Wind turbine types; stall, pitch and variable speed

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The following text focuses on explaining different ways of controlling the output of a wind turbine, both with respect to reducing the power output at high wind speeds and by ensuring a more smooth time history of the power and loads. Roughly the controls are characterized by:

Pitch regulation

Stall regulation

Variable speed machines

For better understanding of the various methods for control the text starts with a small general introduction to wind turbines.

A wind turbine extracts kinetic energy from the wind first into mechanical shaft power and eventually using a generator into electrical power. Assuming no losses and that the velocity is constant and posses no rotation at the outlet of the control volume drawn in Figure 1 the conservation of energy becomes:

$$P = \dot{m}(V_o^2 - u_1^2) = \rho u A(V_o^2 - u_1^2)\,, \qquad (1)$$

where P is the mechanical power, V_o the wind speed, ρ the air density, A the rotor diameter, u is the velocity at the rotor plane and u_1 is the velocity in the far wake. Note that the lateral boundary of the control volume follows the streamlines.

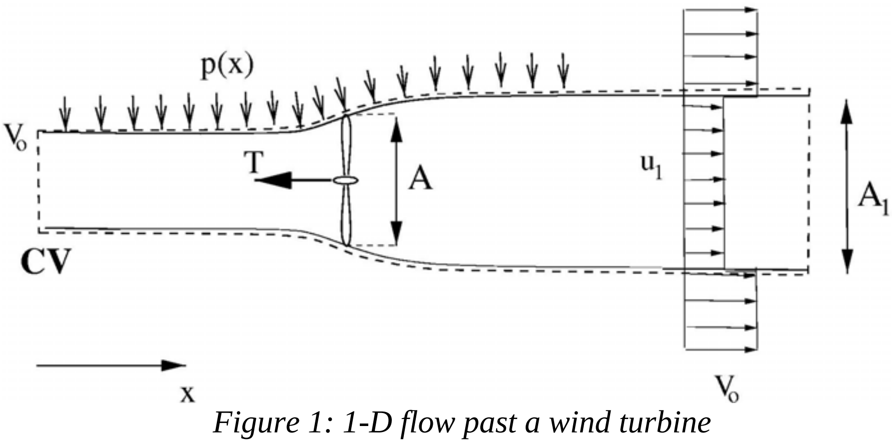

Figure 1: 1-D flow past a wind turbine

In order to extract power the wind speed must be slowed down from V_o to u_1. This requires a force in the opposite direction of the wind speed, and is denoted the thrust, *T*, and stems from a pressure difference over the rotor Δp:

$$T = A \cdot \Delta p \qquad (2)$$

This pressure difference is produced by a number of rotating blades, where the cross section is shaped as an airfoil with the pressure side facing the wind, see Figure 2.

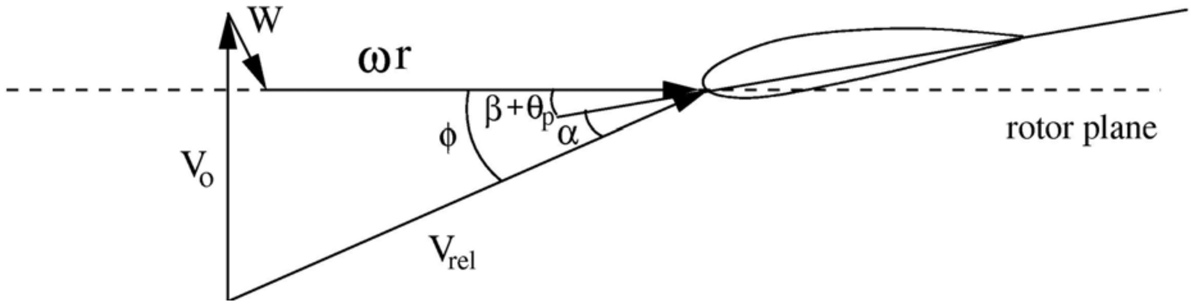

Figure 2: Flow around section of a wind turbine blade

Figure 2 also shows how the relative velocity, $\mathbf{V}_{rel}$, can be constructed from the wind speed, $\mathbf{V_o}$, the rotational, $\omega \cdot r$ speed and the induced velocity **W**. The induced velocity is the result of the influence of the rotor on the incoming flow and can be computed e.g. using the Blade Element Momentum method. For now it is simply assumed that this induced velocity is constant and relatively small compared to the wind speed and the rotational speed. The angle of attack is computed as:

$$\alpha = \phi - (\beta + \theta_p) \qquad (3)$$

The angle, ϕ, between the relative velocity and the rotor plane is called the flow angle. β, is the twist of the blade measured relative to the tip chord, see Figure 3. The angle between the tip chord and the rotor plane is the pitch angle, θ_p.