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ENERGY

Identification of ice build-up and corresponding control optimisation

Winterwind 2017

Skellefteå, Sweden

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- Brief background on ice build-up effect on rotor aerodynamics
- Ice detection and mitigation procedures
- Comparison of strategy with field data

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Motivation

Problem:

In cold weather, wind turbines' blades are exposed to the following:

- Ice adds mass and changes the aerodynamic structure
- Increased mass modifies the structural frequencies and introduces imbalances, both of which increase structural loads.
- Ice degrades the aerodynamic performance and shortens turbines' working life
- Reduced aerodynamic performance impacts the power capture and risks stall

Motivation

Current solutions:

Traditionally, ice detection methods are split into three categories:

- Use of meteorological observing systems
- External monitoring systems
- SCADA based systems

Once ice accretion is detected or assumed, thermal solutions or intermittent operation of wind turbines are common fixes in the industry.

However, they either raise the capital cost of the turbine or reduce the turbine capacity factor when numerous shutdowns occur.

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Motivation

Proposed solution:

Detect ice on blades based on signals from sensors that are already typically available to the turbine controller:

- nacelle anemometer and accelerometers
- generator speed and torque sensors
- blade root or tower mounted strain gauges
- pitch angles sensors

These signals are not available to SCADA systems at the required sample rates for control purposes.

The proposed system identifies the most likely icing state and then selects the most suitable controller to deal with ice build-up.

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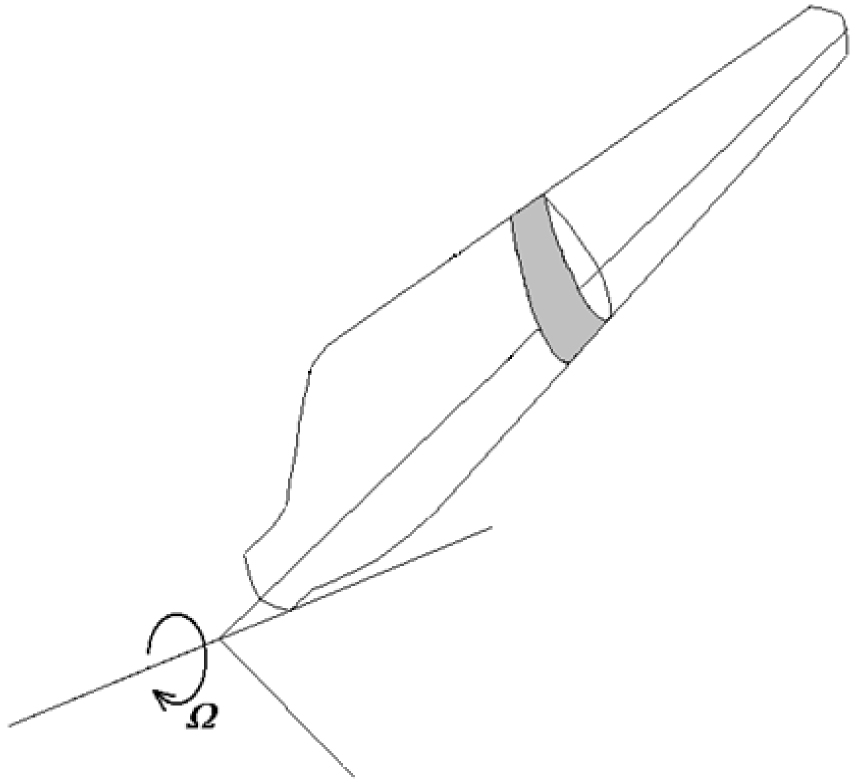
Background - Blade aerodynamics

Modelling wind turbines with ice on the blades requires to consider the effects with respect to power curve and loads.

The aerodynamic performance of the rotor blades is compromised since the lift coefficient, C_L, of the aerofoils decreases, while the drag coefficient, C_D, increases.



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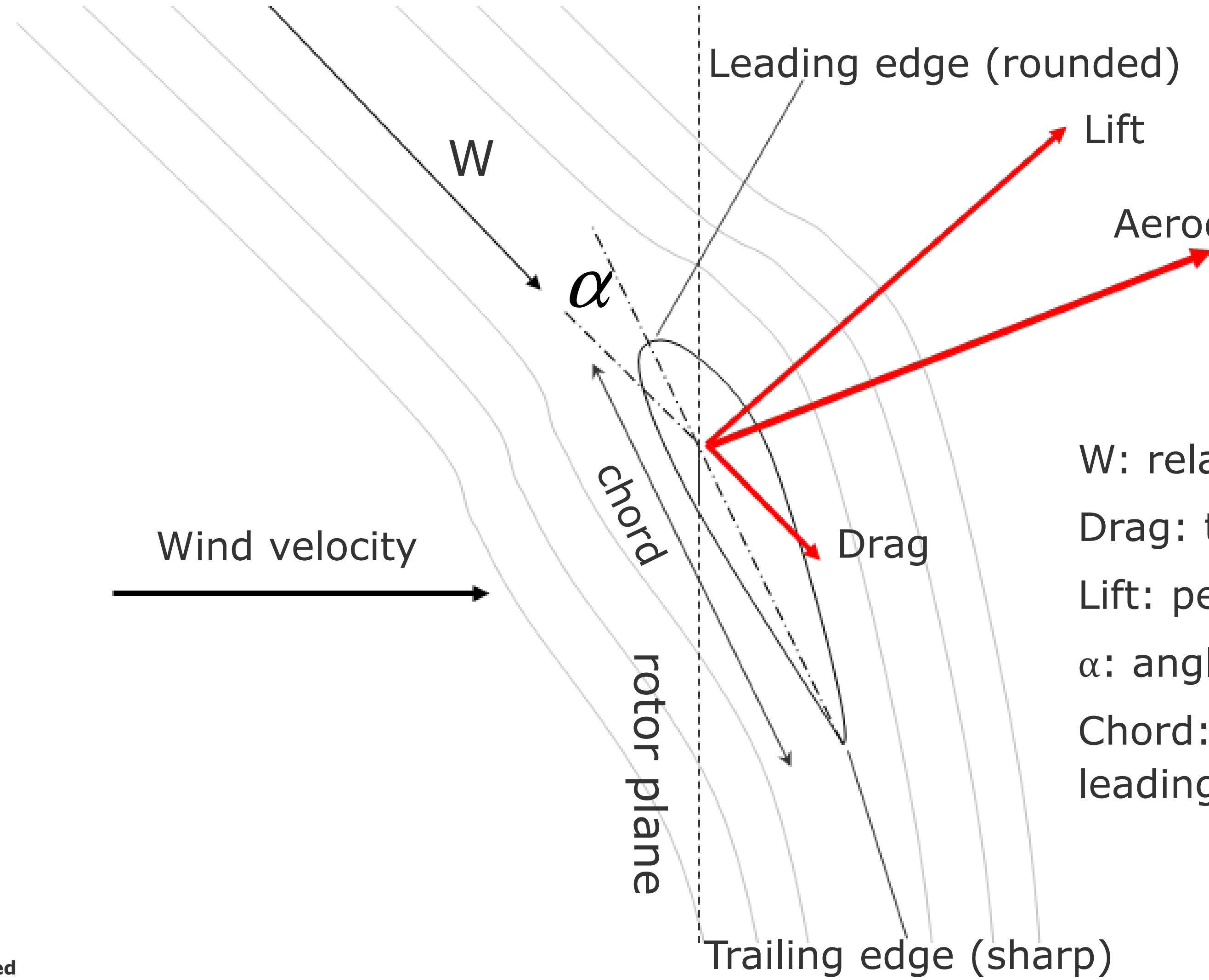
Background - Blade aerodynamics



W: relative inflow velocity

Drag: tangential to flow

Lift: perpendicular to flow

α: angle of attack

Chord: distance between leading and trailing edges

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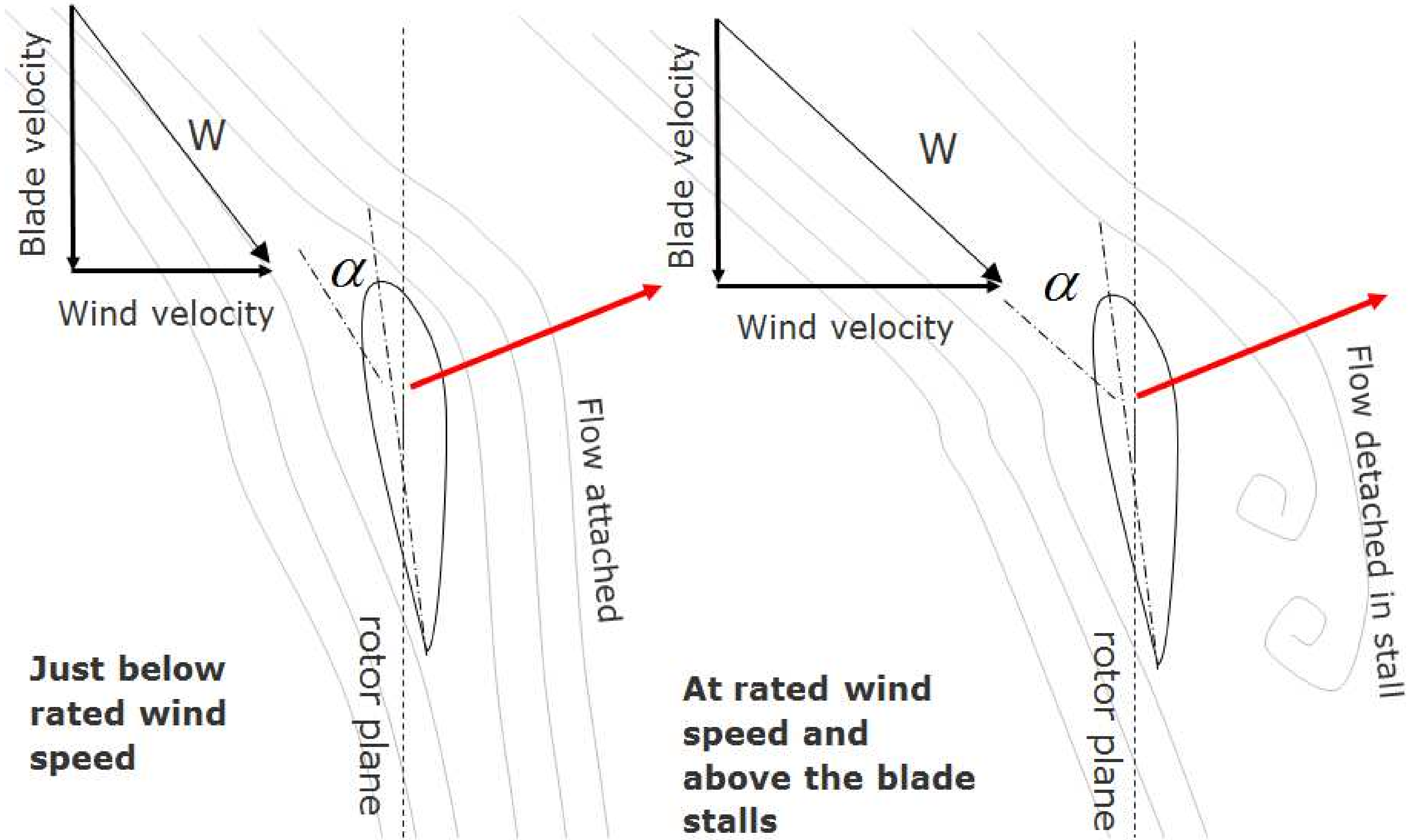
Background - Stalling



Just below rated wind speed

At rated wind speed and above the blade stalls

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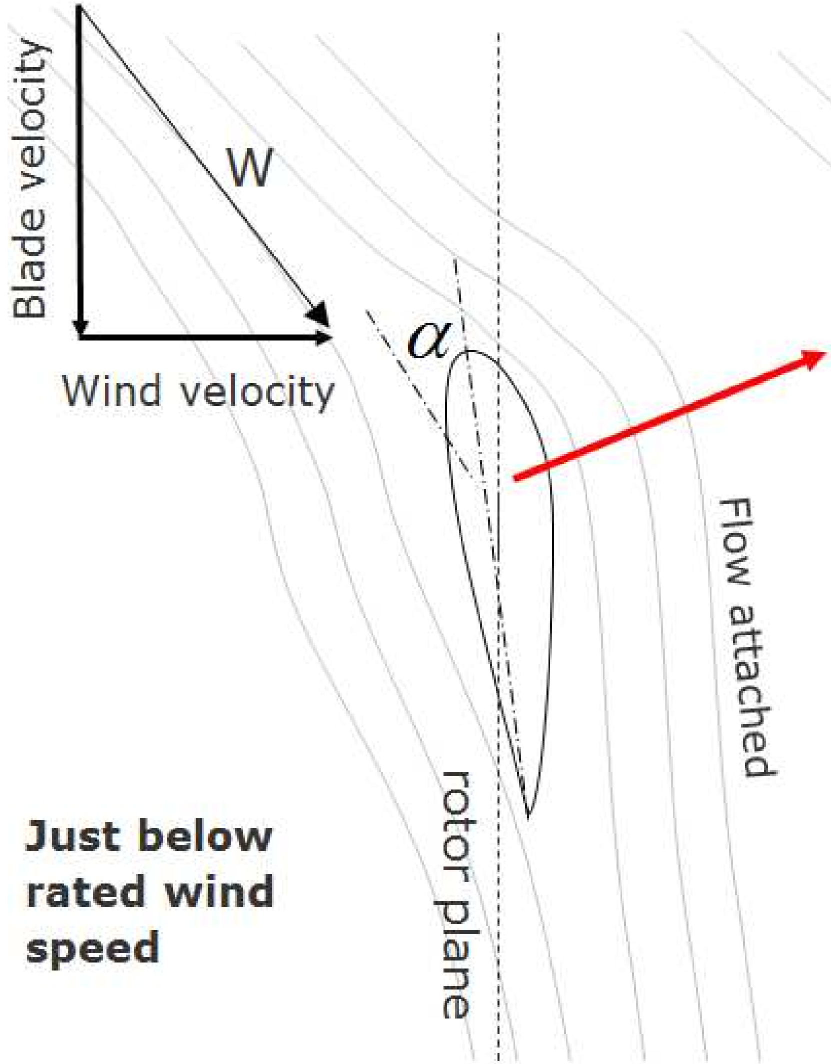
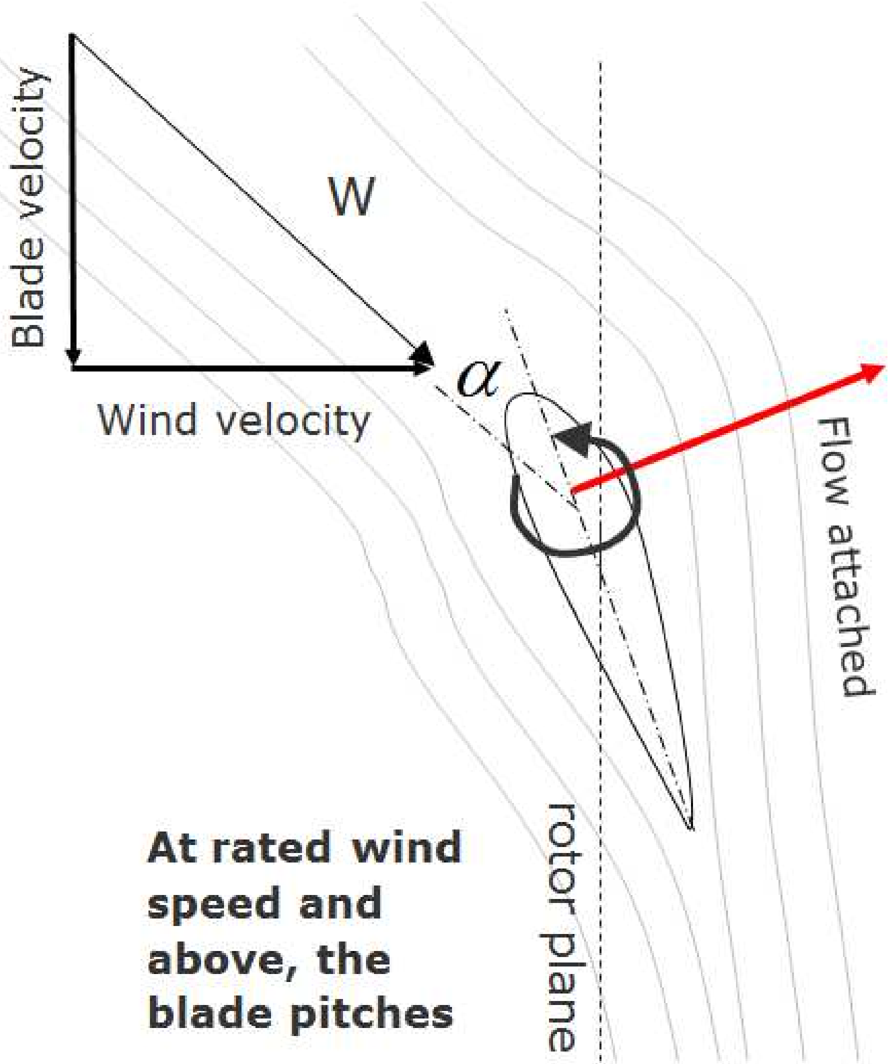
Background - Pitch regulation





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Effect of ice accretion on blades - penalty factors to aerofoils

In order to account for the variations in the aerofoil performance, the following procedure for modifying the static aerofoil characteristics is used.

Aerofoil penalty factors are multiplied to clean aerofoil lift (C_L) and drag (C_D) coefficients for angles of attack from -2° to 14°.

The penalties for both lift and drag coefficients curves are a function of aerofoil angle of attack, α, as follows:

$$C_{L,PF}(\alpha) = -A\alpha^2 - B\alpha + C$$

$$C_{D,PF}(\alpha) = D\alpha + E$$

where

$C_{L,PF}(\alpha) =$ lift coefficient penalty factor

$C_{D,PF}(\alpha) =$ drag coefficient penalty factor

$\alpha =$ Angle of attack

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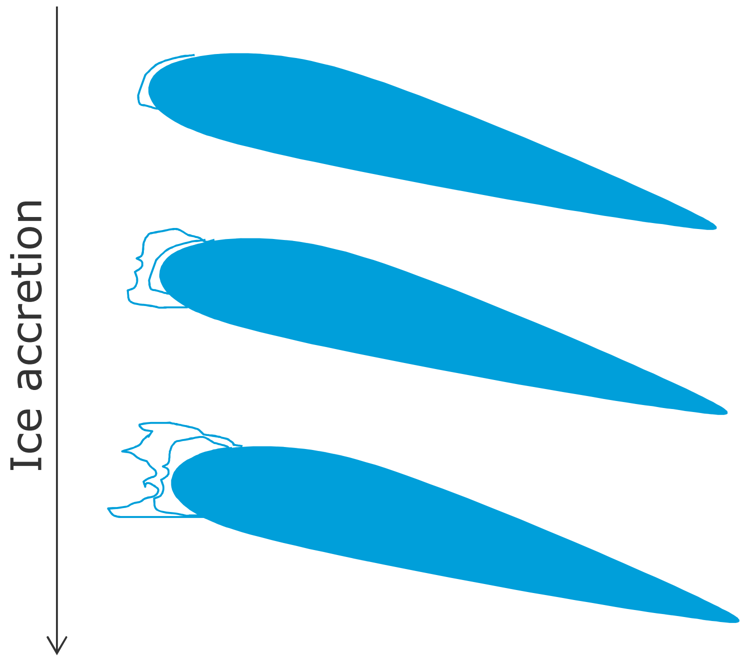
Effect of ice accretion on blades - penalty factors to aerofoils

The coefficients A to D vary depending on the amount of ice modelled.



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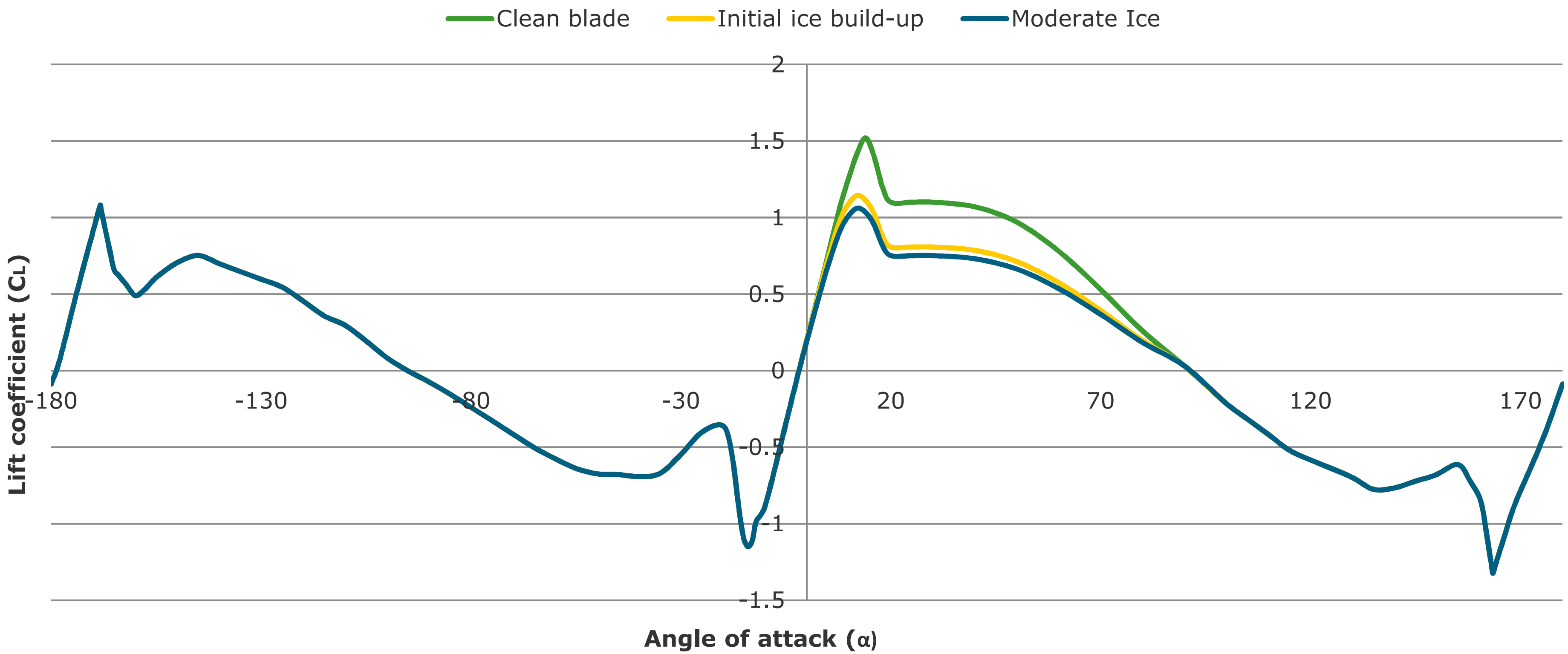
Influence of the blade icing on the aerodynamic performance of the profiles



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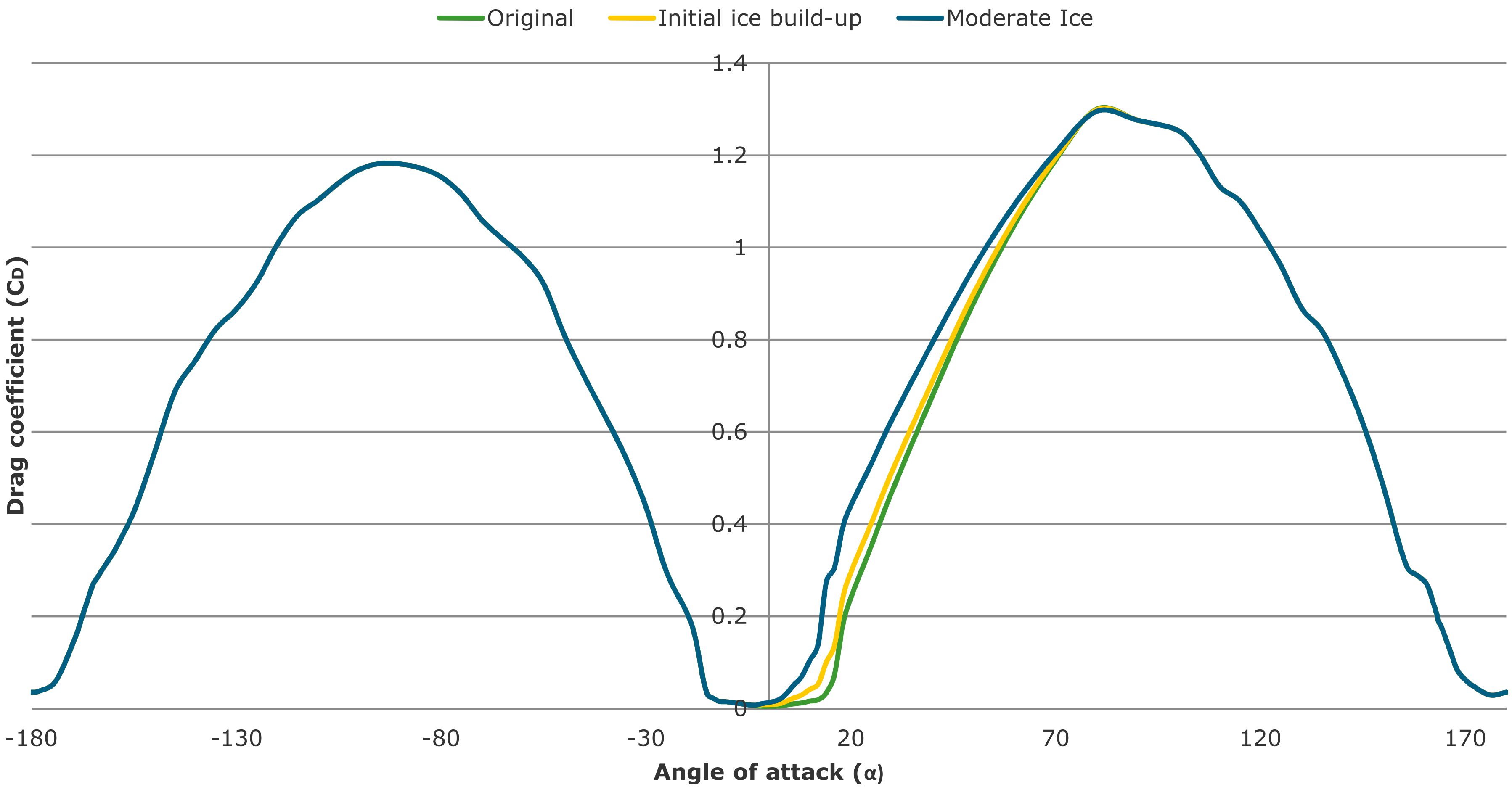
Influence of the blade icing on the aerodynamic performance of the profiles



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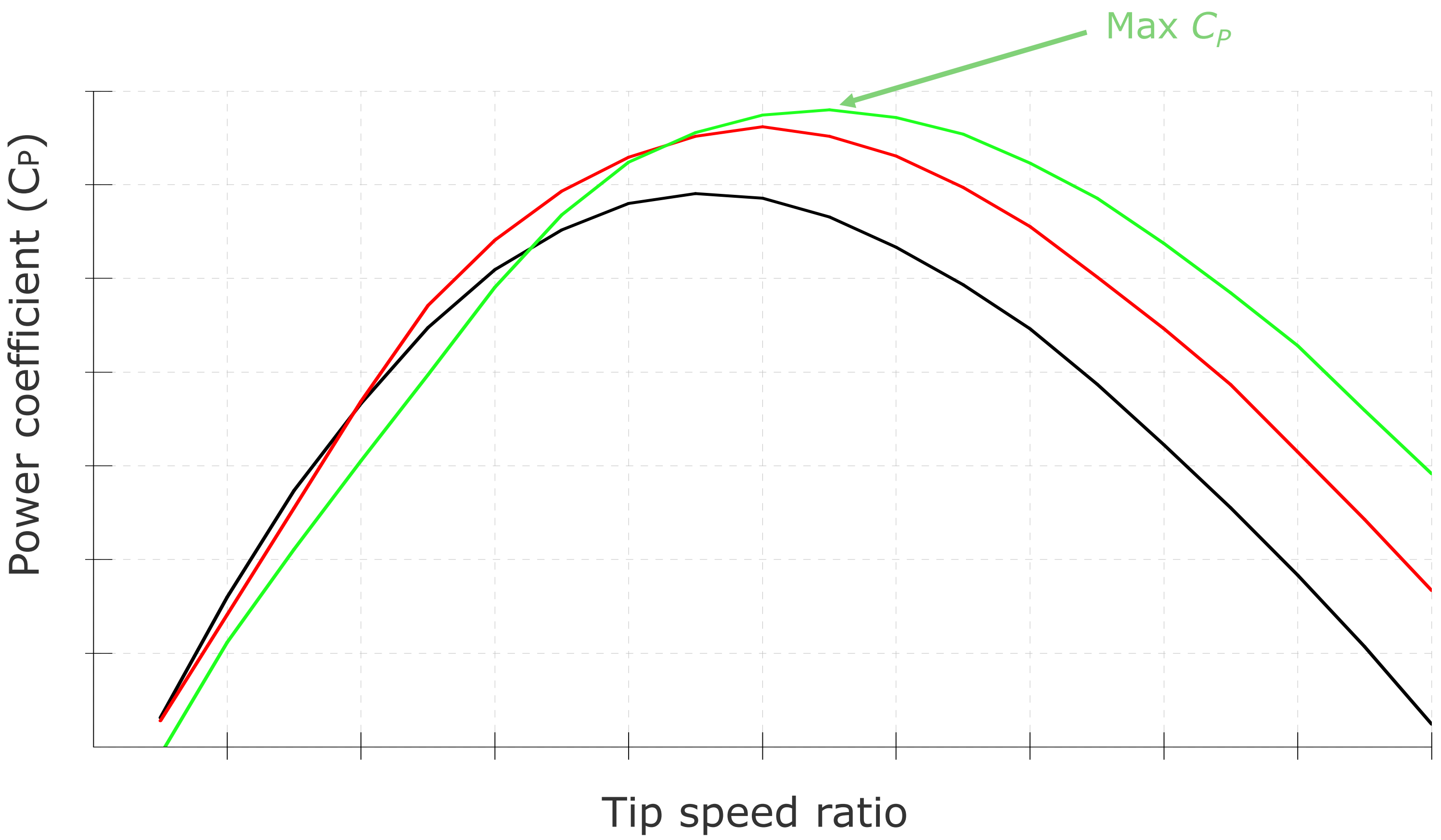
Power coefficient

$$P = \frac{1}{2}\rho A C_P U^3$$

C_P depends on the pitch angle and on the tip speed ratio



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Optimal mode gain

- $\lambda = \frac{\omega_r R}{U} = \frac{\omega_g R}{GU}$
- $U = \frac{\omega_g R}{G\lambda}$
- $P = \frac{1}{2}\rho A C_P U^3 = \frac{1}{2}\rho\pi R^2 C_P \left(\frac{\omega_g R}{G\lambda}\right)^3 = \frac{\rho\pi C_P R^5 \omega_g^3}{2\mathrm{G}^3\lambda^3}$
- $Q_d = \frac{P}{\omega_g} = \boxed{\frac{\rho\pi C_P R^5}{2\mathrm{G}^3\lambda^3}}\omega_g^2 = K_{opt}\omega_g^2$

λ	tip speed ratio
U	wind speed
R	rotor radius
ω_g	generator speed
G	gearbox ratio
P	power
C_P	power coefficient
ρ	air density
A	rotor area
Q_d	generator torque
K_{opt}	optimal mode gain

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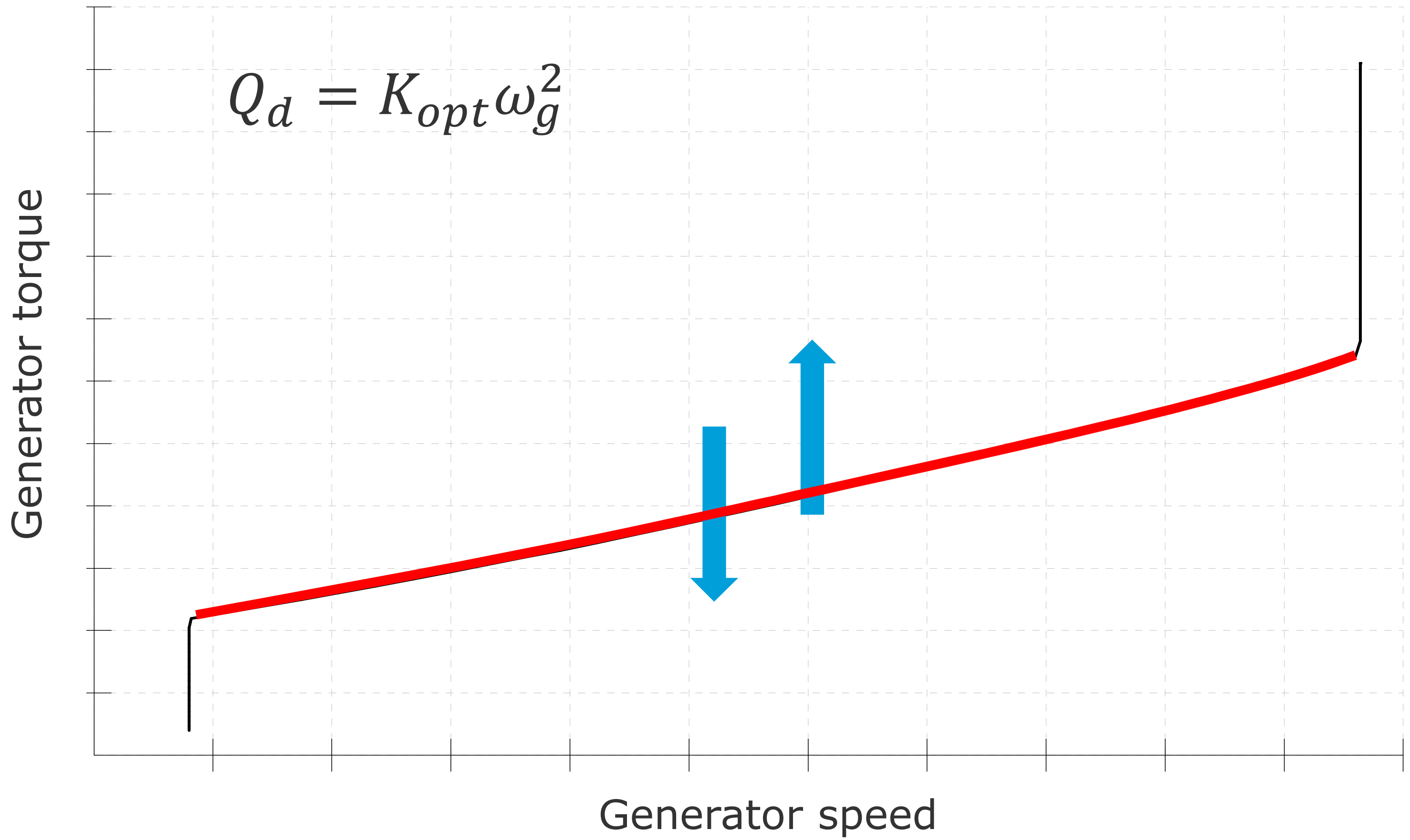
Steady-state torque-speed operating curve



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Ice detection procedure - Offline

1. Run simulations under normal conditions.

2. Learn the relationship from rotor speed, generator speed and wind speed to rotor acceleration.

3. Store the relationship as a look-up table.

Repeat process for different ice models.

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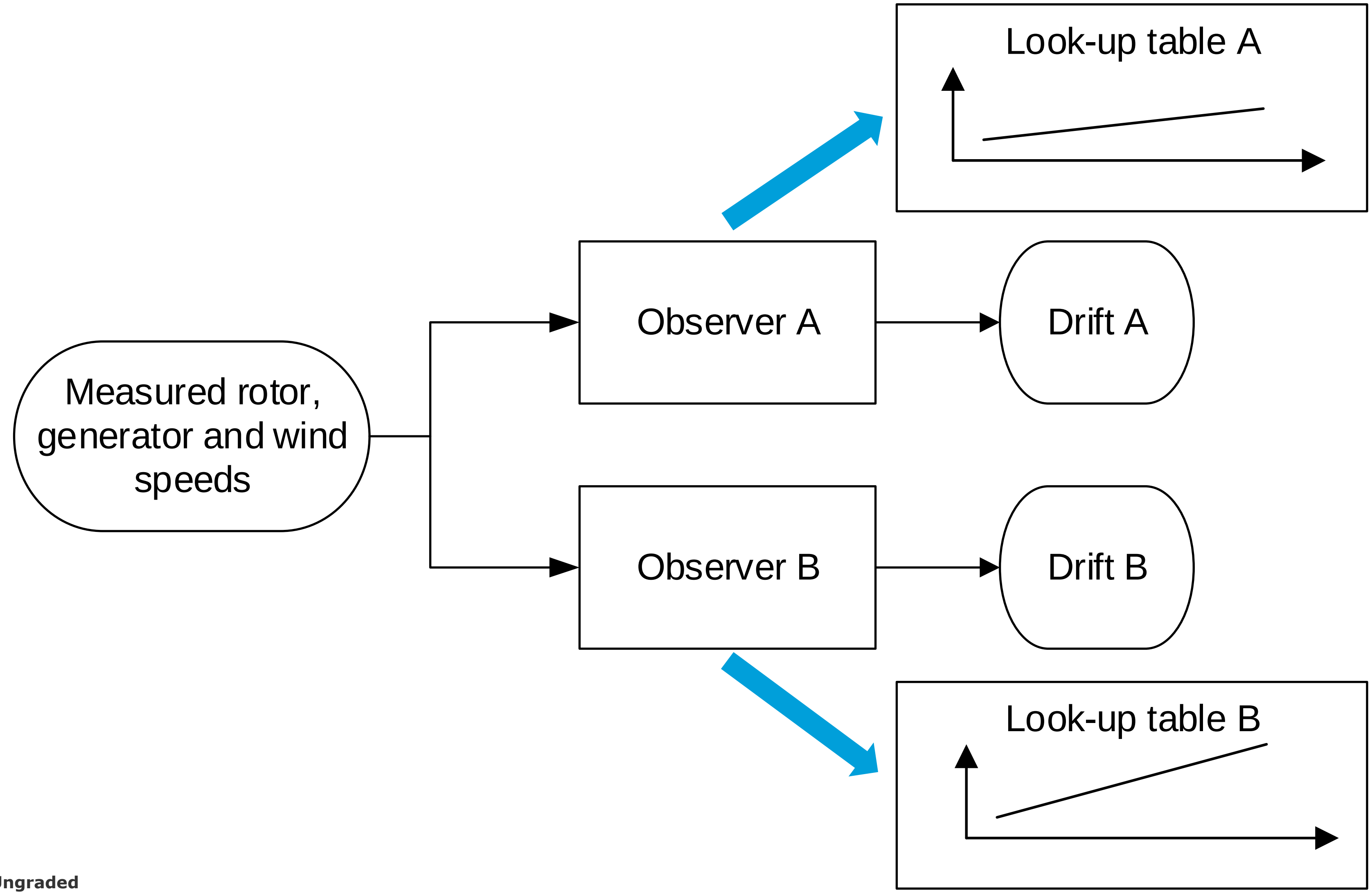
Ice detection procedure - Online



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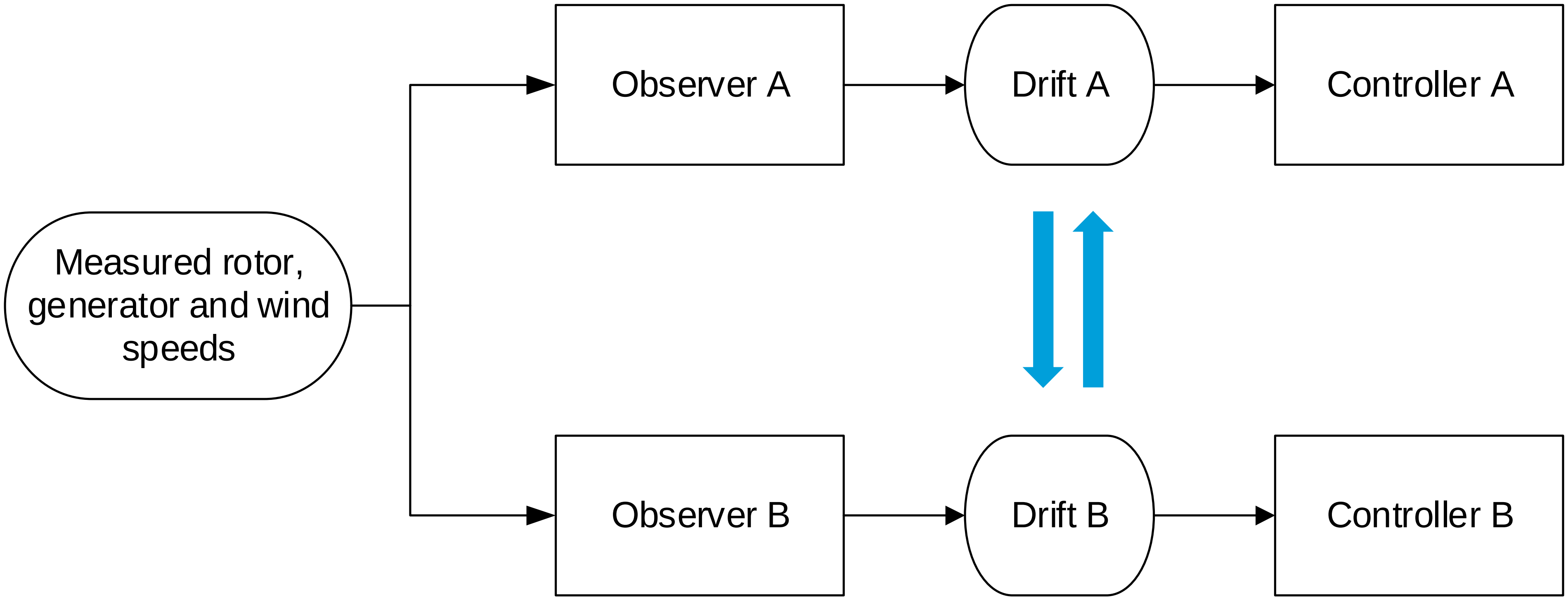
Ice detection procedure - Online



A catalogue of iced turbine models and corresponding controllers exist.

The observers work out the drift produced between the estimated data and the measured one.

Where the controller to be used is the one that corresponds to the smallest drift.

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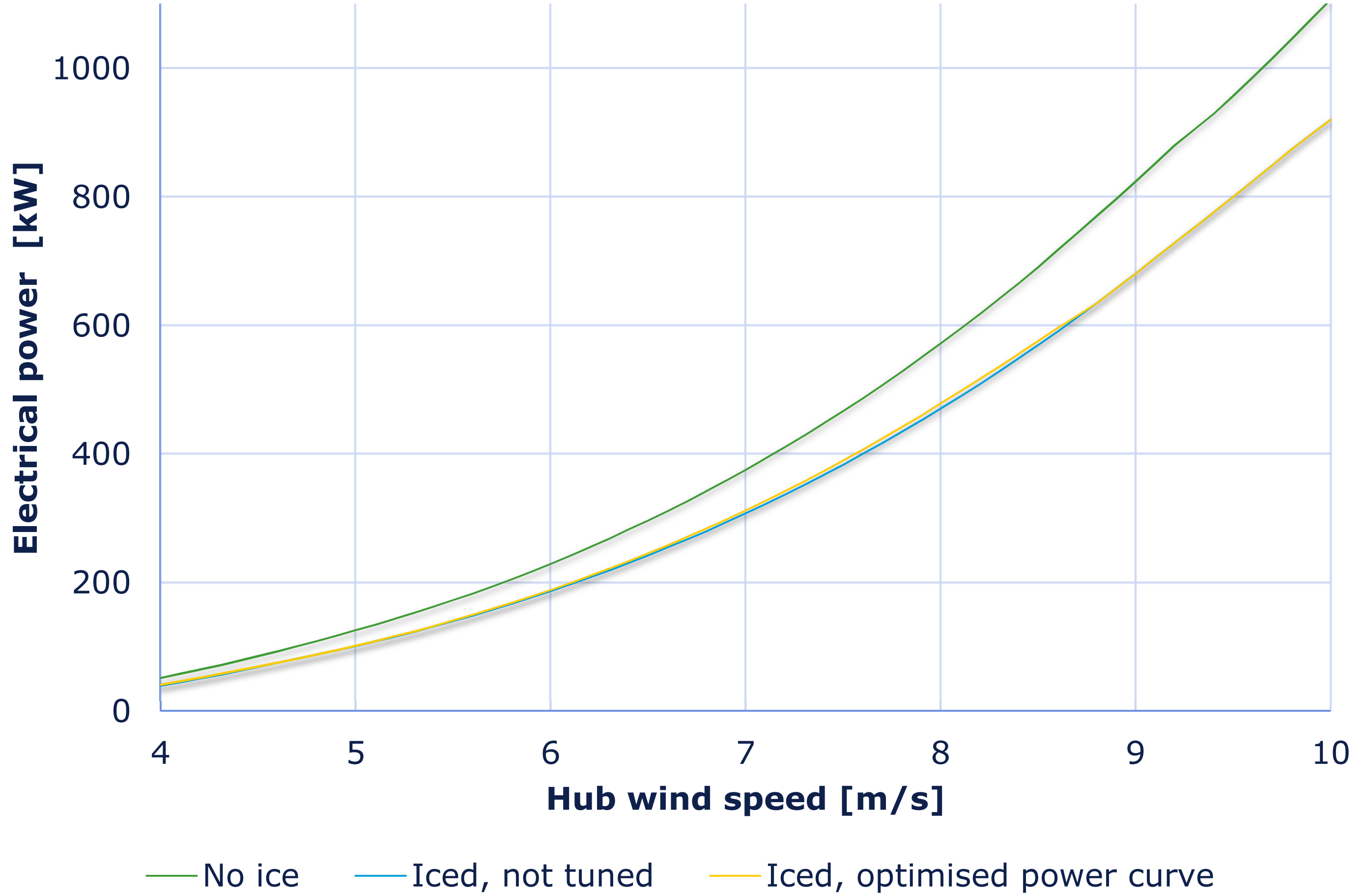
Simulated power curves

Generic 2MW 3-blade wind turbine, 75m rotor diameter, 63.125m tower height

Addition of 2kg of ice per blade



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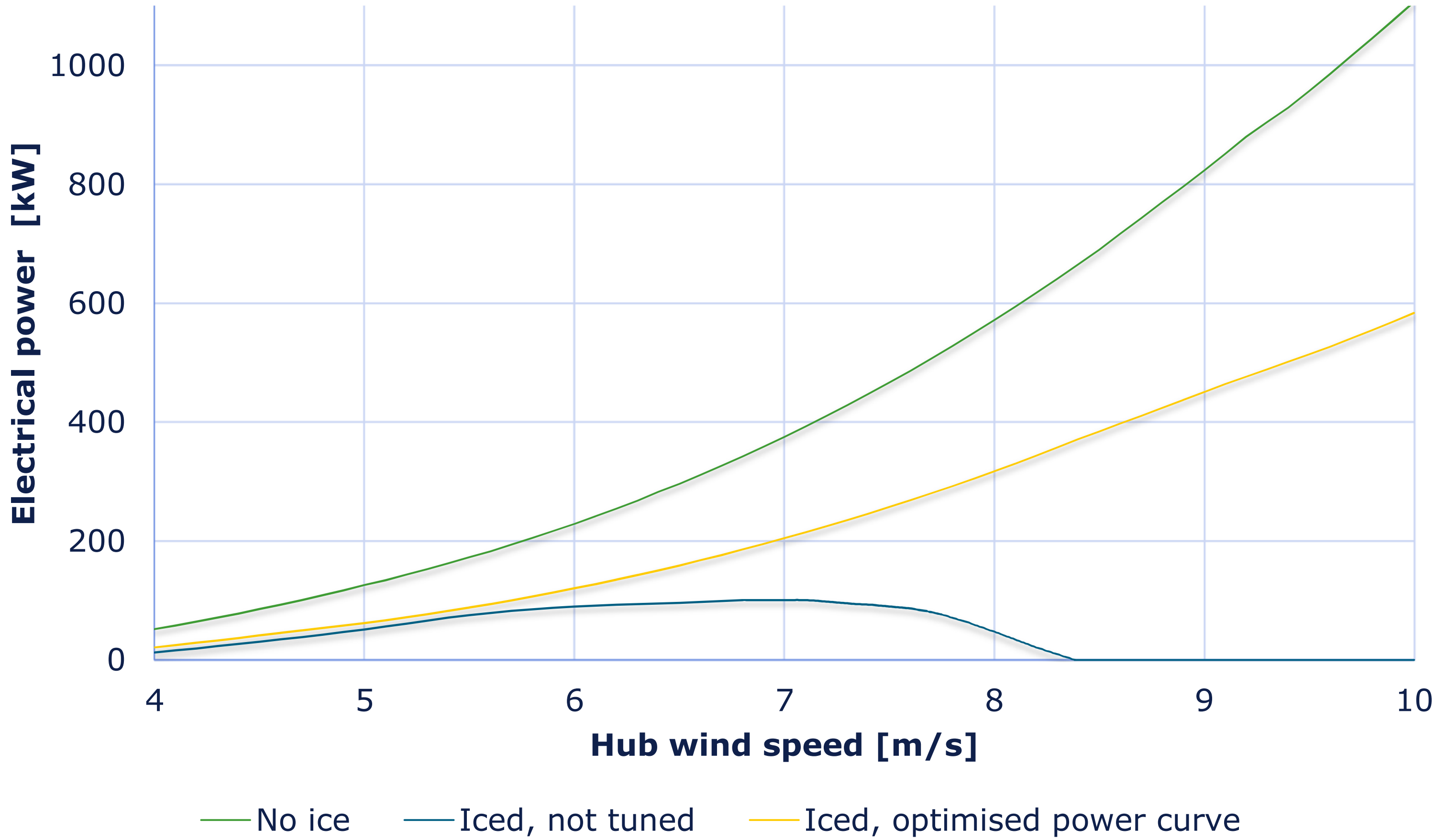
Simulated power curves

Generic 2MW 3-blade wind turbine, 75m rotor diameter, 63.125m tower height

Addition of 112kg of ice per blade



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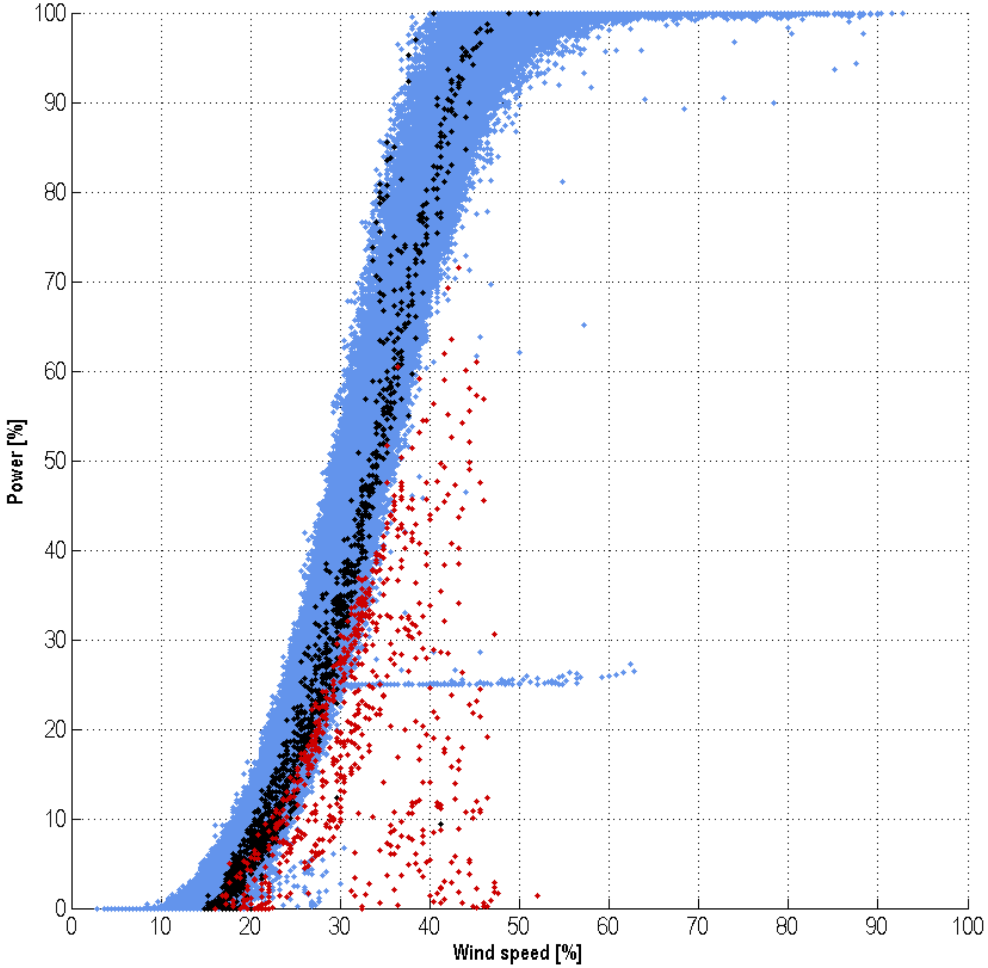
Collected data from the wind farms

Normal operation vs. operation during winter



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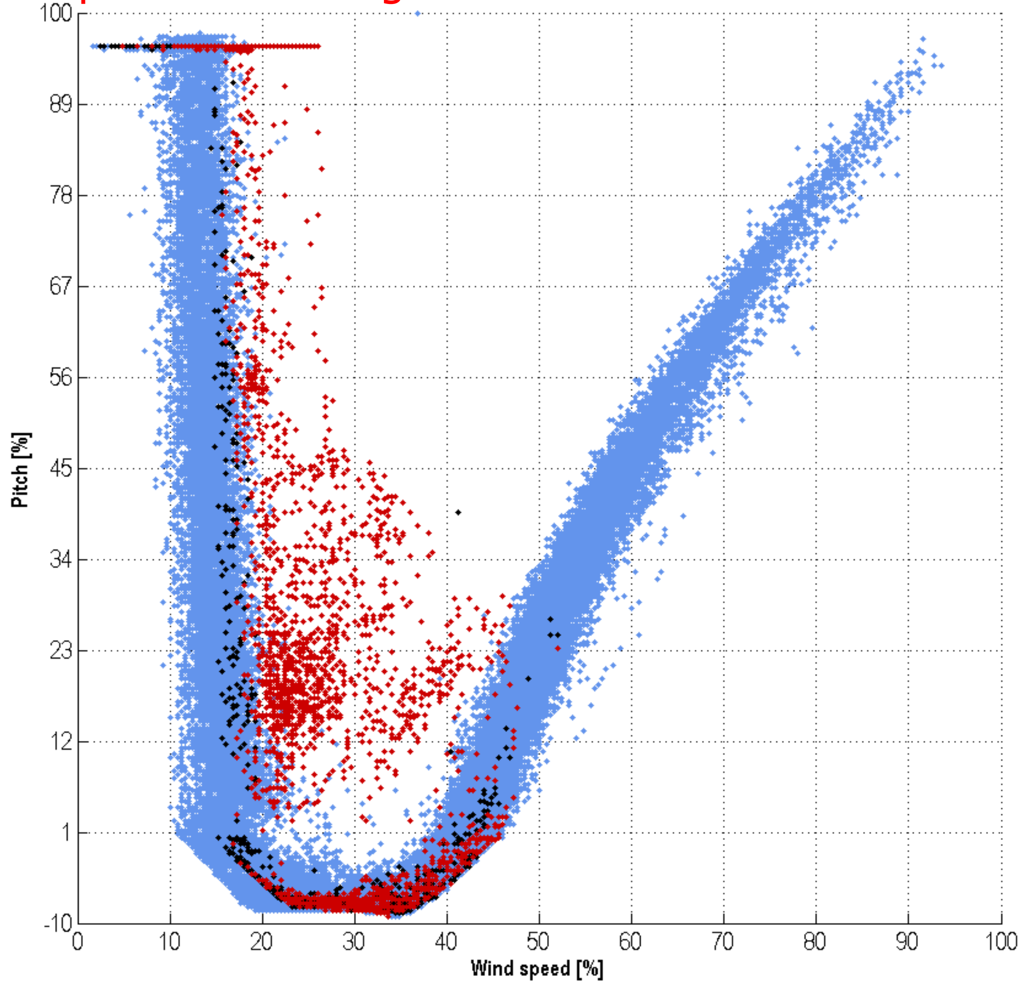

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Collected data from the wind farms

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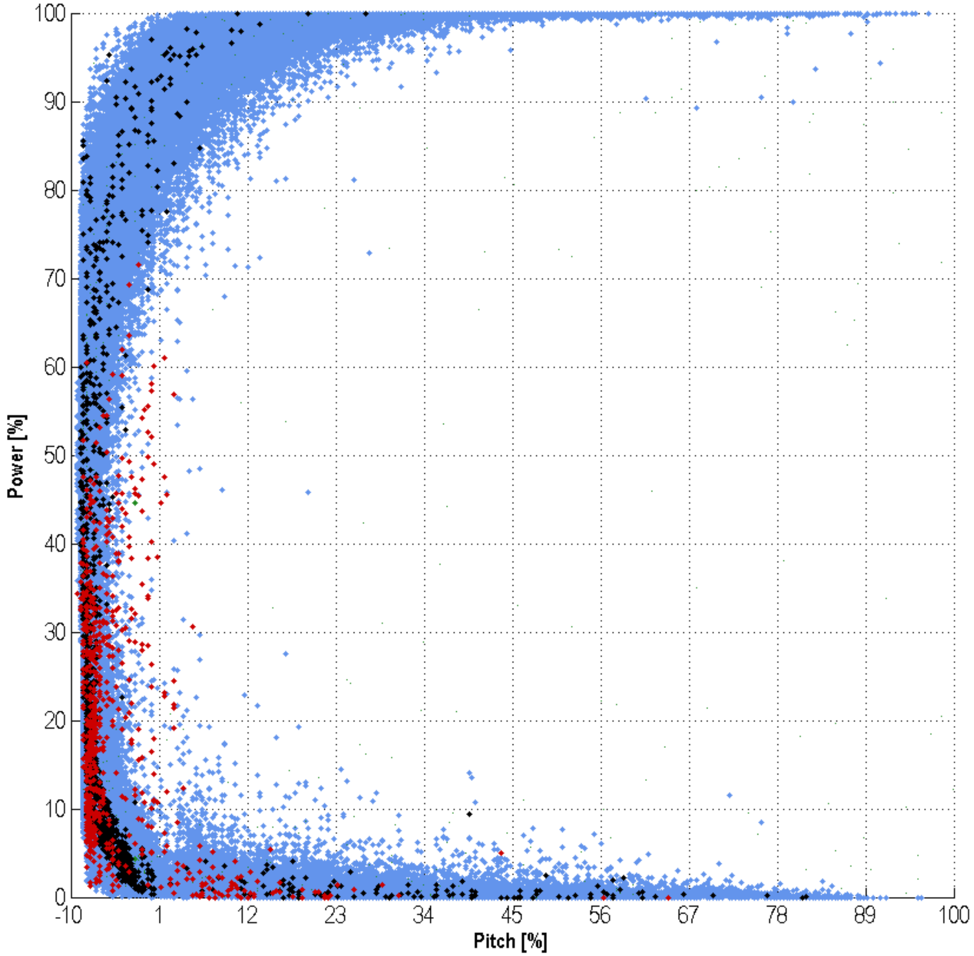

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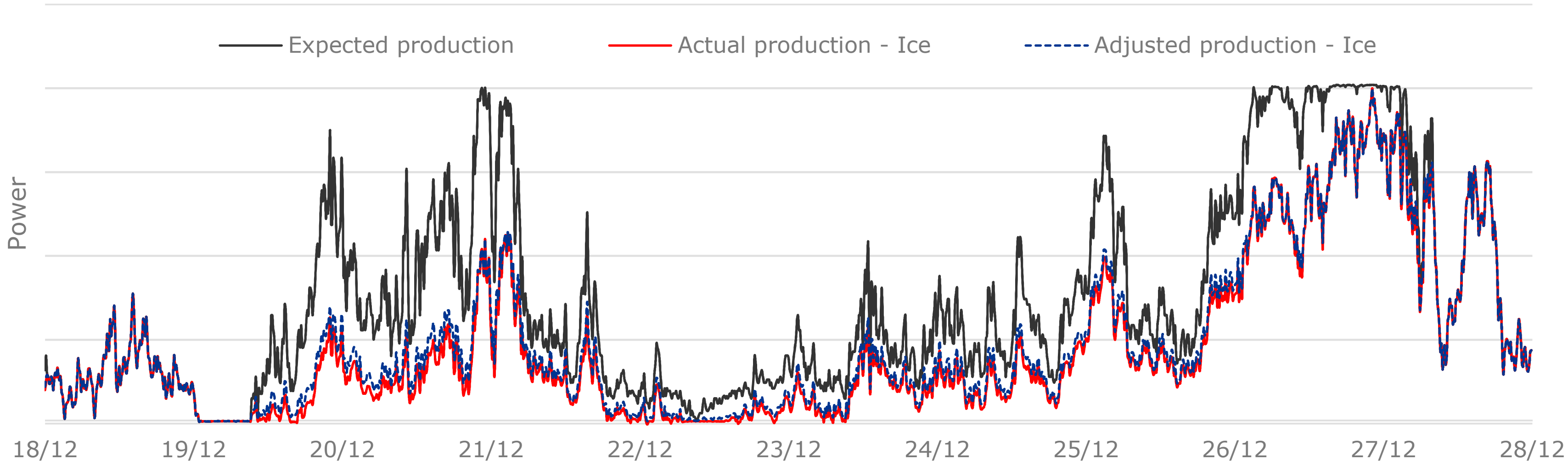
Ice detection and its mitigation: Impact on power production

- Operational data reviewed for 3 projects with a range of production loss due to icing (high, medium and low).
- For each record where icing detected:
  1. Actual icing loss = Actual production - Expected production
  2. Adjusted production = Actual production * difference between Optimised and Non-optimised power curves
  3. Adjusted icing loss = Adjusted production - Expected production
  4. Impact = Actual icing loss – Adjusted icing loss
- Actual production assumed to be representative of the non-optimised power curve.



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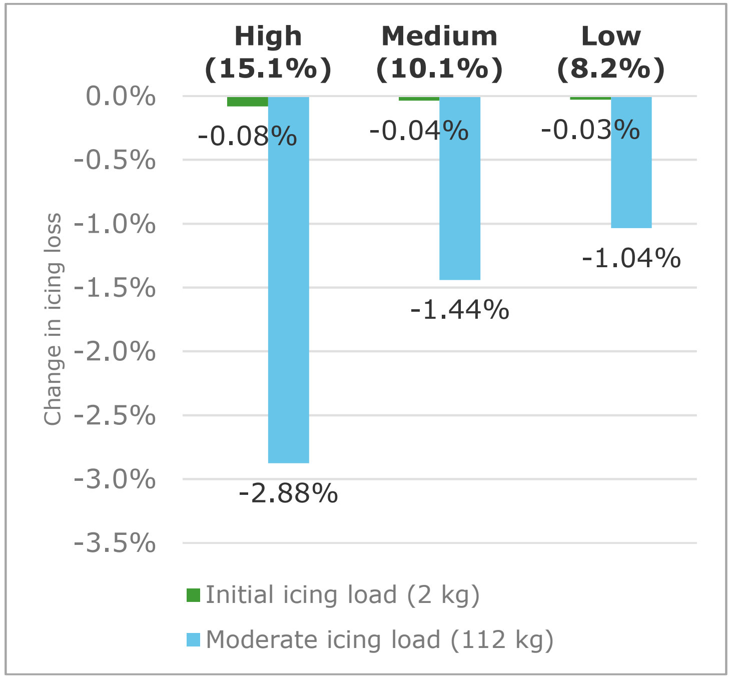
Ice detection and its mitigation: Impact on power production

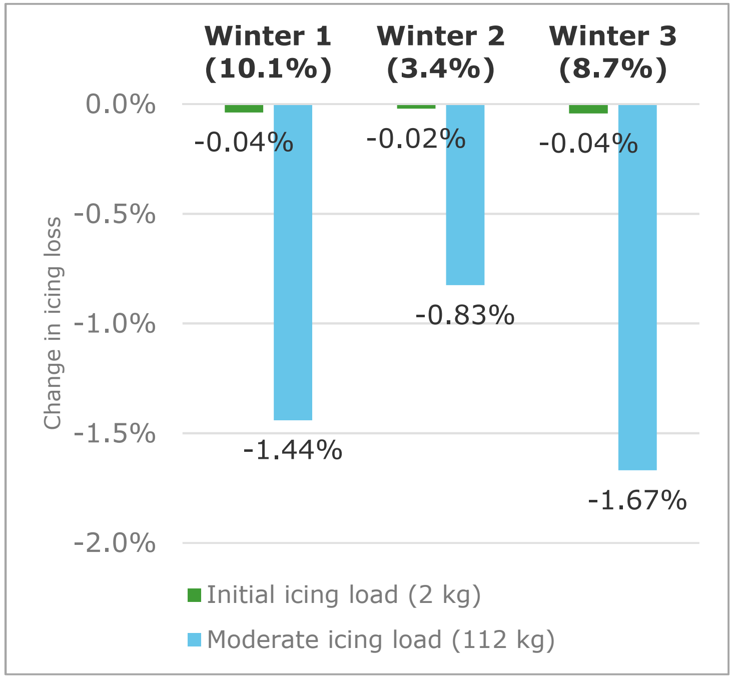
- Impact of optimised power curve reviewed against non-optimised power curve for two cases:
  - Initial icing load (2 kg added mass per blade)
  - Moderate icing load (112 kg added mass per blade)

Site



Largest reduction seen for high icing loss site and higher icing load.

Winter



Reduction in icing loss for a single project varies by year

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Conclusions

- A method for detecting ice accrued on blades from signals that are commonly used wind turbine controllers has been proposed.

- A mitigation to ice build-up on blades has been presented for increasing the energy capture.

- Measured field data has been used for estimating the increase in power production when the method is applied.

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Thank you!

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