Wind speed estimators: principles and risks for performance monitoring

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Wind speed estimator vs nacelle anemometer

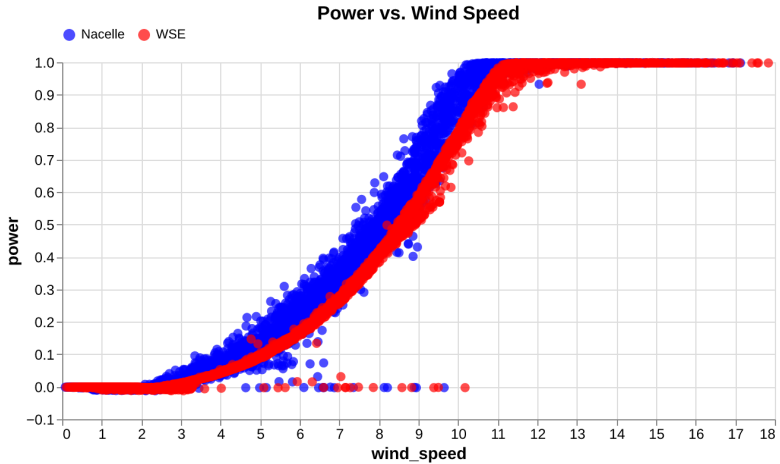
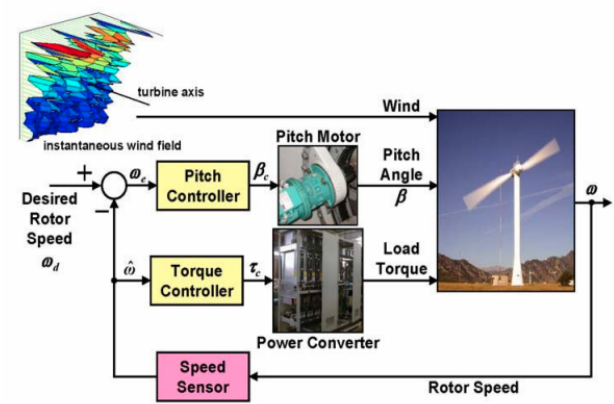


Figure 1: Power vs nacelle wind speed, and vs estimated wind speed

A Wind Turbine Control Block Diagram [1]



[1] Pao, L. Y., & Johnson, K. E. (2009, June). A tutorial on the dynamics and control of wind turbines and wind farms. In 2009 American Control Conference (pp. 2076-2089). IEEE.

Operating regions of a typical wind turbine

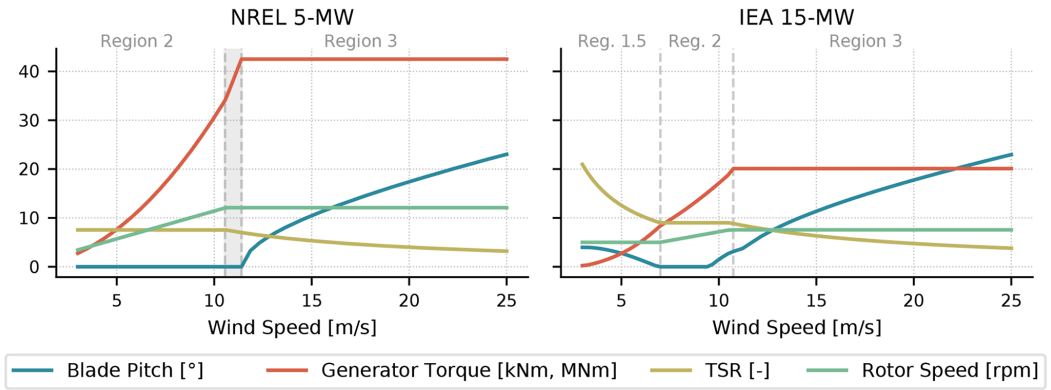


Figure 2: Steady-state operating points [2]

[2]Abbas, N. J. et al. (2022). A reference open-source controller for fixed and floating offshore wind turbines.

Benefits for wind turbine control

Tipspeed

Variable speed operation (region 2)

Goal
Maximize power extraction

How
Maintain the tipspeed ratio close to its optimal constant (i.e., rotor speed proportional to wind speed)

Action
Use generator torque demand to control rotor speed

Benefit of WSE
Estimating wind speed and its rate of change helps track the tipspeed ratio effectively

Benefits for wind turbine control

Tipspeed

Above rated operation (region 3)

Goal
Maintain power constant while minimizing loads

How
Maintain rotor speed and torque as steady as possible

Action
Use pitch angle to control aerodynamic torque

Benefit of WSE
Estimating wind speed and its rate of change allows optimizing the pitch angle to maintain rotor speed and torque constant

Principles to derive the estimated wind speed

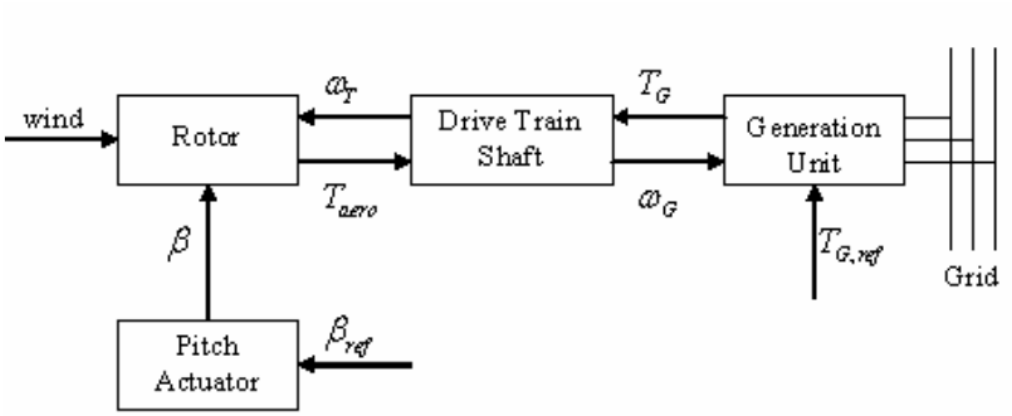


Figure 3: Wind Energy Conversion System Structure [3]

[3]Lescher, F., Zhao, J. Y., & Borne, P. (2005). Robust gain scheduling controller for pitch regulated variable speed wind turbine. Studies in Informatics and control, 14(4), 299.

Principles to derive the estimated wind speed

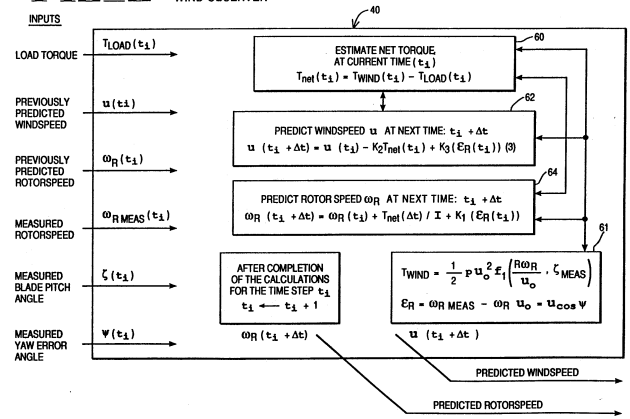
Tipspeed

- Rotor speed and aerodynamic torque are estimated by a combined state and input observer
- These two variables combined with the measured pitch angle are then used to calculate the effective wind speed by an inversion of a static aerodynamic model [4]

[4] Østergaard, K. Z., Brath, P., & Stoustrup, J. (2007, July). Estimation of effective wind speed. In Journal of Physics: Conference Series (Vol. 75, No. 1, p. 012082). IOP Publishing.

Details from a pioneering patent

FIG_3 WIND OBSERVER



Key issue for power performance monitoring

Tipspeed

- The aerodynamic model used to derive the estimated wind speed is simplified
- It does not account for fine changes in the turbine aerodynamics, such as those caused by blade fouling, icing, or other degradation mechanisms
- When the aerodynamics of the turbine degrades, the model is not aware
- The turbine then tends to estimate a lower wind speed, to explain a lower power

Nacelle anemometers vs rotor estimated wind speed

Tipspeed

- Rotor estimated wind speed was developed to be used in the control system, not for performance monitoring
- Current wind speed estimators are such that they more or less lead to the same power curve, irrespectively of performance degradation
- Nacelle anemometers also have their own issues...