoring systems means that such solutions are generally unattractive for wind farm owner/operators. These issues motivate the need for developing smart predictive maintenance tools that offer more than standard SCADA systems.

As in many other sectors, data analytics approaches like machine learning have become an essential part of the wind farm O&M provider's toolset, as they yield models with the ability to make decisions on the operational strategy of instrumented products "in time". Nevertheless, there are limitations to a purely data-driven approach. Foremost is the fact that such models are trained using historical data. Models are unable to accurately identify anomalous events that they have not encountered. Attempting "what-if" scenarios, where hypothetical situations are tested becomes difficult in such a context. Physics-based models, in contrast, attempt to represent faulty behaviour starting from first principles and thus can capture any faults representable by physics. This justifies the introduction of virtual, physics-based models in predictive-maintenance applications.

System simulation offers a flexible framework for realising model-based diagnostics tools as they allow the representation of multi-domain physical systems (mechanical, thermal, hydraulic, electrical etc) in a standardised way. Fault modelling for these different domains can likewise be realised in a systematic way.

In this work, we demonstrate how a holistic approach combining data-driven and physics-based models can be deployed to realise an application that provides in-time estimate of wind turbine asset health and operational performance.

[1] Dao C, Kazemtabrizi B, Crabtree C. Wind turbine reliability data review and impacts on levelised cost of energy. *Wind Energy.* 2019;22:1848-1871. https://doi.org/10.1002/we.2404

More recent condition monitoring systems offer data acquisition at higher rates.