Closed-loop supervisory control for defined component reliability levels and optimized power generation

PO.287

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Abstract

Multi-Megawatt-wind turbines are large, flexible structures employed in rough, changing and strongly site-specific environmental conditions. A common requirement is continuous operation over a time span of 20 or even 25 years with very high availability. Currently, maintenance is planned based on statistical information about component failure behavior and the current state of the main turbine components. However, this is still reactive: Predicted or existing failures in the turbines drive the maintenance schedule. Instead, a more flexible approach with planned unavailability would be preferred.

We propose the use of optimization-based reliability control for autonomous adaptation of wind turbines (WTs). It allows for an adaptation to individual structural strength of each turbine and to specific site conditions.

Optimization-based reliability control

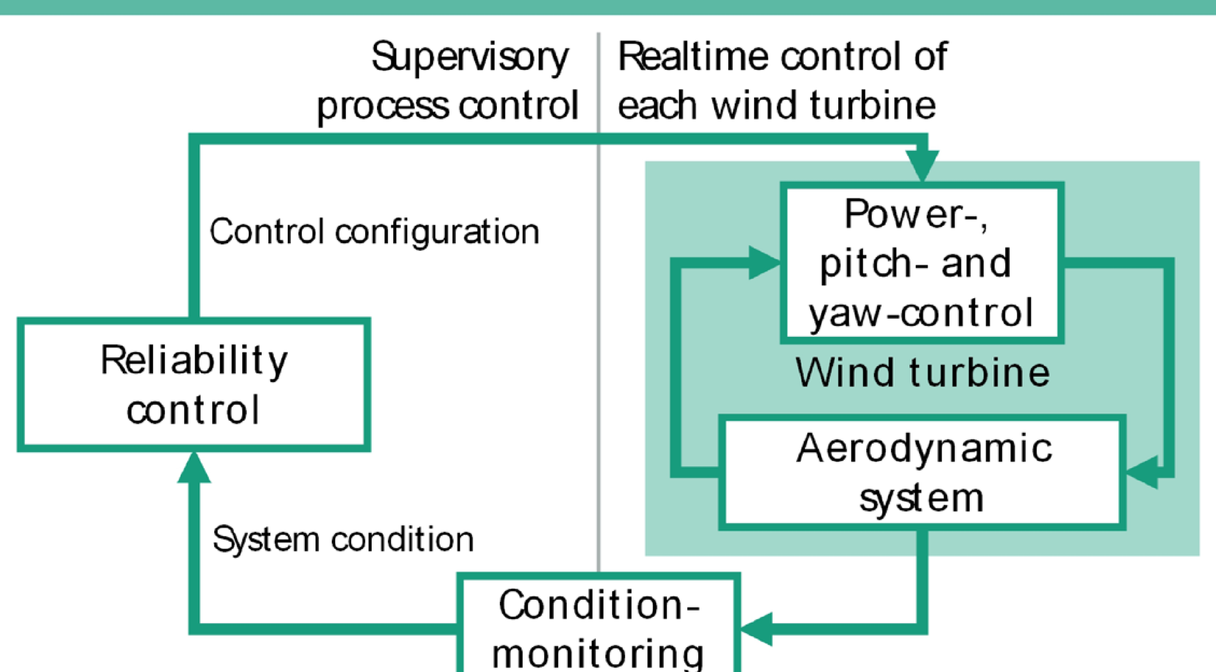

Fig. 1: Basic outline of reliability control loop.

For closed-loop control of wind turbine reliability, a supervisory process control on turbine or on windfarm level is introduced. It interfaces with realtime WT control by means of parameter adaptation for power-, pitch- and yaw-control systems. To obtain the current degradation state, condition monitoring is employed. Reliability control then selects a control configuration such that reliability requirements are fulfilled [1]. Model-based self-optimization for system behavior adaptation [2] has already proven suitable for reliability control of automotive components [1] and quality control of manufacturing processes [3]. It is considered to have high potential also for application in wind turbines.

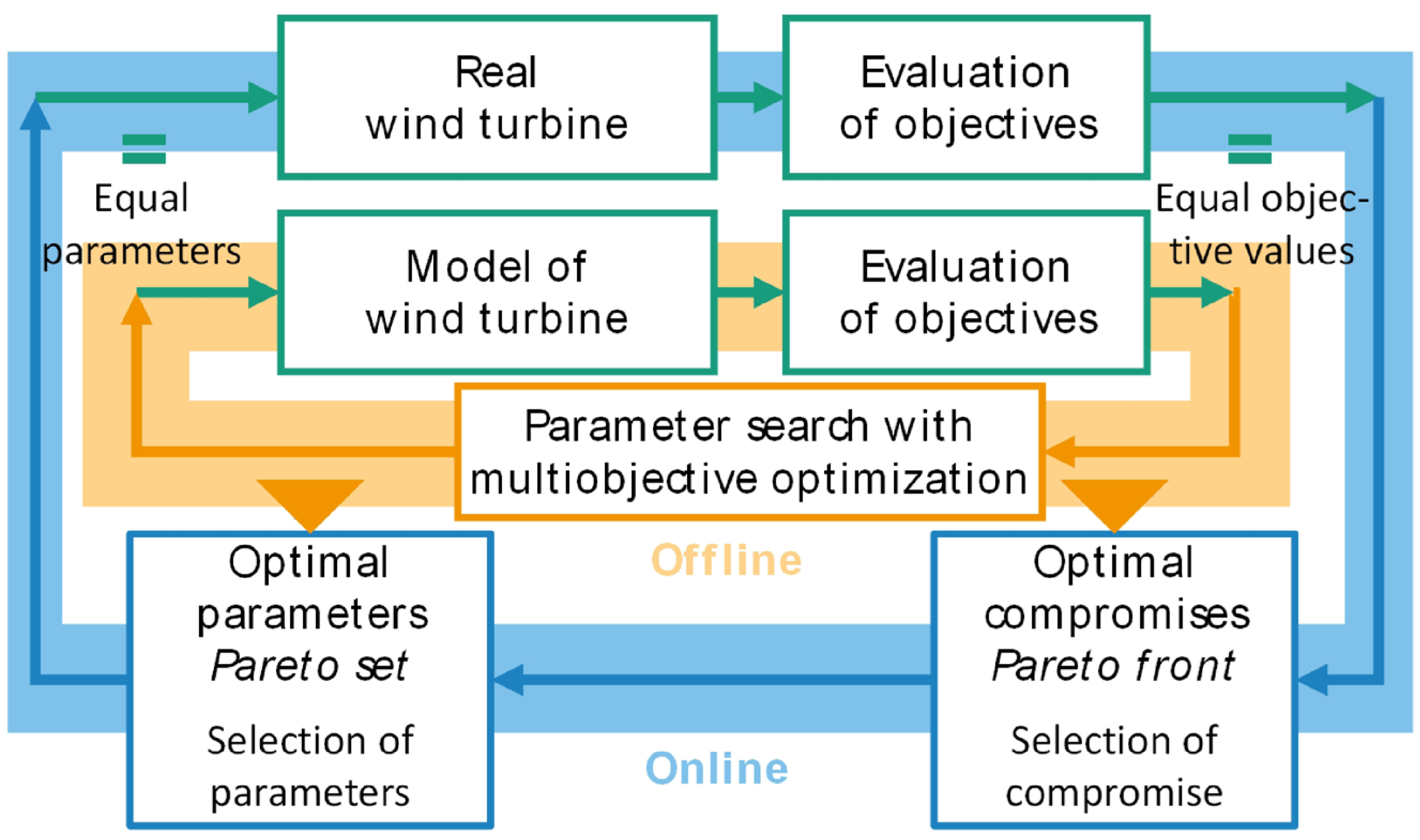

Fig. 2: Numerical multiobjective optimization as basis of behavior adaptation.

Model-based self-optimization is based on a selection among optimal control configurations. Models of turbine or wind park performance, loads and specific component degradation are used. To employ numeric multiobjective optimization algorithms, the models, simulation tools and objective function algorithms are combined into a set of objective functions. The optimization algorithm then optimizes all objective functions by means of parameter adaptation. In wind turbines, power generation is the main performance objective and fatigue damage rate is the main reliability objective. Parameters are e.g. pitch controller parameters or set points such as yaw misalignment angles or reduced power. Commonly, performance and reliability objectives contradict one another and make it impossible to find one single optimum parameter set. Instead, result from multiobjective optimization is a set of all optimal compromises for which an improvement of one objective necessitates impairment of other objectives. For certification, the number of parameter sets can be reduced and each can be certified individually.

Compensation of varying strength

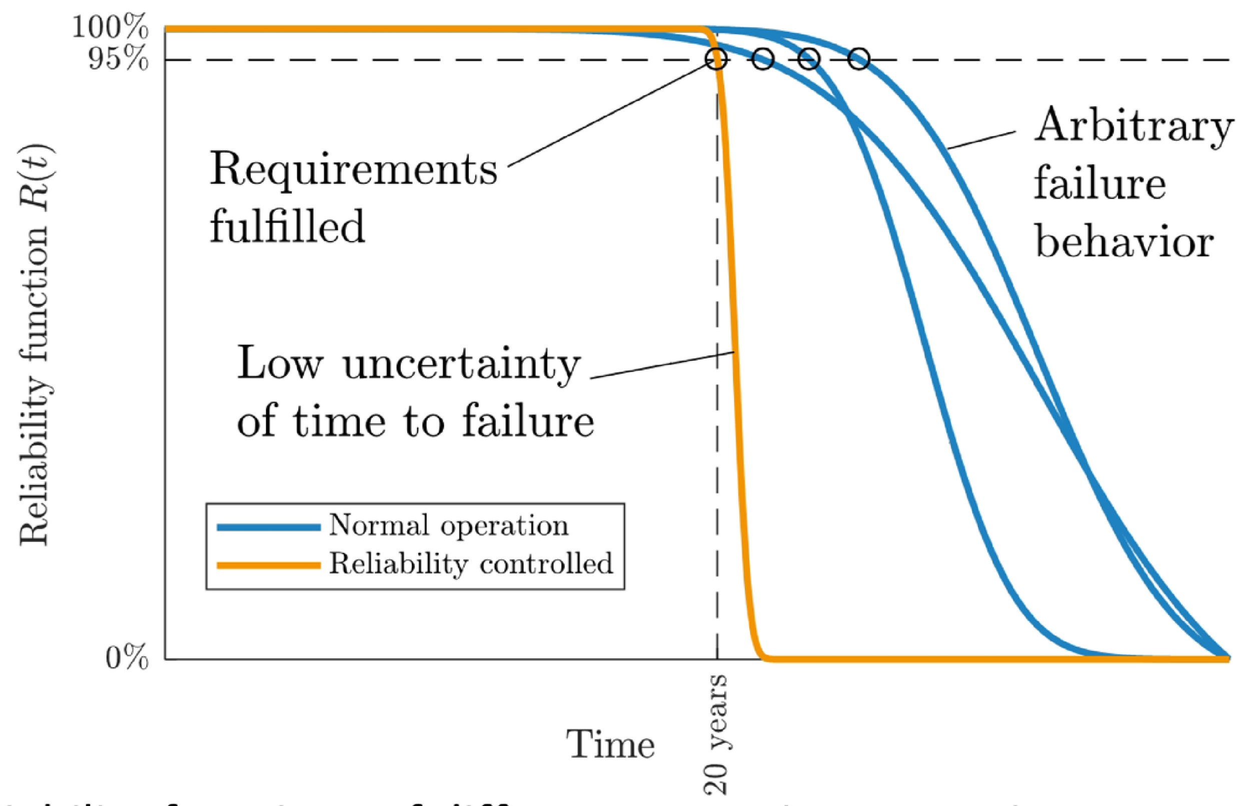

Fig. 3: Reliability functions of different operating strategies.

Figure 3 illustrates reliability functions of wind turbines with different operating strategies. WTs with static control configuration show a large variation in time to failure; to obtain 95% reliability, they have to be designed with a mean time to failure much higher than intended operating time. The higher load bearing capacity of WTs with high strength is wasted. Reliability control increases power output of these systems, which uses up their load bearing capacity faster. Similarly, the time to failure of WTs with low strength is increased by reducing loads. Together, reduced variance in time to failure is achieved. This can be used to plan maintenance close to the actual failure time or to design WTs with reduced safety factors. Resource consumption is reduced both ways.

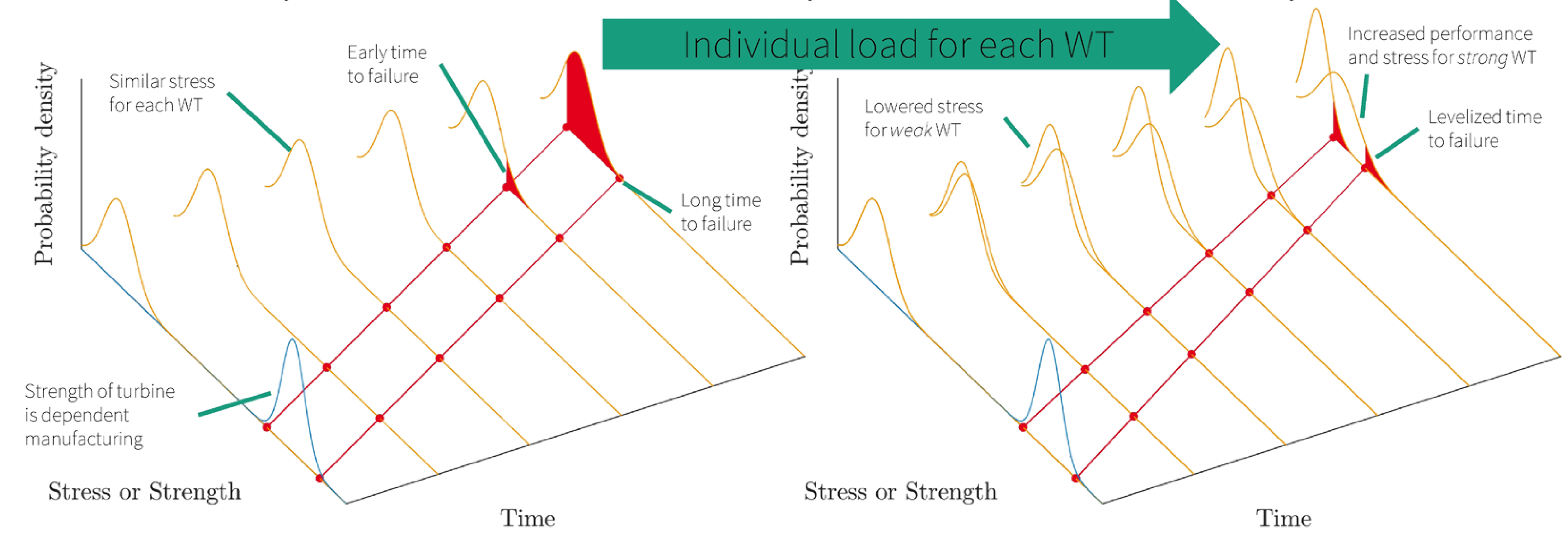

Fig. 4: Load on structurally *weak* WTs is reduced, performance of *strong* WTs is increased. In effect, time to failure is levelized.

Autonomous adaptation to specific site

An individual wind turbine also adapts to site-specific wind loads. This makes it possible to automatically fine-tune system operation of non-site-specific turbines to optimally cope with the wind experienced without specific hardware design. Wind turbines rated higher than actual wind conditions can be used to generate higher revenues with more aggressive power curve and control dynamics. In contrast, if the wind conditions at a specific site threaten to overload the turbine, which would shorten time to failure, reliability control reduces loads. This way, it allows for more flexible deployment of standardized components across different site conditions without increased risk of operation.

Conclusions

The conflict of high reliability and availability, low resource consumption and high performance can only be solved with novel methods for control and operation. Optimization-based reliability control is a very promising method which has shown good results in diverse applications. Its application to wind turbines requires a model of turbine performance and loads and, to allow for continuous control, advanced condition monitoring. With reliability control, time-to-failure of multiple turbines can be levelized or adapted as required for efficient maintenance, but also autonomous adaptation of a single turbine to a specific site becomes possible

References

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