ECE 333

Green Electric Energy Systems

Lecture 11

TSR, Turbine Power Curves

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Slides Courtesy Prof. Tim O'Connell

Notes

- HW 5 assigned
  - Due Thursday at the beginning of class
- Last Time: Betz's Limit
- Today
  - Feedback
  - Rotor Efficiency Curves
  - Power Curves
  - Speed Control Methods
  - Weibull and Rayleigh Wind Distribution

Informal Early Feedback

- Pace – about right
- HW – mostly useful
- Reading – mixed results
- Likes: break, discussion, material, mix of lectures
- Dislikes: history, long video, derivations, mix of lectures, my handwriting
- Change for the better?
  - Handwritten notes posted
  - Piazza

Tip Speed Ratio (TSR)

- Actual rotor efficiency will be less than the Betz limit
- For a given wind speed, efficiency is a function of the rotor rotational speed
  - Spin too slowly, wind passes by without being "captured"
  - Spin too quickly, blades cause wind turbulence which reduces the efficiency of the blades.
- Efficiency can be expressed in terms of the Tip Speed Ratio:

$$\text{Tip speed ratio (TSR)} = \frac{\text{Rotor tip speed}}{\text{Upwind wind speed}} = \frac{\text{rpm} \times \pi D}{60v} \quad (7.30)$$

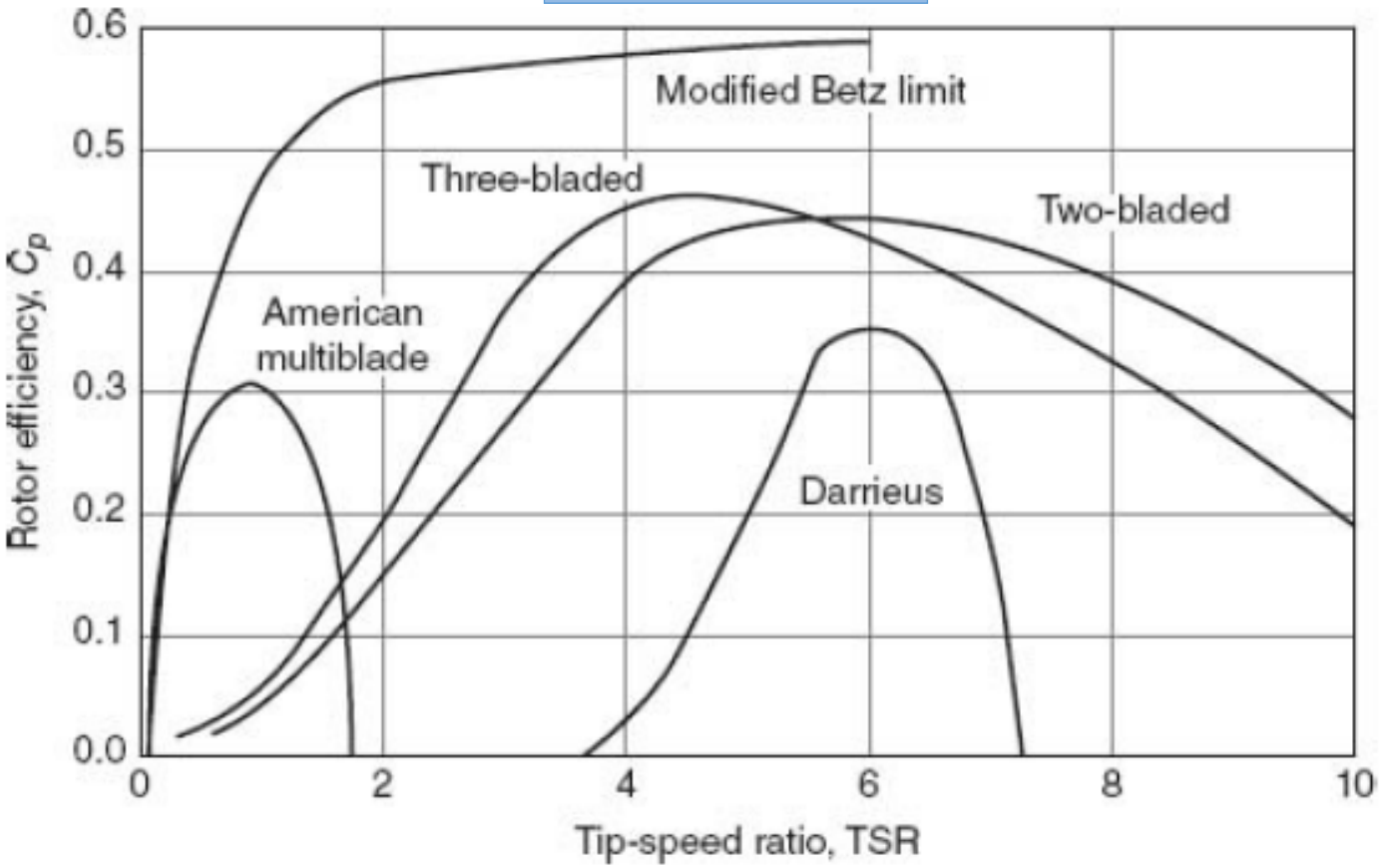
[m]

[m/s]

Tip Speed Ratio

- Optimal TSR for 2- and 3-blade modern turbines is in the 4-6 range.

Fig. 7.18



Idealized Power Curve

Electric machines are limited by their power rating.

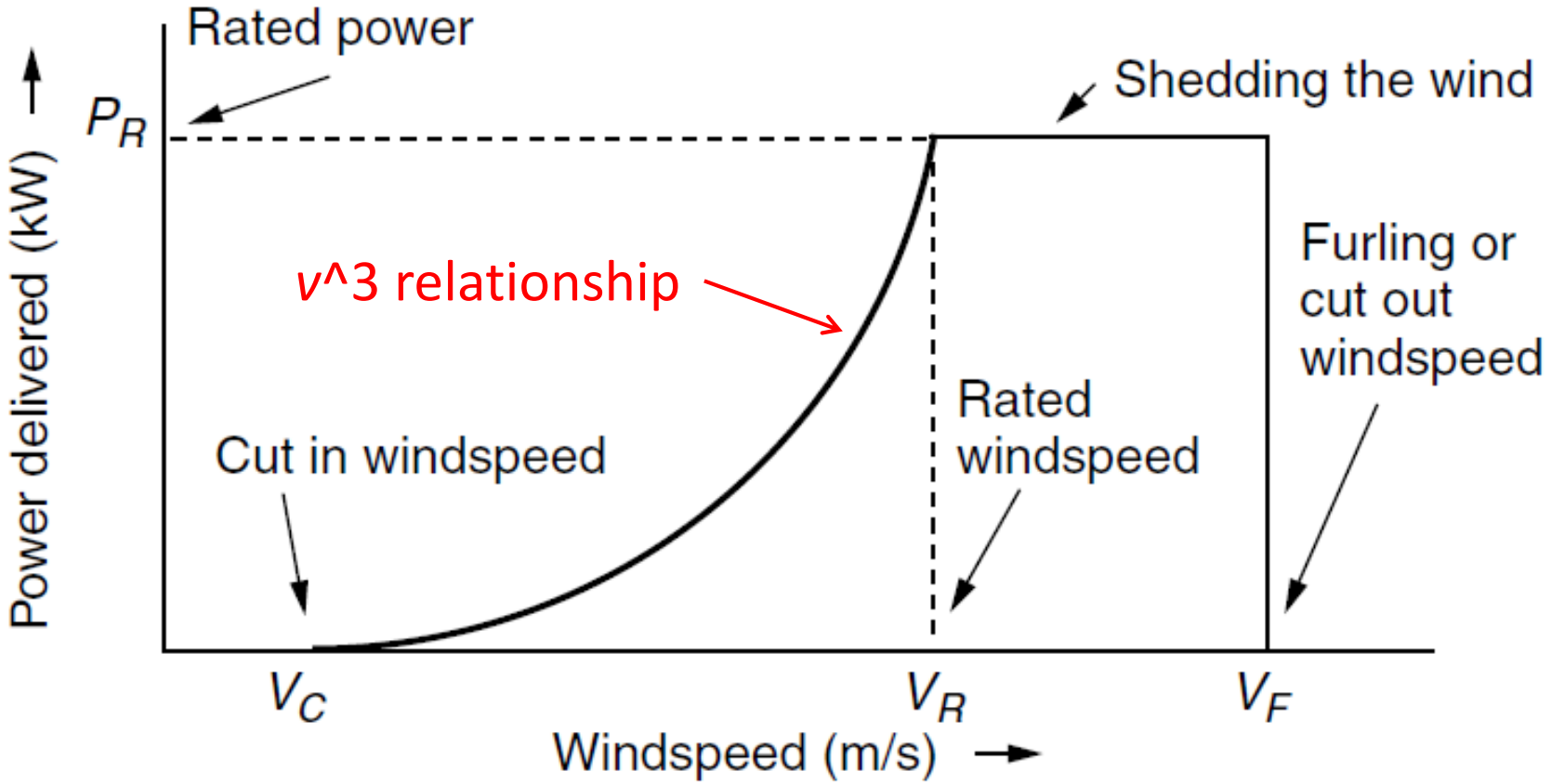
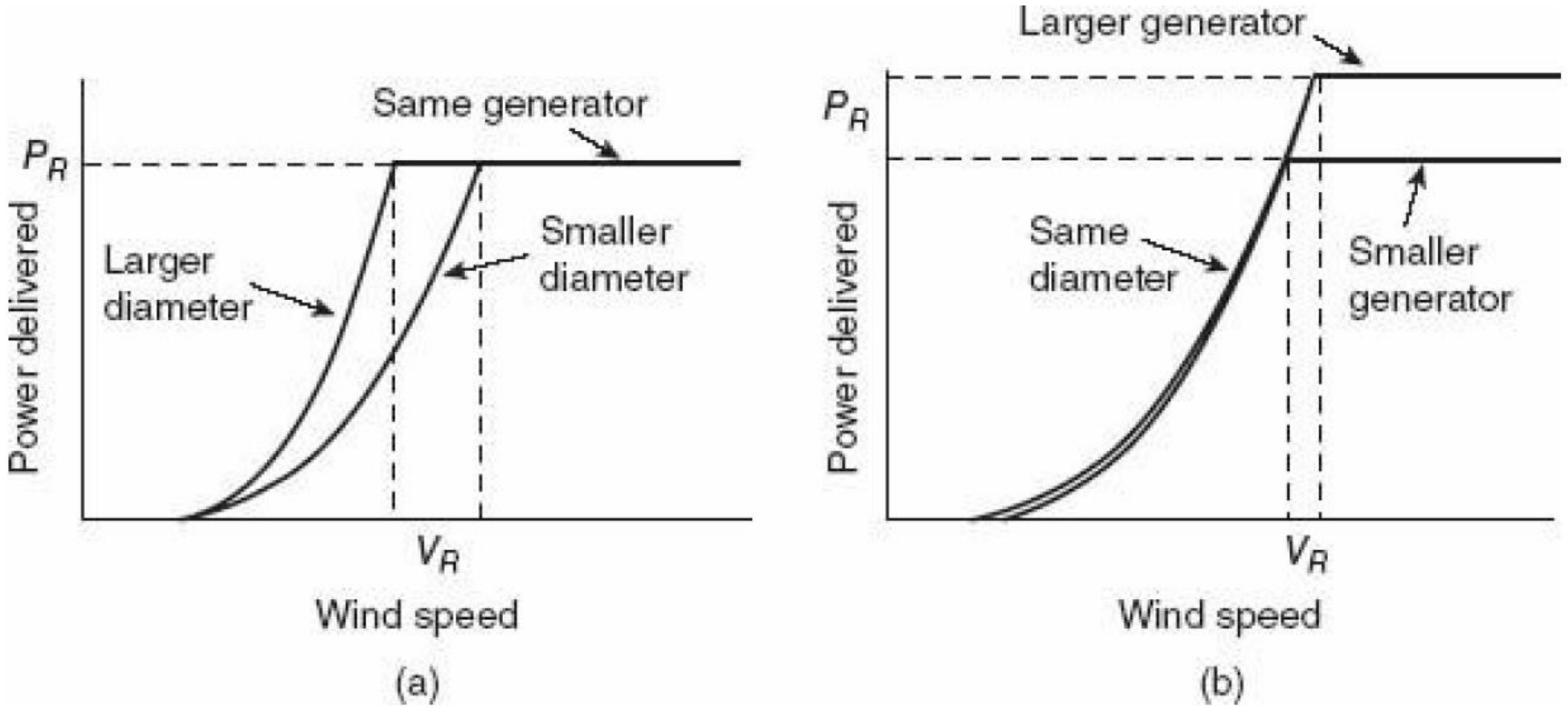


Figure 7.19

Real Power Curves

- Tradeoffs between rotor diameter and generator size (power rating)

Figure 7.20



Real Power Curves

- First number: Power rating
- Second number: Rotor diameter

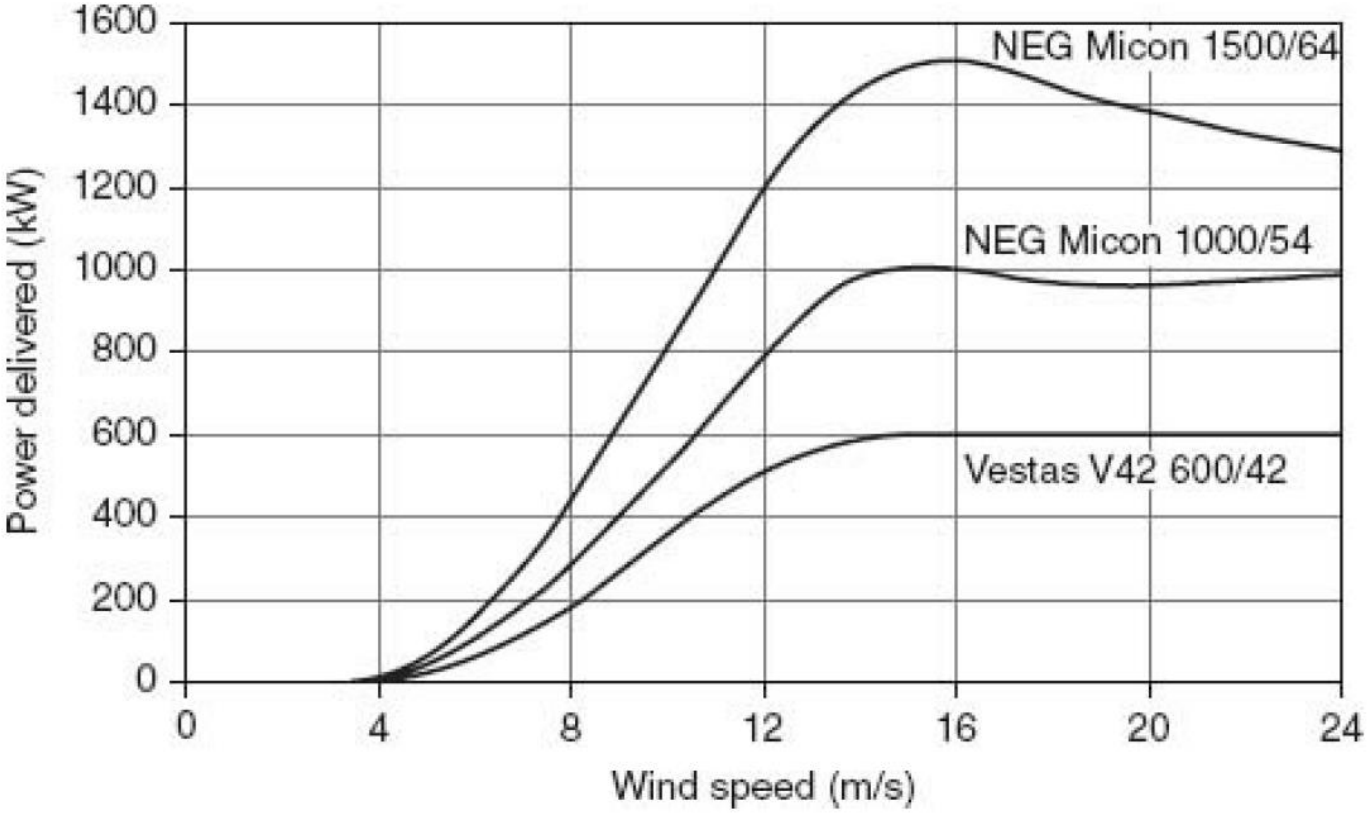


Figure 7.21

Some Aerodynamics

- Wind turbine blades have one added complication over airplane wings: **they create their own relative wind as they rotate**
- Blade is moving faster at its tip than at its hub, so the net resulting wind is different along the blade
  - Blade is twisted along its axis to keep the angles right

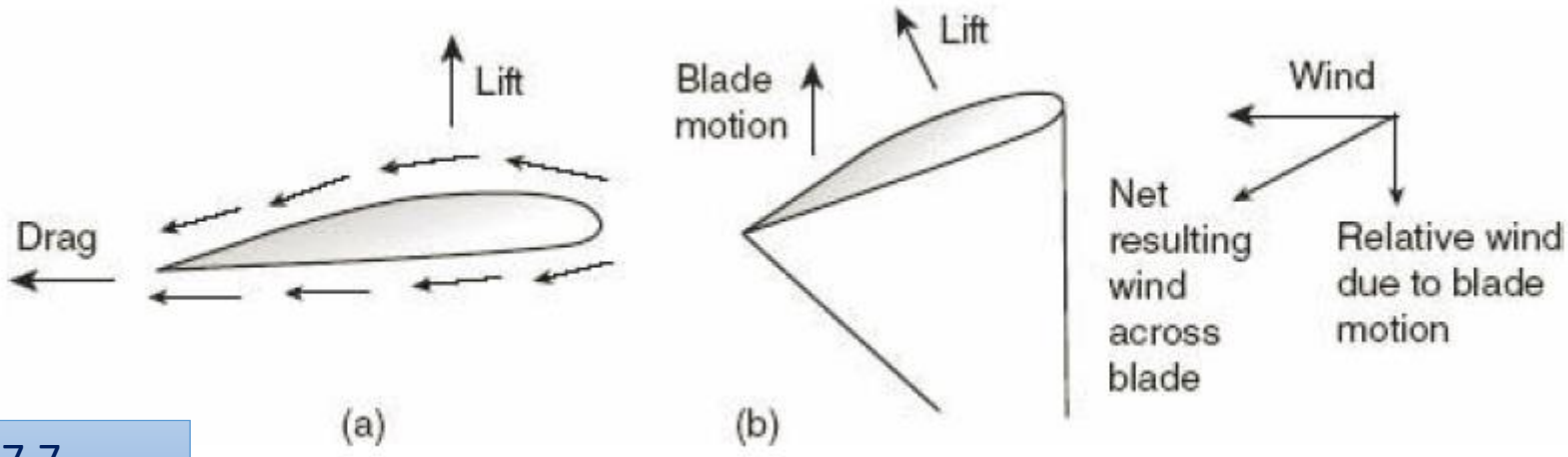


Fig. 7.7

Some Aerodynamics

- Angle of Attack (AoA) is constantly adjusted to achieve the optimal efficiency or desired power output
- Increasing AoA increases lift and drag, but eventually will cause the airfoil to stall (no more lift)

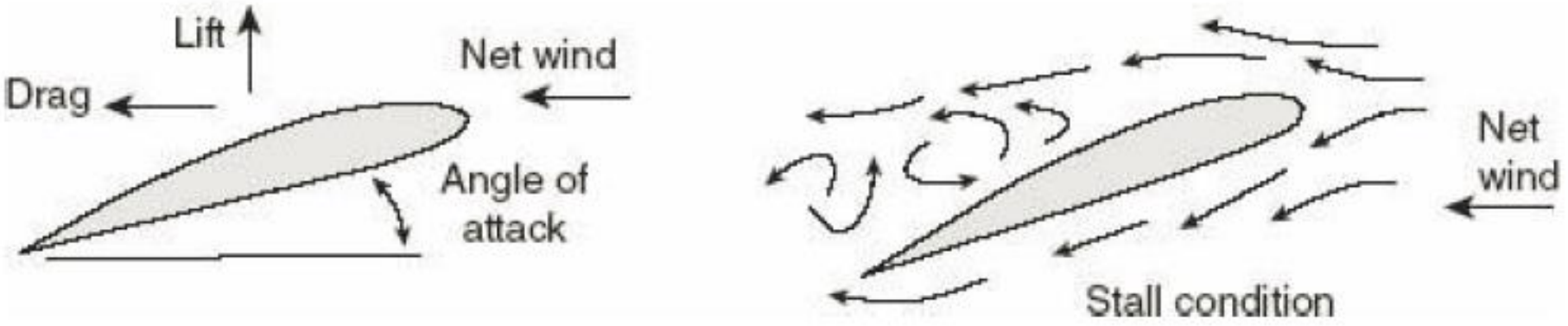


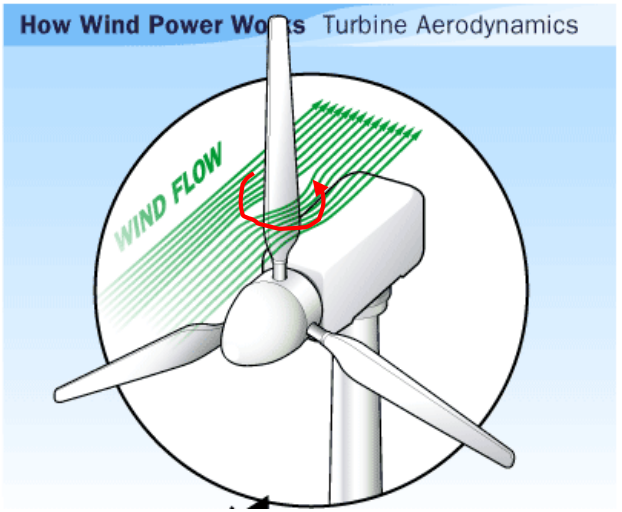
Fig. 7.8

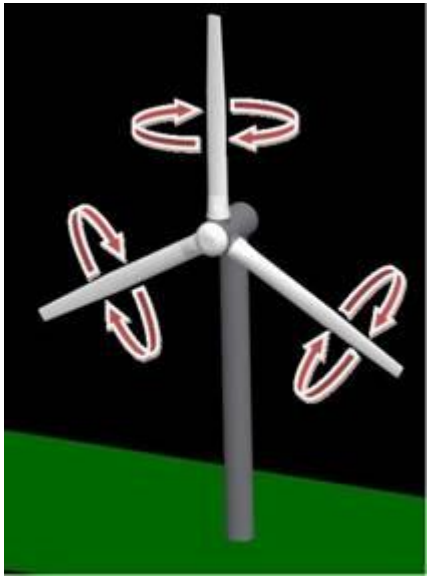
Turbine Speed Control Methods

- Passive stall-control
  - No moving parts
  - Blades carefully designed → They twist along their length to gradually reduce lift as wind speed increases
  - Simple and reliable
  - Sacrifices power at lower wind speeds
  - Used mostly on turbines below 1 MW in size

Turbine Speed Control Methods

- Active pitch-control
  - Blade pitch is adjusted to shed wind as wind speed increases
  - AoA is reduced when winds are high
  - Pitch controlled with hydraulic actuation system
  - Used on most large turbines

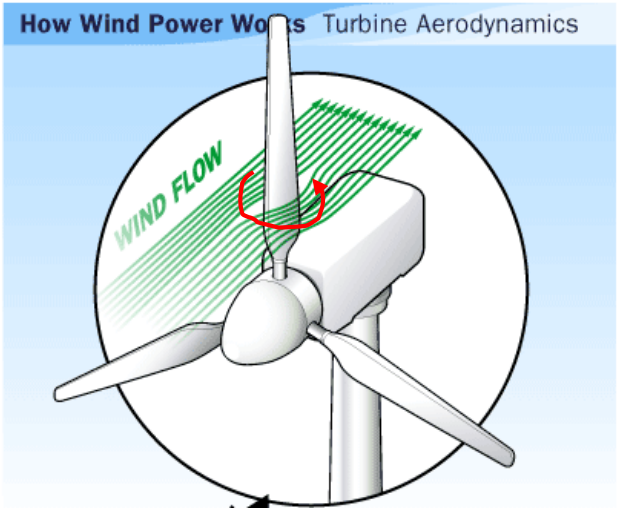


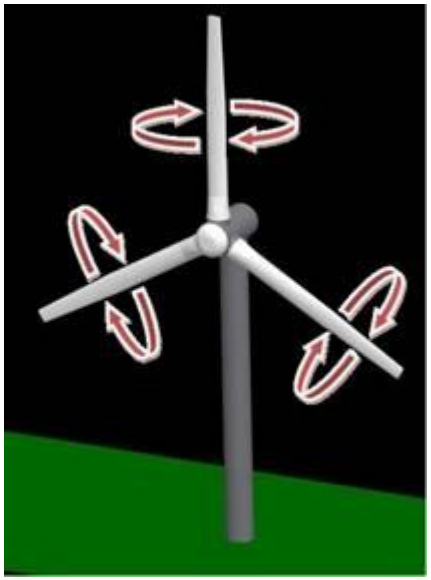


http://www.ni.com/white-paper/8189/en/

Turbine Speed Control Methods

- Active stall-control
  - Same as active pitch-control under normal wind speeds
  - But, when wind speed exceeds the turbine's rated value, AoA is increased to induce stall





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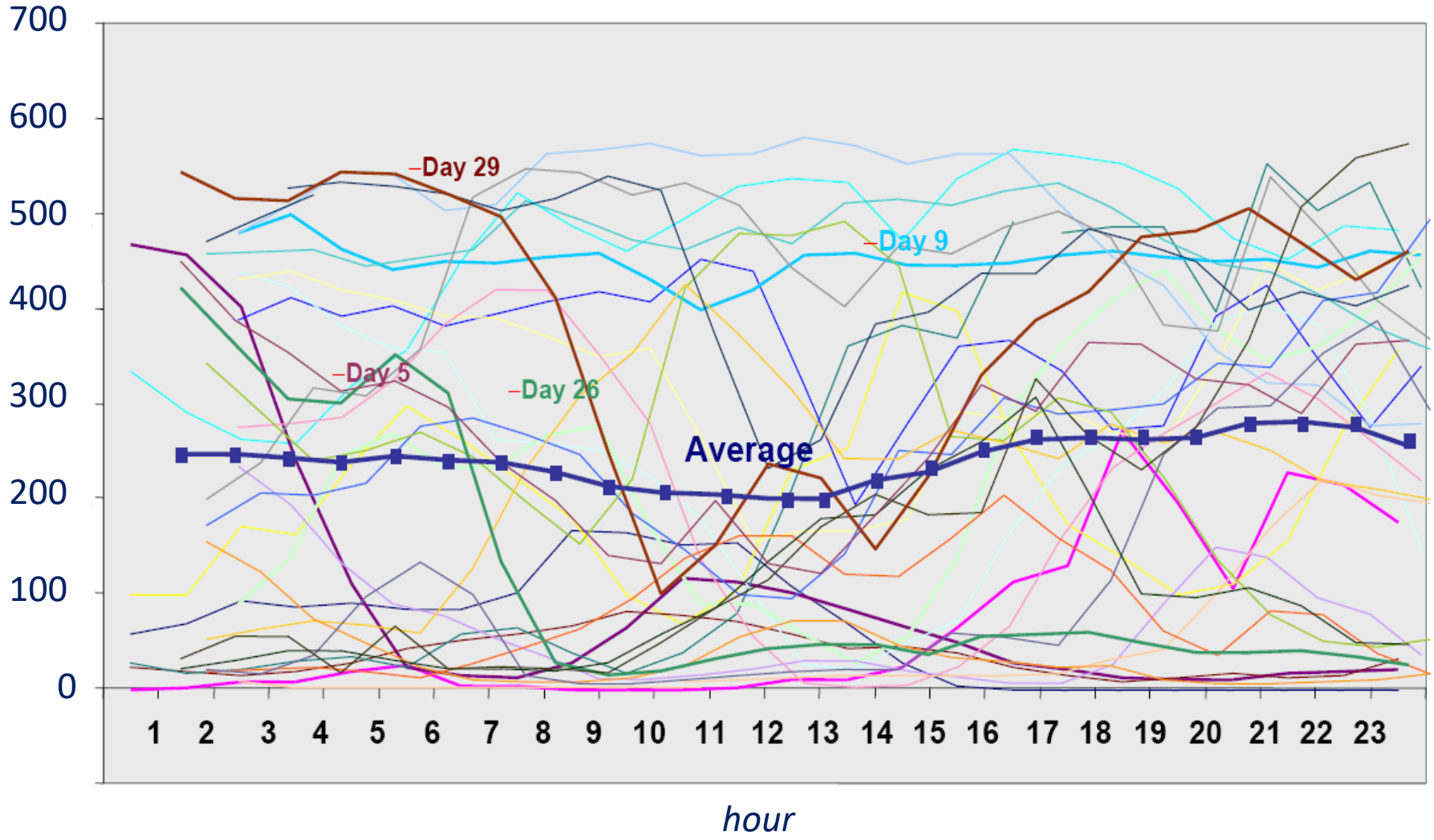
Wind Statistics: California ISO Daily Wind Energy



Wind Speed Histogram