# DAT460 Förnyelsebar elproduktion och eltransporter lp2 HT20 (3,5 hp)

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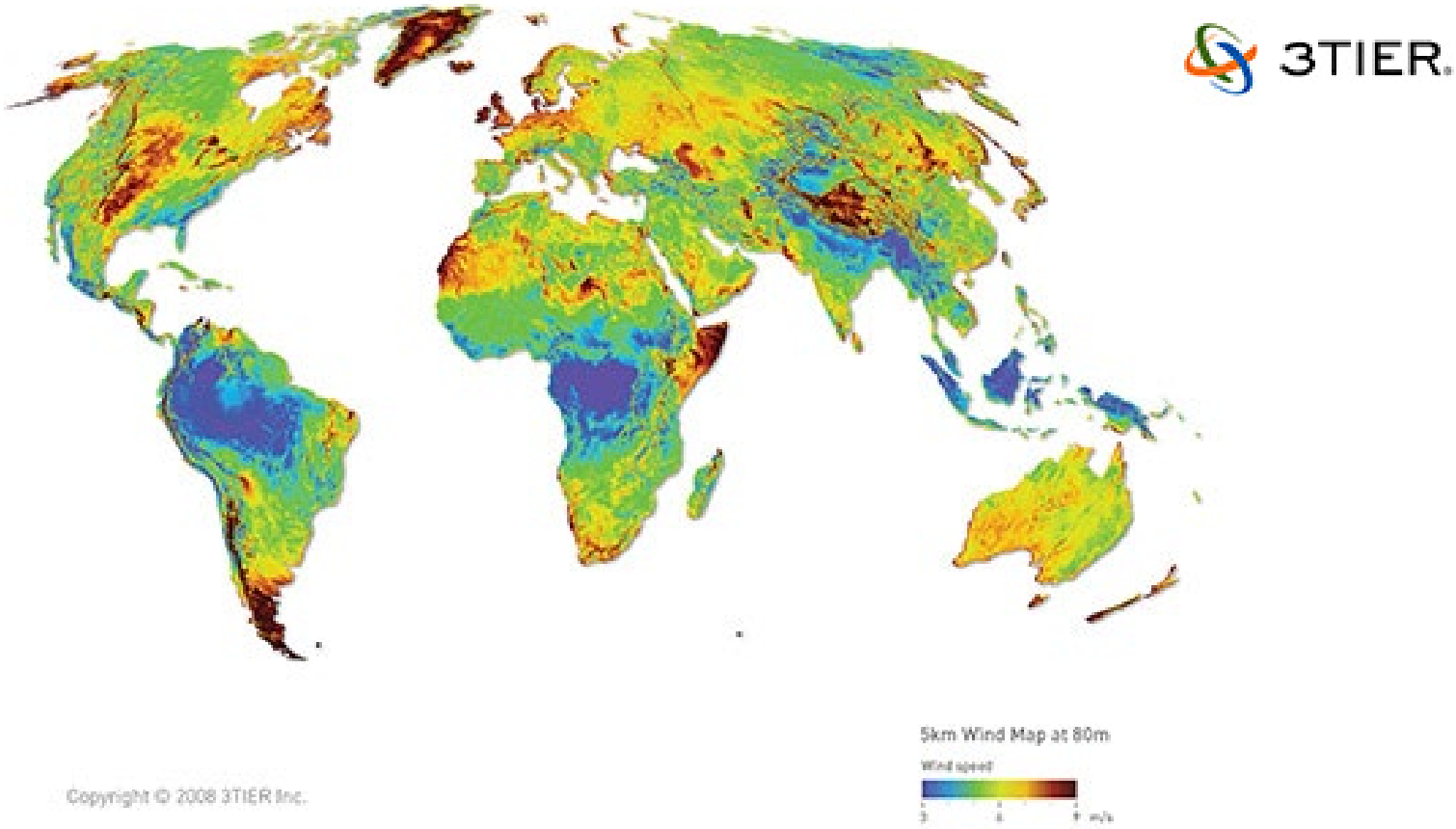
Chalmers

20201104

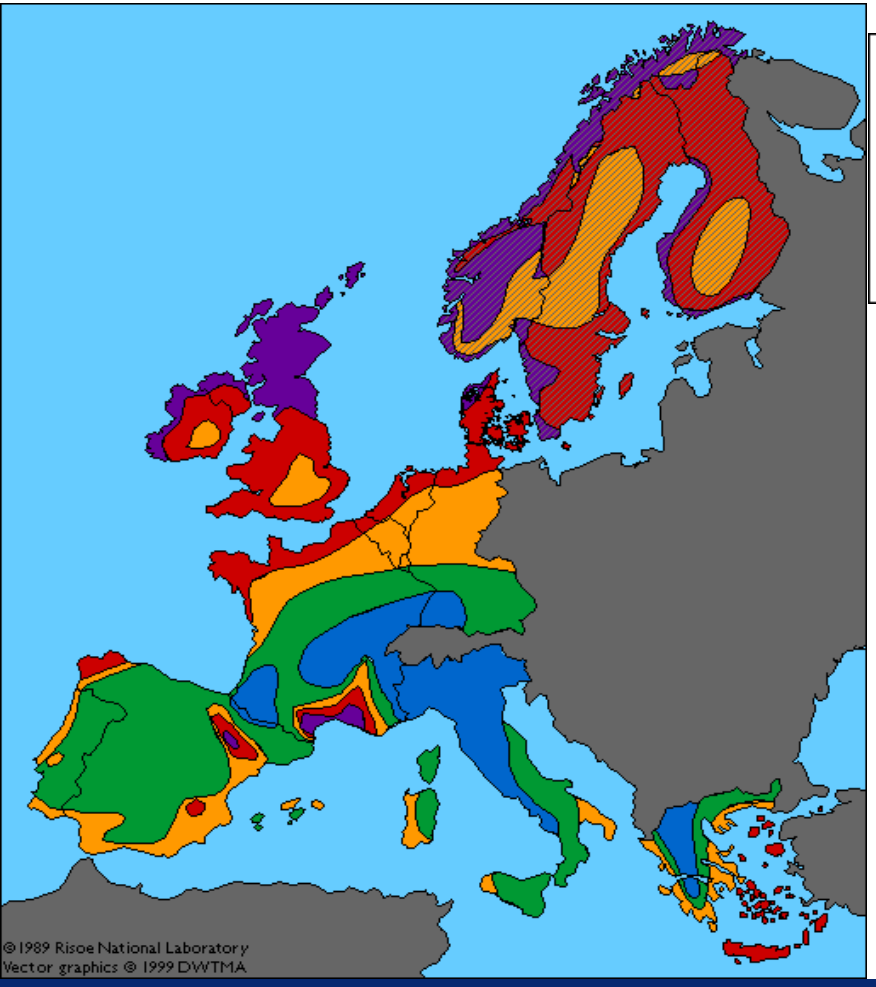
Grundläggande Vindkraftsteknik

# Wind speed



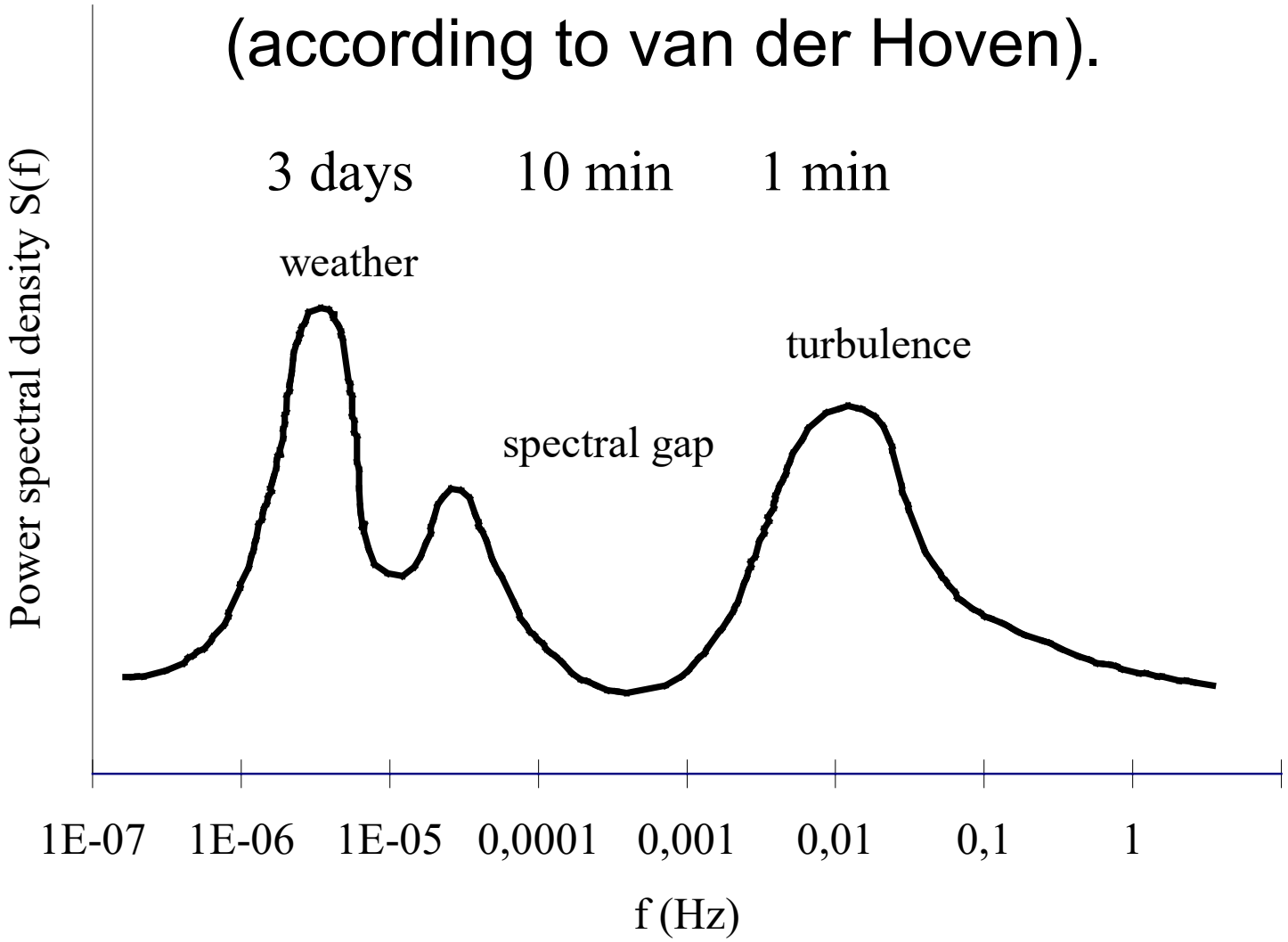

3 – 6 – 9 m/s

# Wind conditions

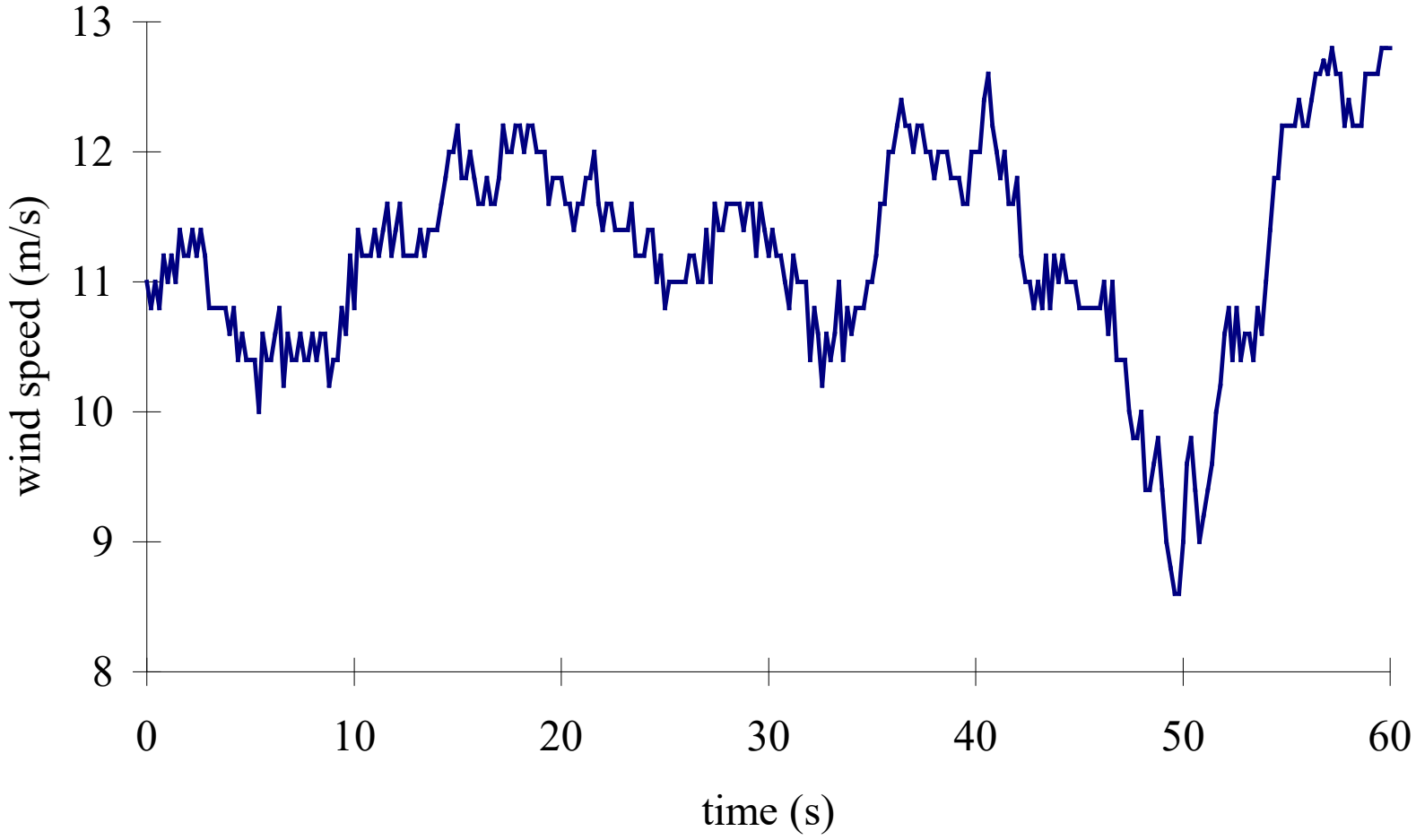



| | m/s | W/m² | m/s | W/m² | m/s | W/m² | m/s | W/m² | m/s | W/m² |
|---|---|---|---|---|---|---|---|---|---|---|
| | >6.0 | >250 | >7.5 | >500 | >8.5 | >700 | >9.0 | >800 | >11.5 | >1800 |
| | 5.0-6.0 | 150-250 | 6.5-7.5 | 300-500 | 7.0-8.5 | 400-700 | 8.0-9.0 | 600-800 | 10.0-11.5 | 1200-1800 |
| | 4.5-5.0 | 100-150 | 5.5-6.5 | 200-300 | 6.0-7.0 | 250-400 | 7.0-8.0 | 400-600 | 8.5-10.0 | 700-1200 |
| | 3.5-4.5 | 50-100 | 4.5-5.5 | 100-200 | 5.0-6.0 | 150-250 | 5.5-7.0 | 200-400 | 7.0-8.5 | 400-700 |
| | <3.5 | <50 | <4.5 | <100 | <5.0 | <150 | <5.5 | <200 | <7.0 | <400 |
| | | | >7.5 | | | | | | | |
| | | | 5.5-7.5 | | | | | | | |
| | | | <5.5 | | | | | | | |

# Schematic power spectrum of wind speed (according to van der Hoven).

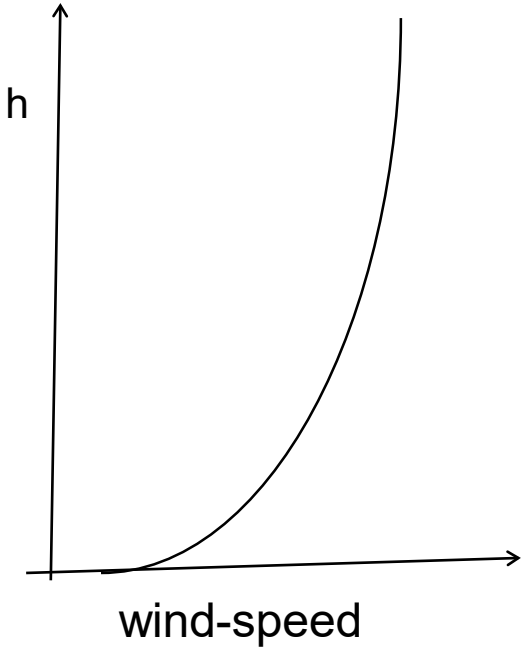


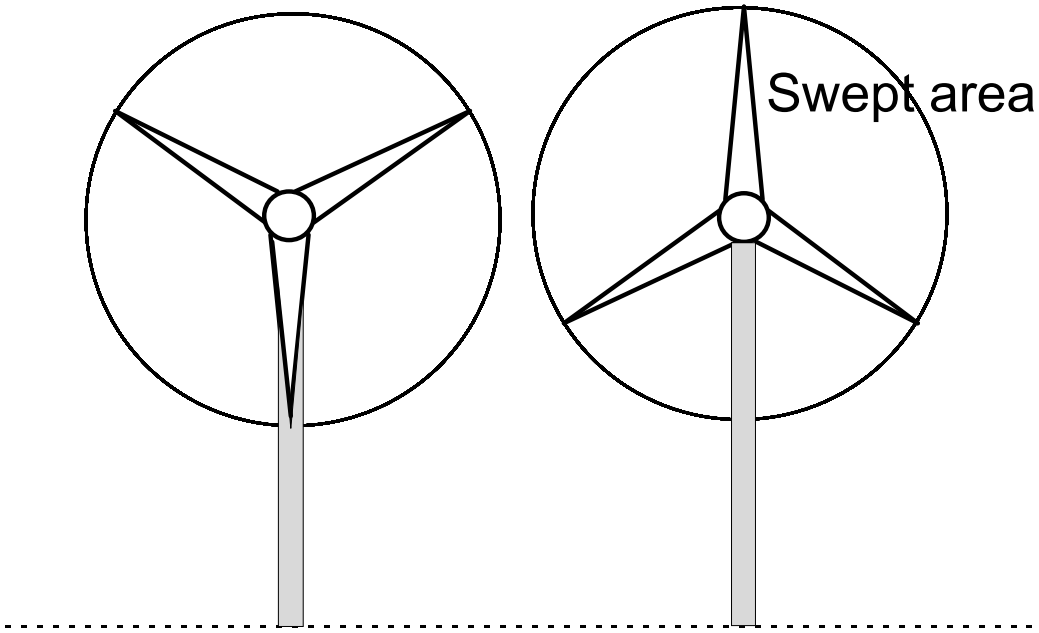
# Wind speed measured at the harbour of Gothenburg, Sweden



# Higher up more wind and more power

Different rotor positions of a three-blade turbine. The tower shadow and the wind gradient, both contribute to power fluctuations



# Wind shear

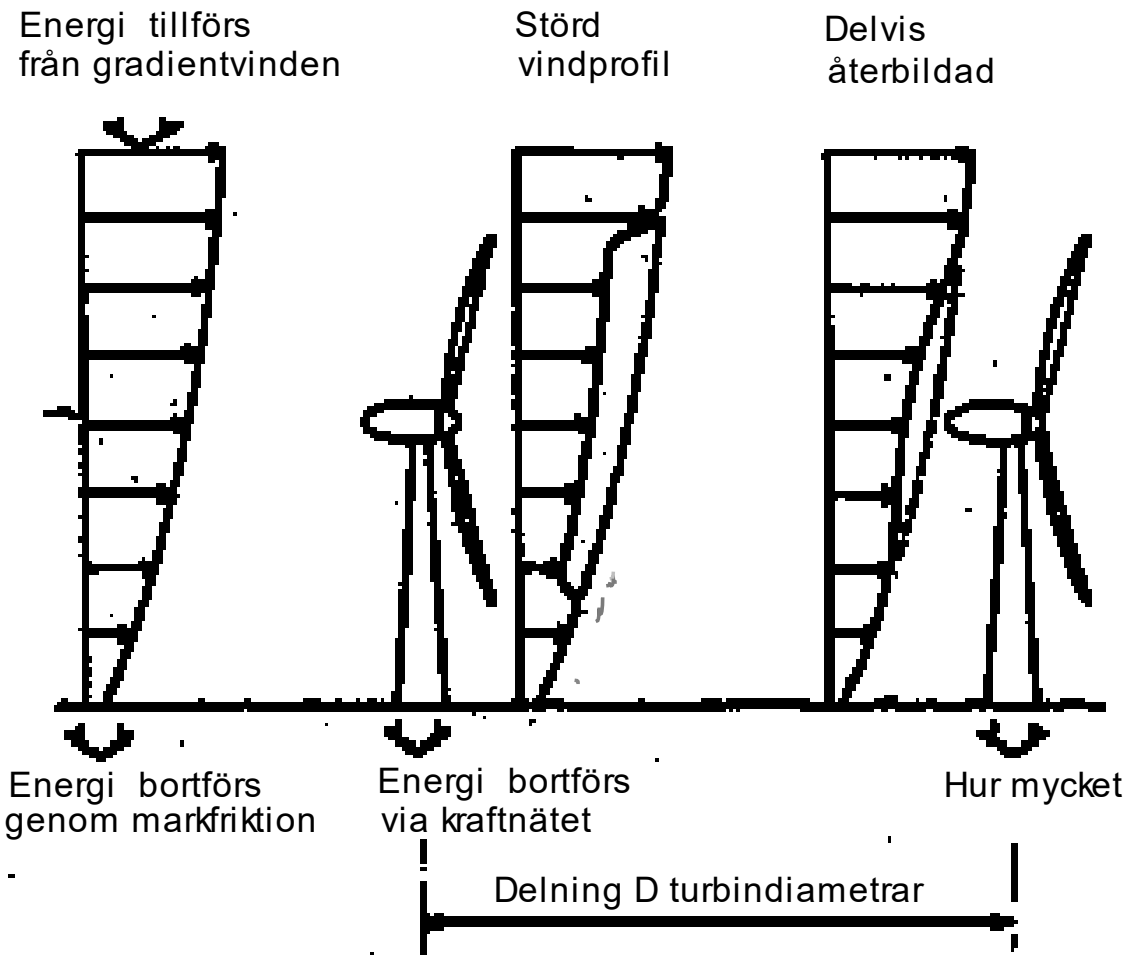
$$\frac{\overline{w_{hub}}}{\overline{w_{ane}}} = \left(\frac{h_{hub}}{h_{ave}}\right)^{\alpha}$$

$\overline{w_{hub}}$ is the average at hub height
$\overline{w_{ave}}$ is the average wind speed at anemometer height
$h_{hub}$ is the hub height
$h_{ave}$ is the anemometer height
$\alpha$ is the wind shear exponent

Gradient of the wind

Wind decreases due to turbine

Wind reforms



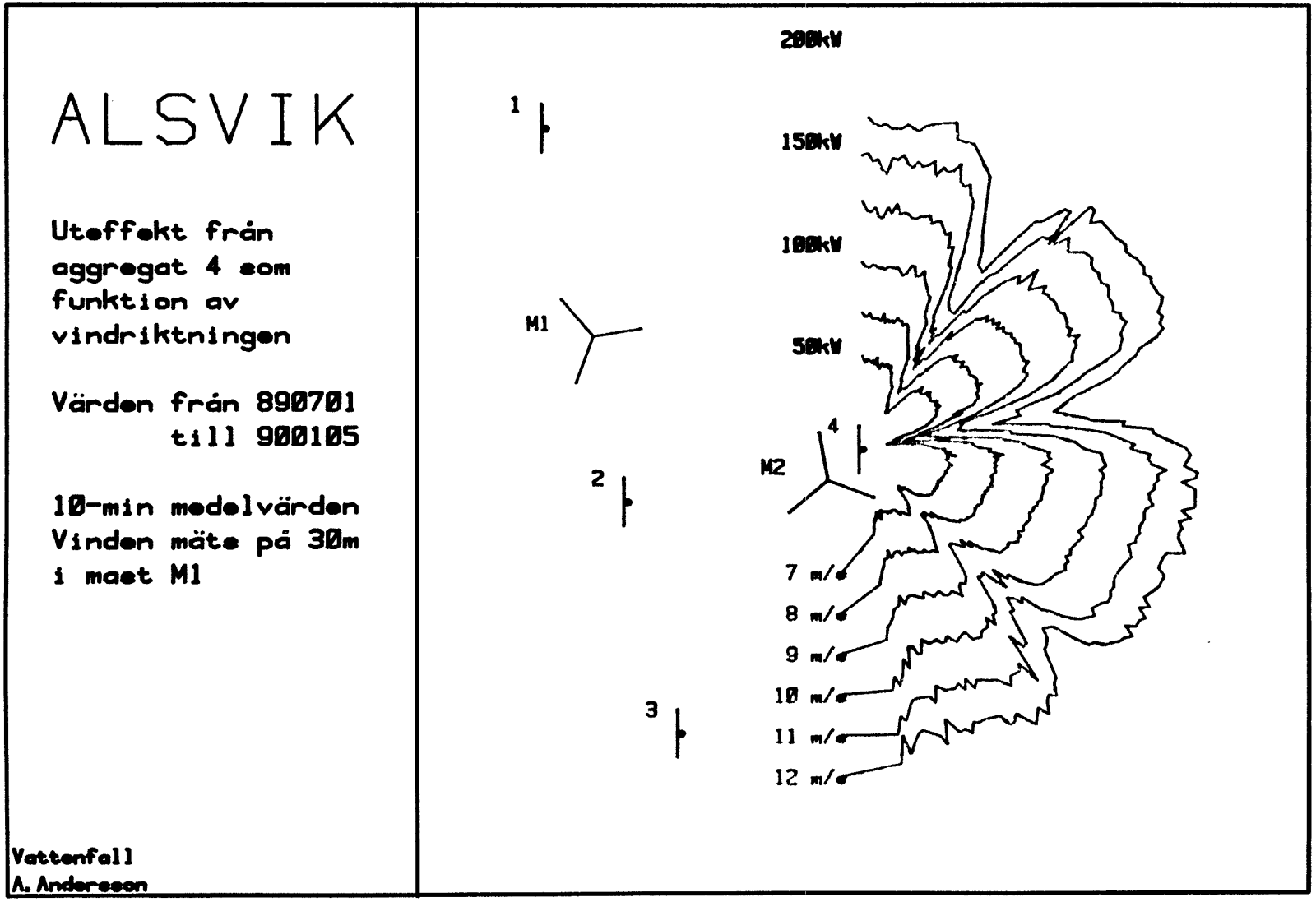

5 to 10 rotor diameters

Energy decreases due to land friction

Energy to the grid

How much left?

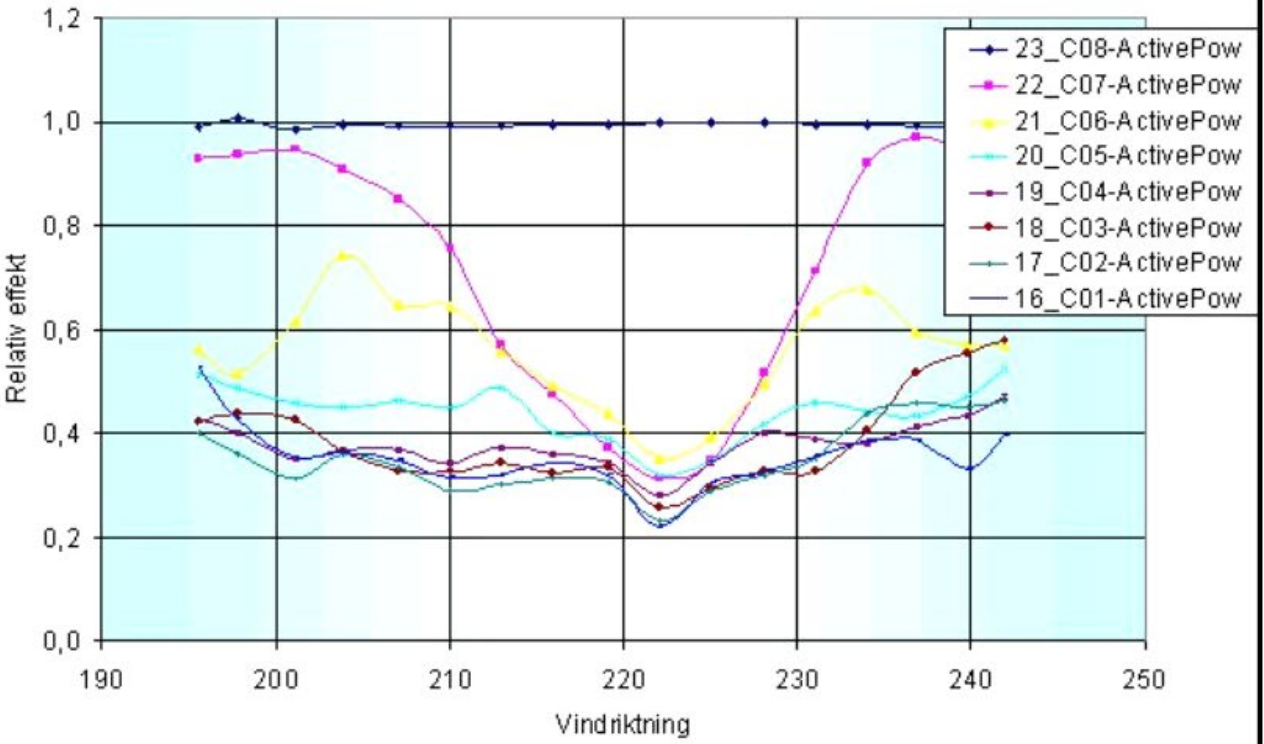
# Shadow effects



# Lillgrund vindpark utanför Malmö



## Effektförlust turbinrad




Effektförluster i raden vid ca. 220° är 65 – 80%

© Vattenfall AB

# Produced wind power / month

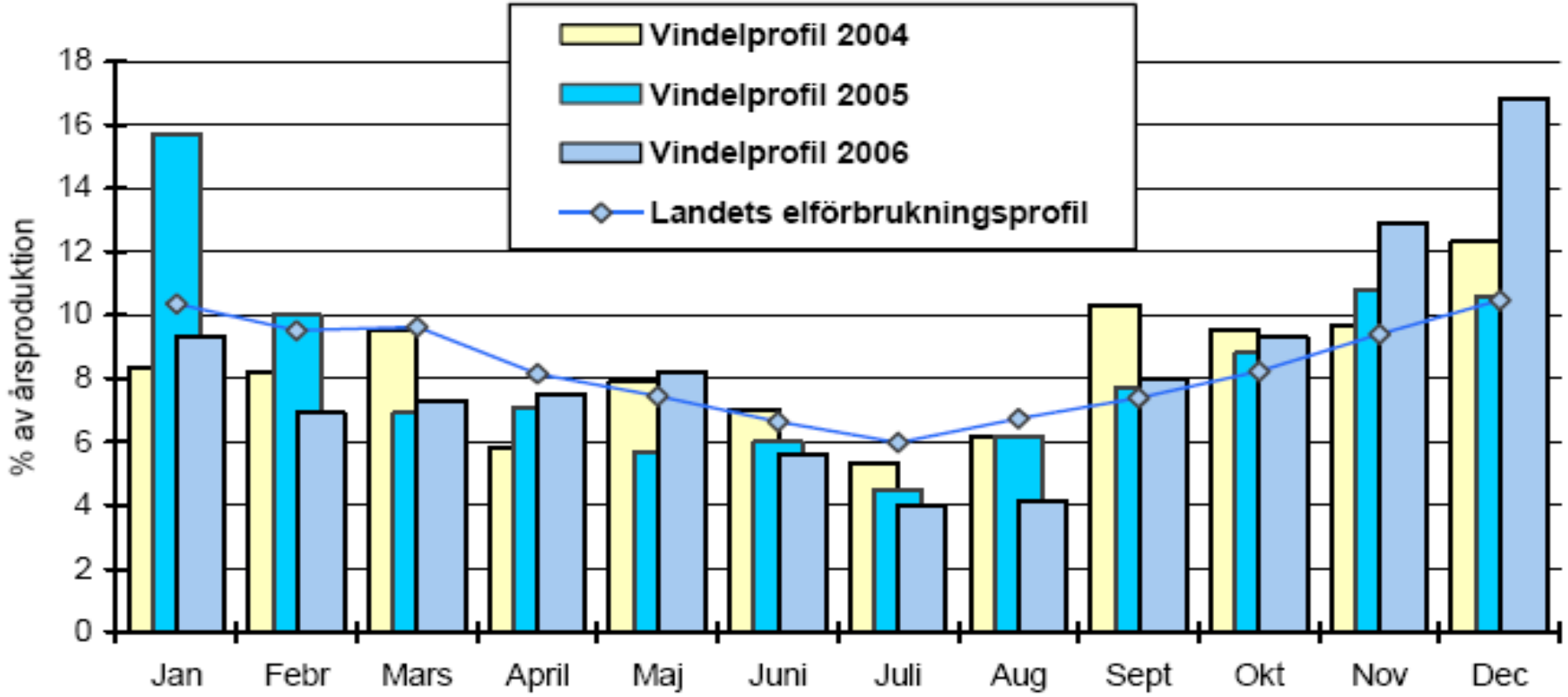
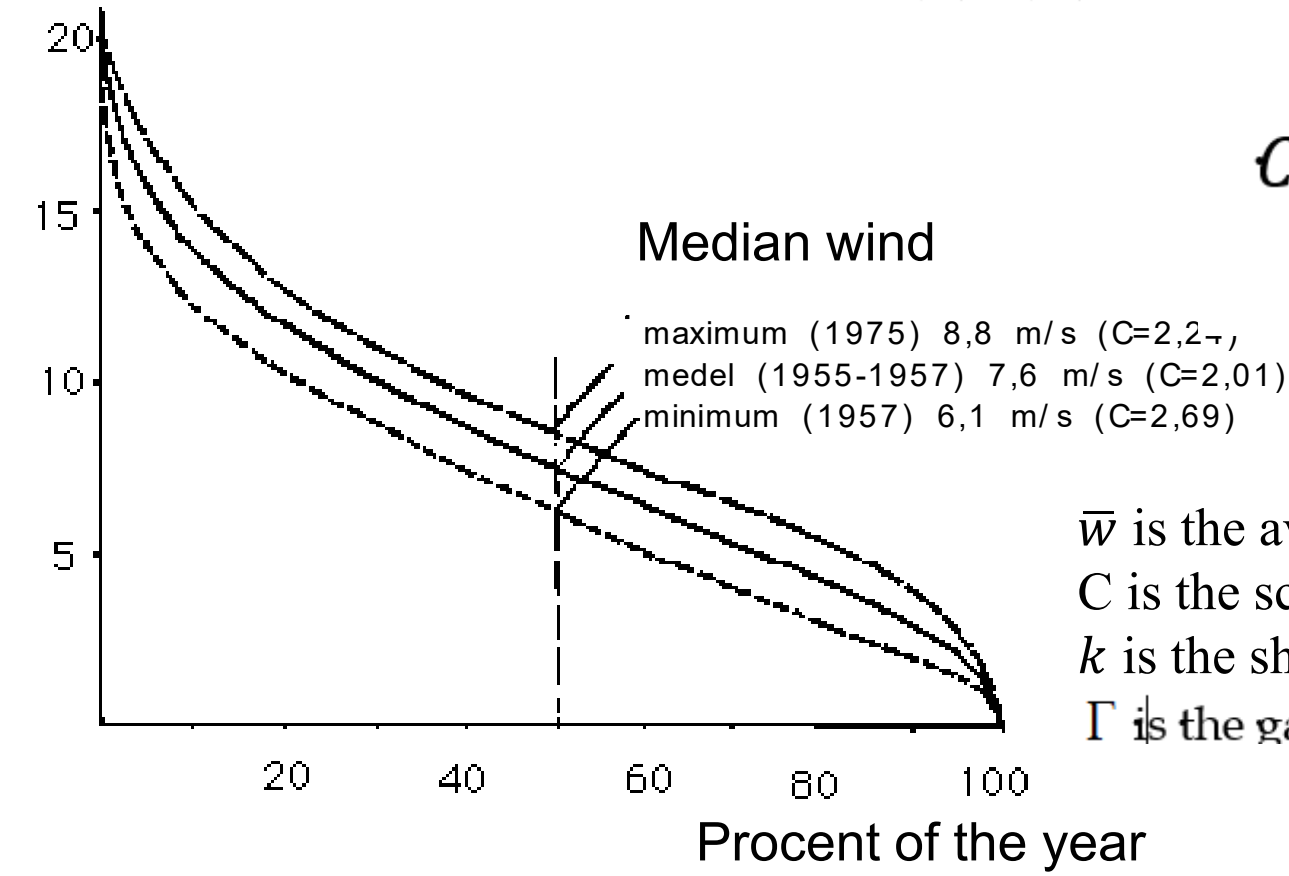



Diagram 6. månadsfördelning av vindelproduktion.

# Weibull distribution

$$f(w) = \left(\frac{k}{c}\right)\left(\frac{w}{c}\right)^{k-1} exp\left[-\left(\frac{w}{c}\right)^{k}\right].$$

$$C = \frac{\bar{w}}{\Gamma\left(1+\frac{1}{k}\right)}$$



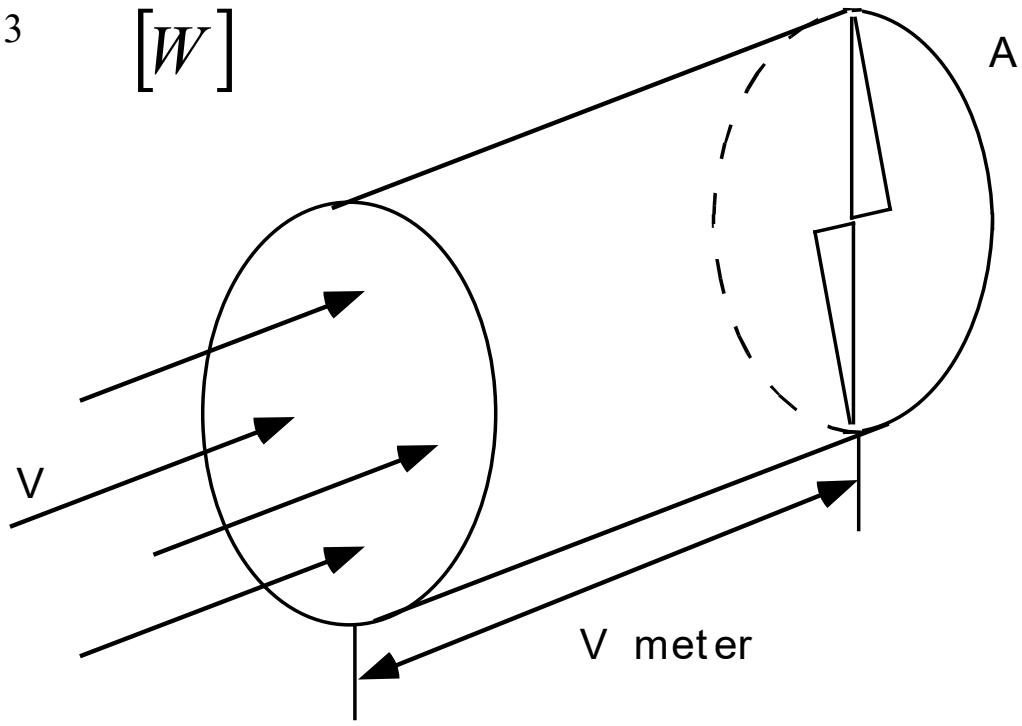

$\bar{w}$ is the average wind speed
C is the scale factor
$k$ is the shape factor ($K > 1$)
$\Gamma$ is the gamma function.

# Power of the wind

$$P_{kin} = \frac{1}{2}(\rho A V)V^2 = \frac{1}{2}\rho A V^3 \qquad [W]$$

Mass flow rate

$$\dot{m} = \rho A V$$




ρ = air density[kg/m$^3$]
V = air velocity[m/s]
A = rotor disk area[m$^2$]
m = mass of the air

# Wind energy distribution

$$P(w) = 0.5\rho w^3 A$$ Effekt

$$E(w) = f(w)P(w)T$$ Energi distribution

$w$ is the wind speed
T is the hours per year

# Wind power density

$$\bar{P} = \frac{1}{T}\int_0^{\infty} E(w)\, dw$$

# Power from the wind turbine

$$P = \frac{1}{2}\rho A C p V^3$$

Where

Cp = power coefficient

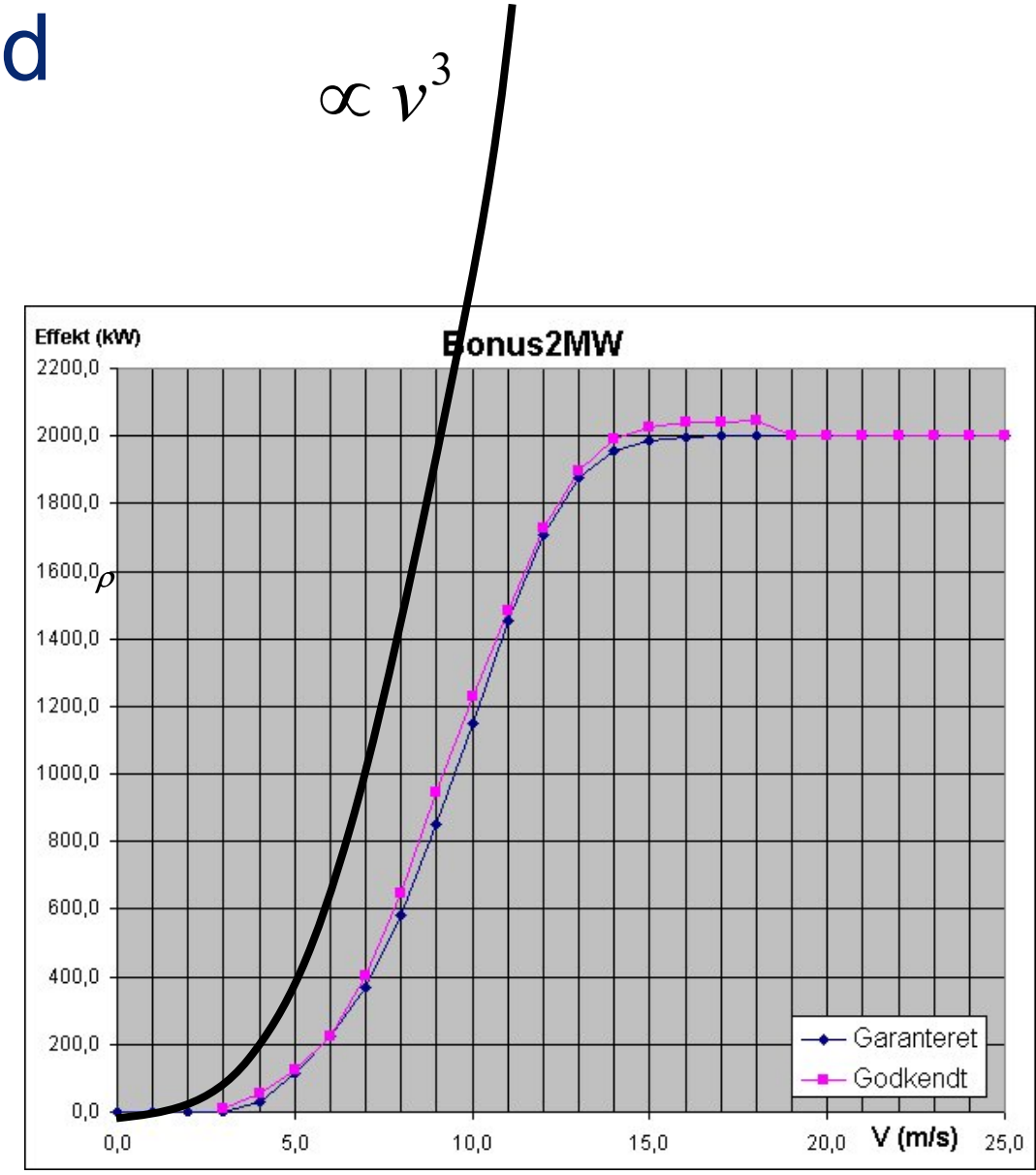
A = Swept area

V = Wind speed

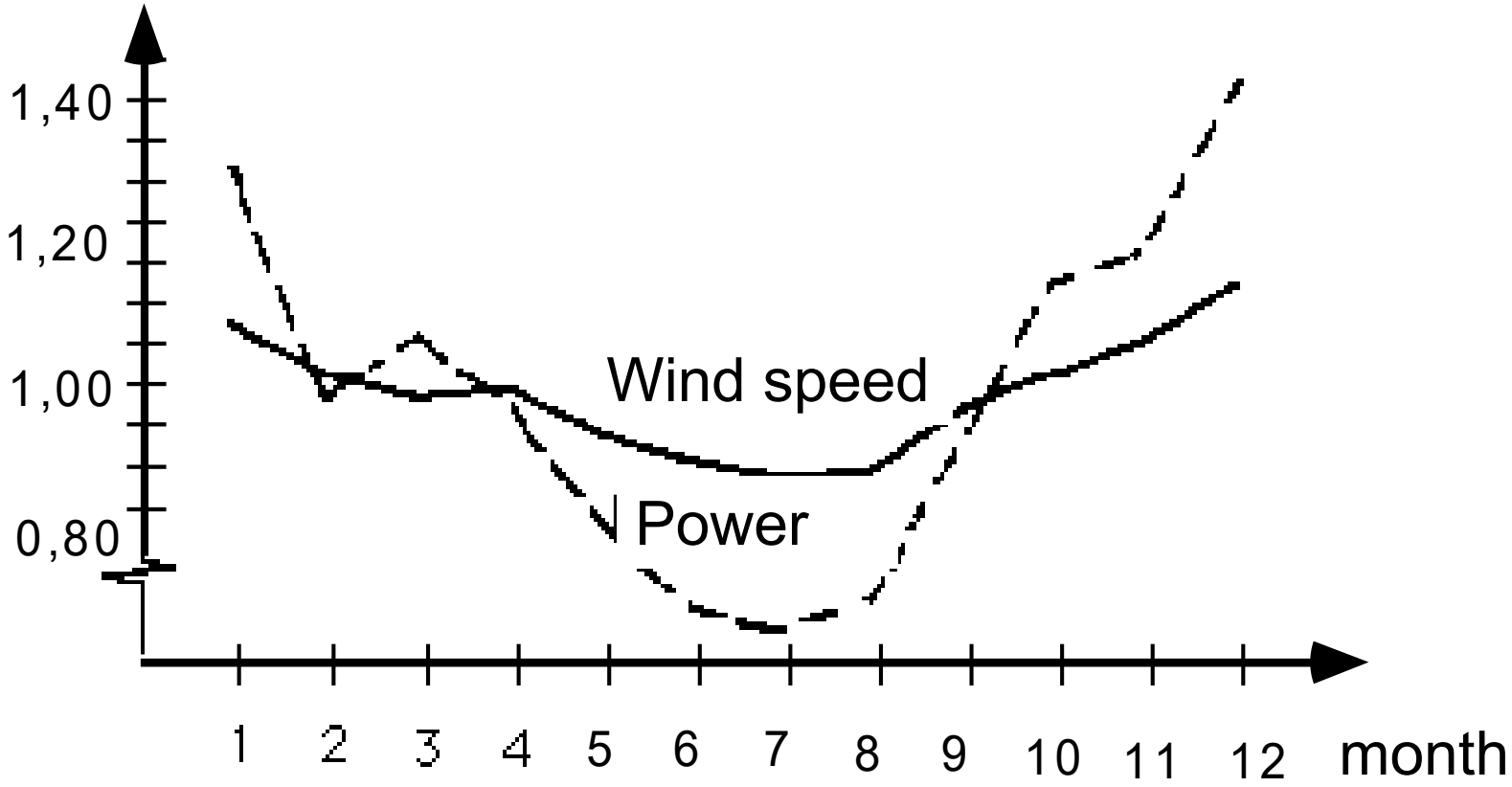
$\rho = air$ density

For new wind turbines
$C_p$ is 0.4 – 0.5

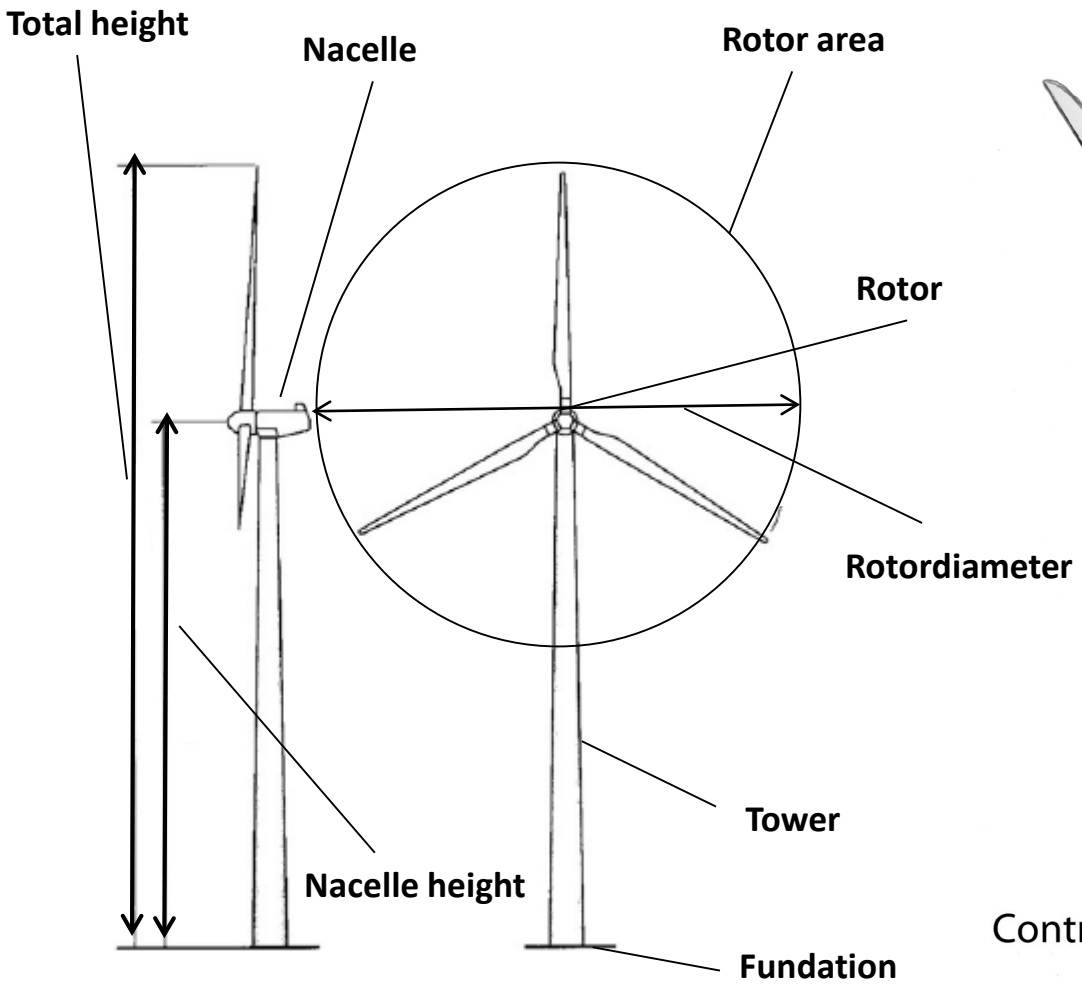
$C_{pmax}$ by teori is 0.593

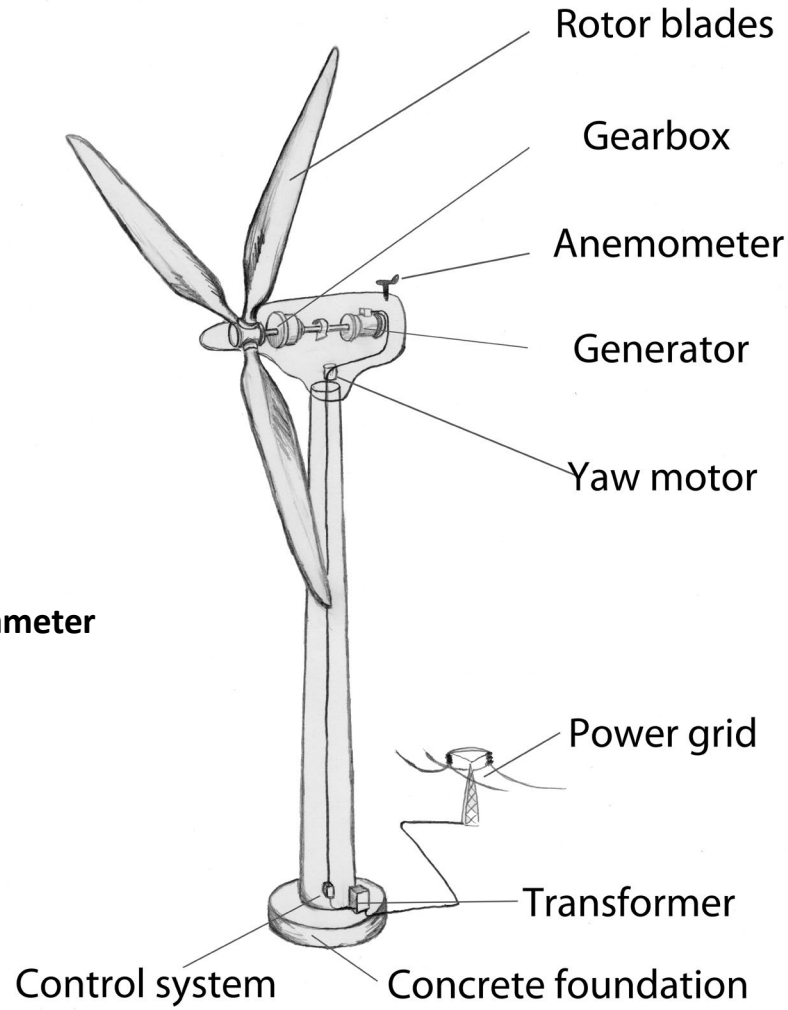


# Average value

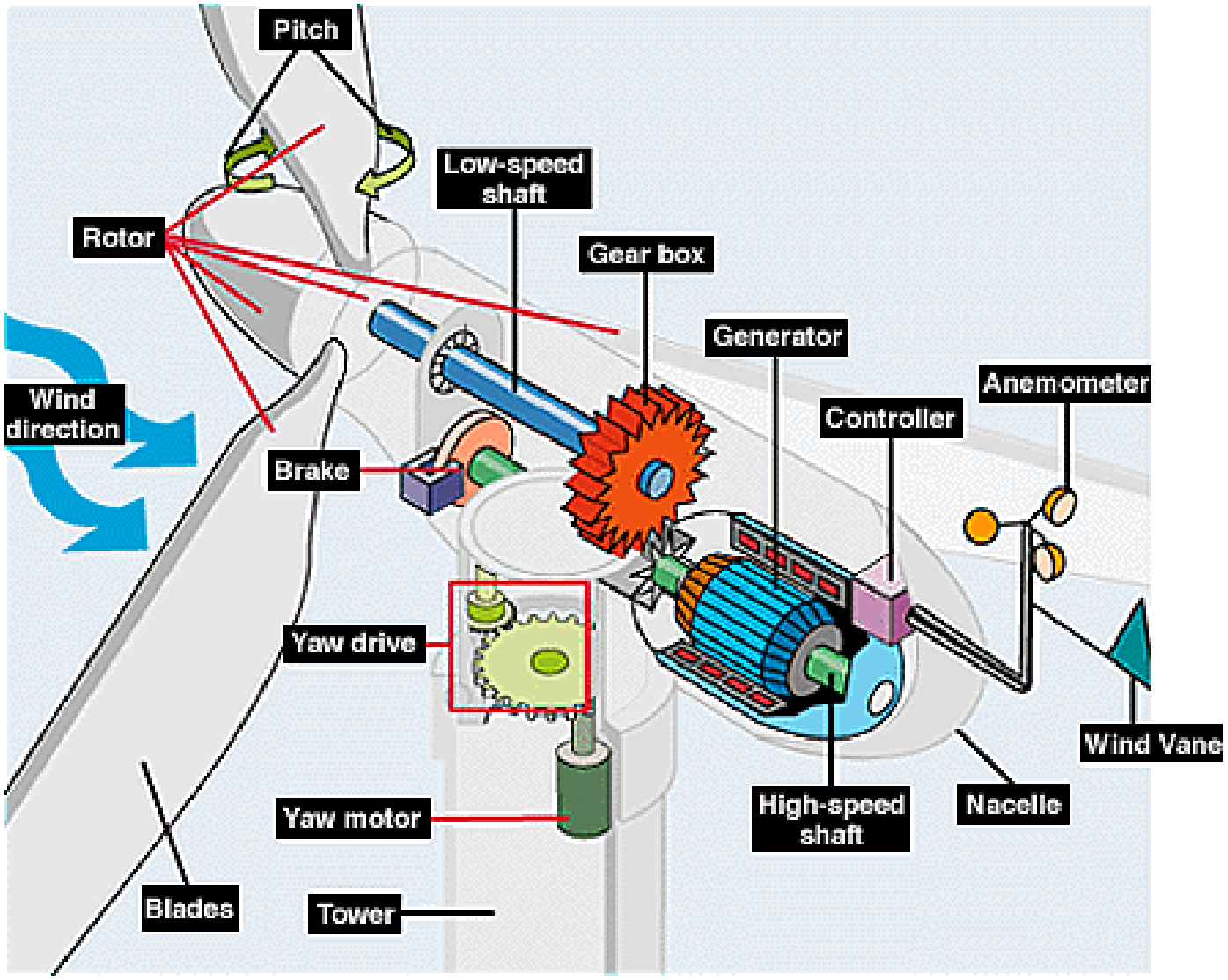


# Wind turbine parts

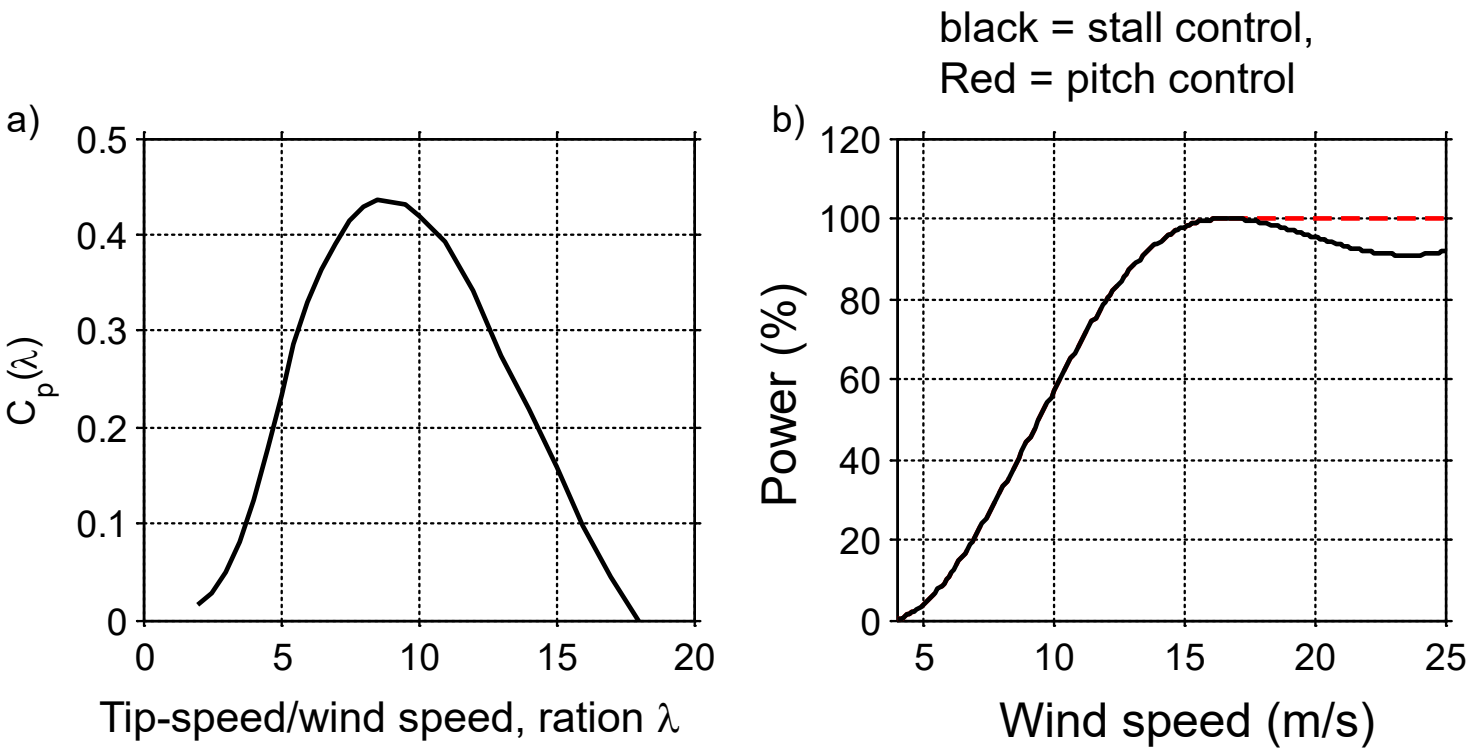


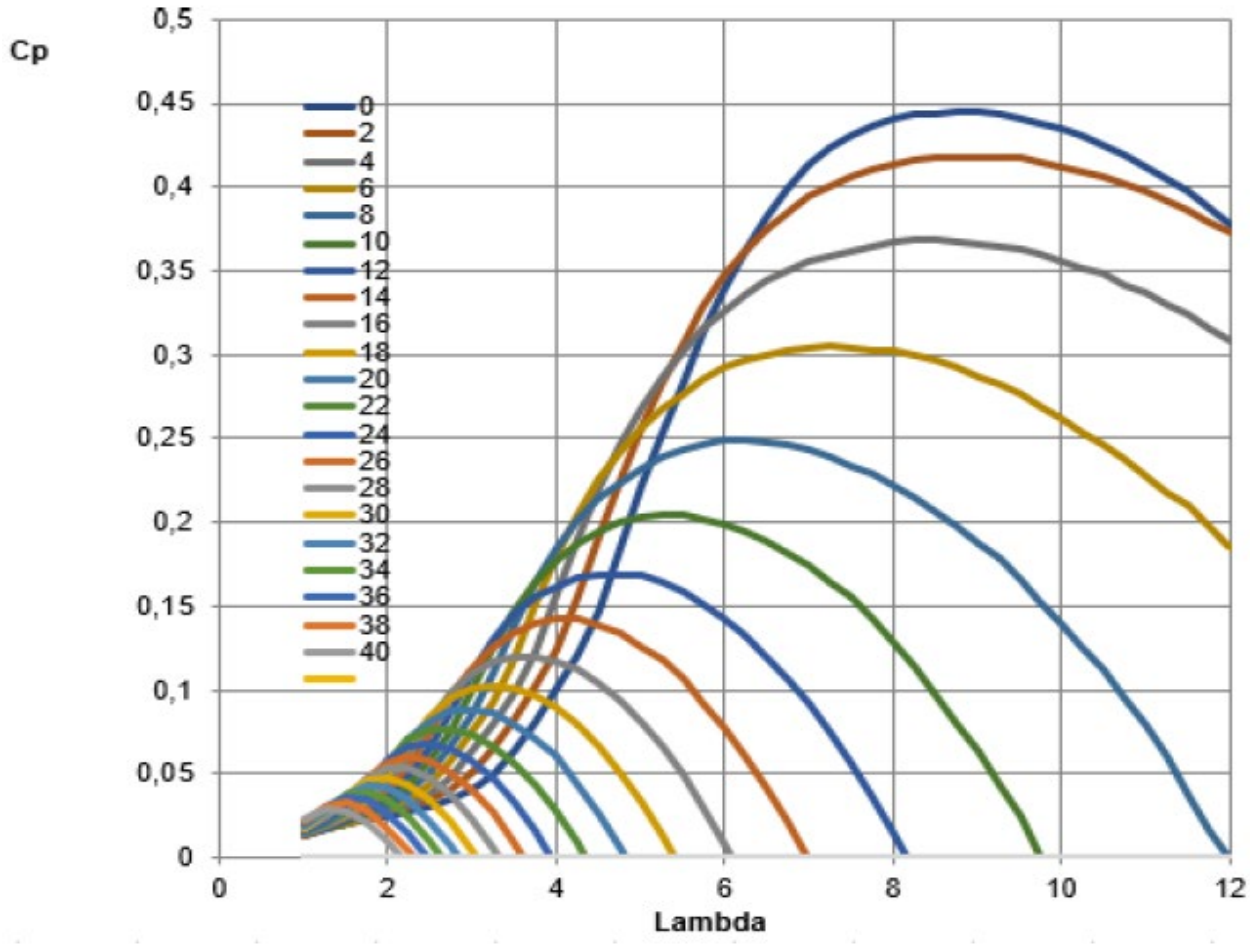
# Typical wind power nacelle



# Power coefficient and power curves

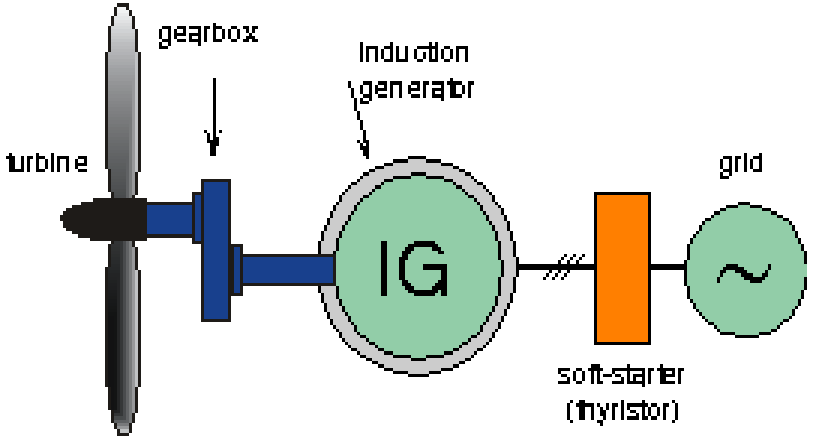


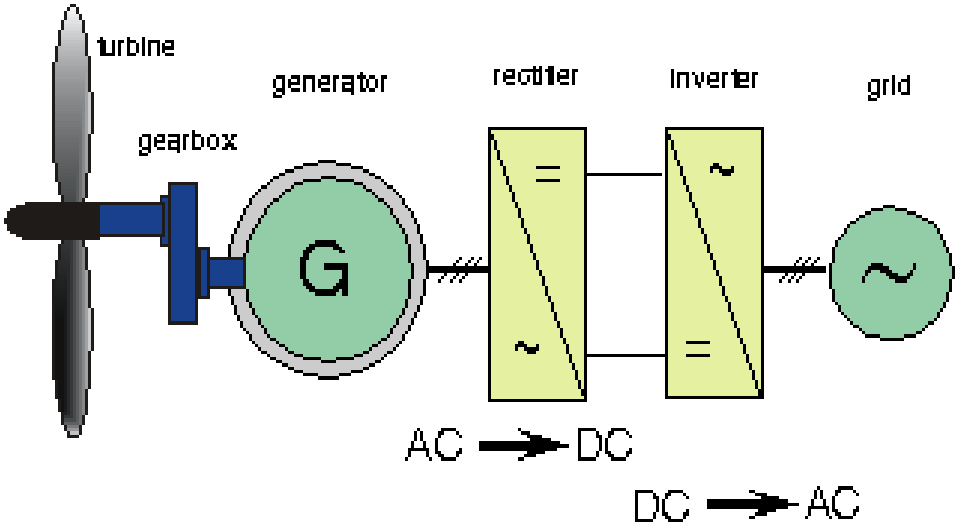
# For pitch control



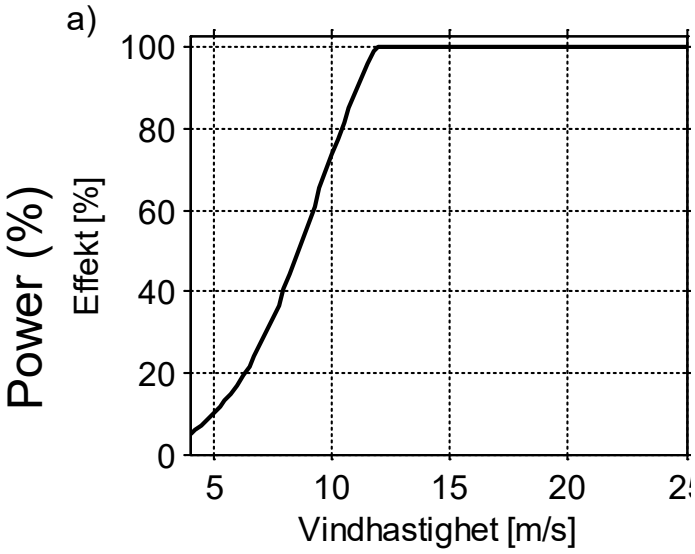

The relationship between $C_p$ and TSR with varying pitch angles.

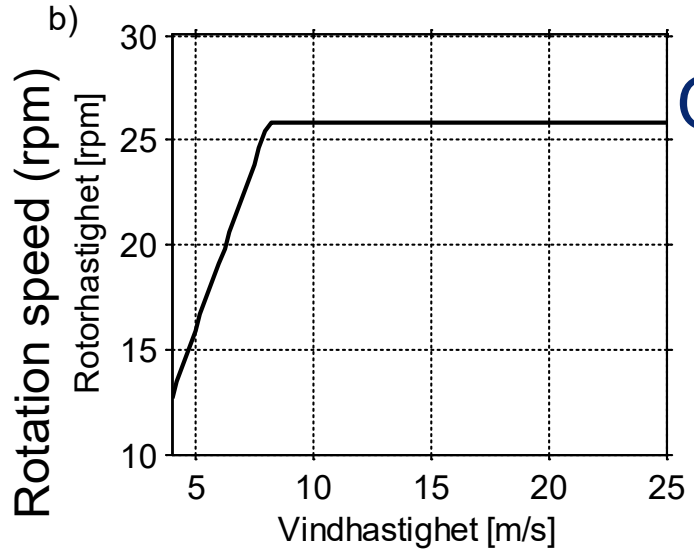
# Konstant och Variabelt varvtal utan och med frekvensomriktare

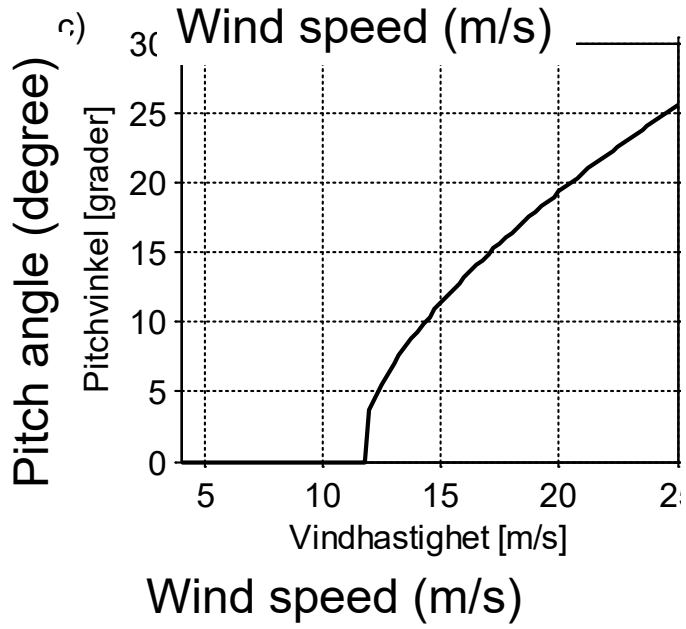


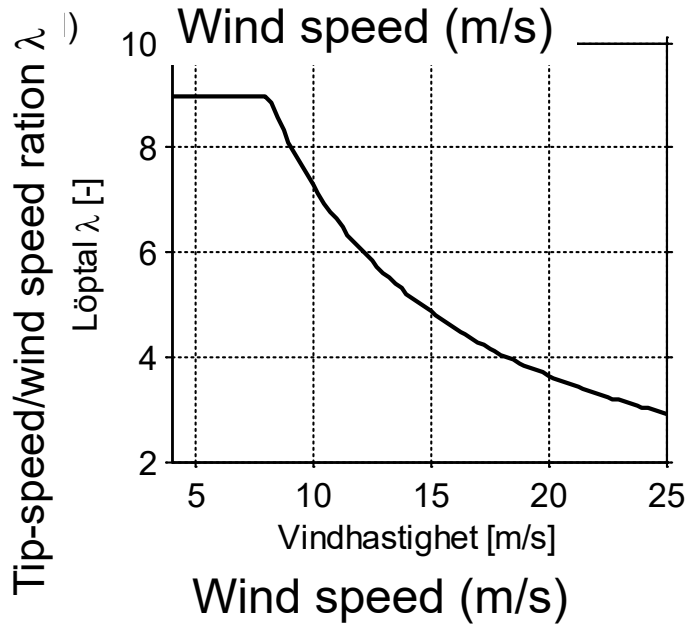



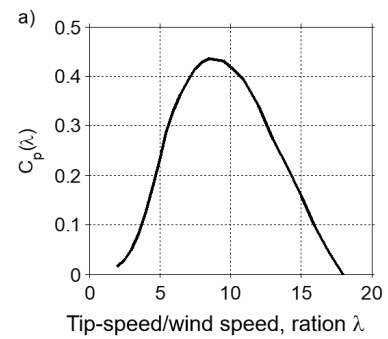
# Operation of a variable speed wind turbine



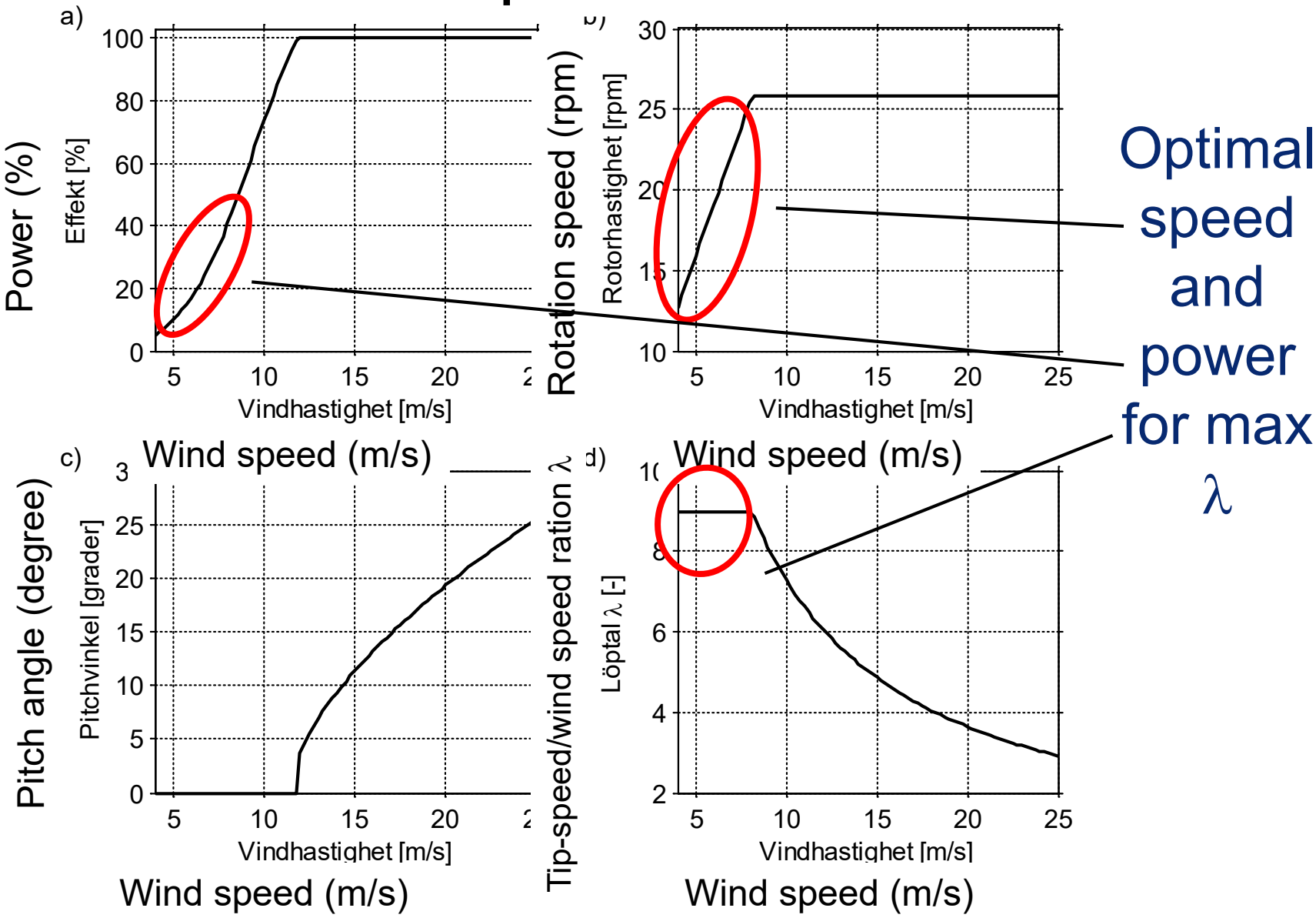



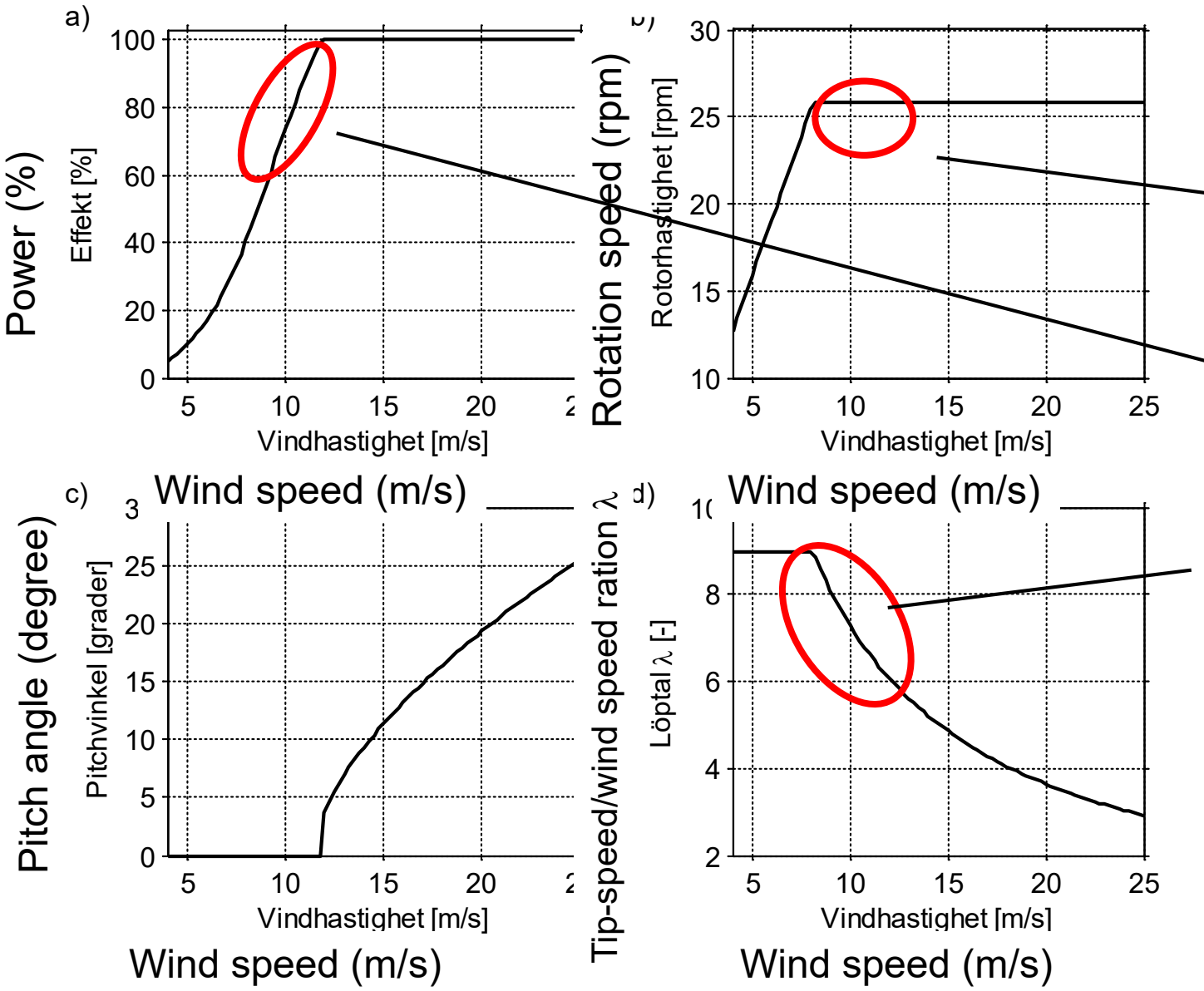



# Optimal mode

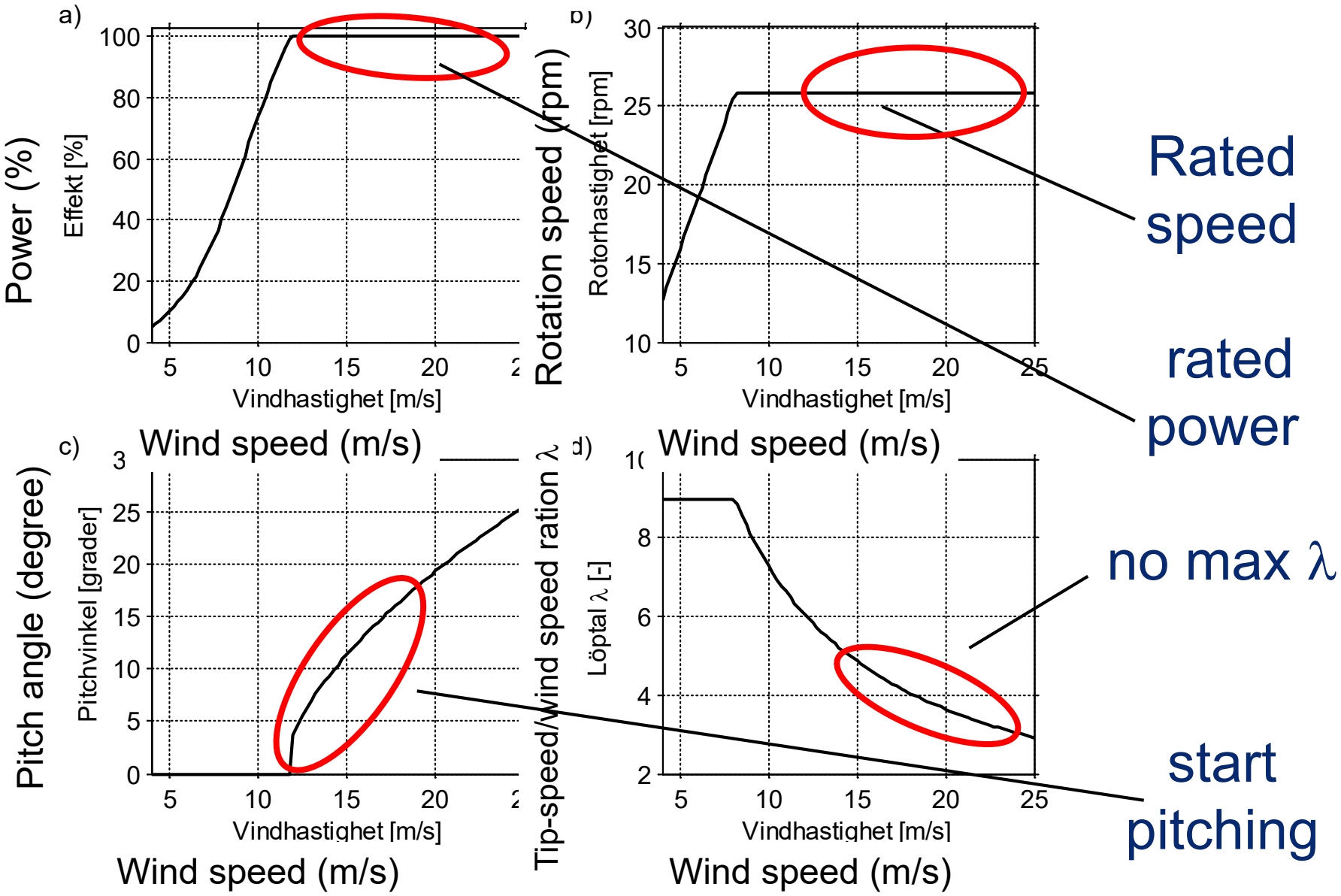


# Middel mode




constant speed and power increases and no max λ

# Rated mode


a)
Power (%)
Effekt [%]
Vindhastighet [m/s]
Wind speed (m/s)
b)
Rotation speed (rpm)
Rotorhastighet [rpm]
Vindhastighet [m/s]
Wind speed (m/s)
c)
Pitch angle (degree)
Pitchvinkel [grader]
Vindhastighet [m/s]
Wind speed (m/s)
d)
Tip-speed/wind speed ration λ
Löptal λ [-]
Vindhastighet [m/s]
Wind speed (m/s)
Rated speed
rated power
no max λ
start pitching

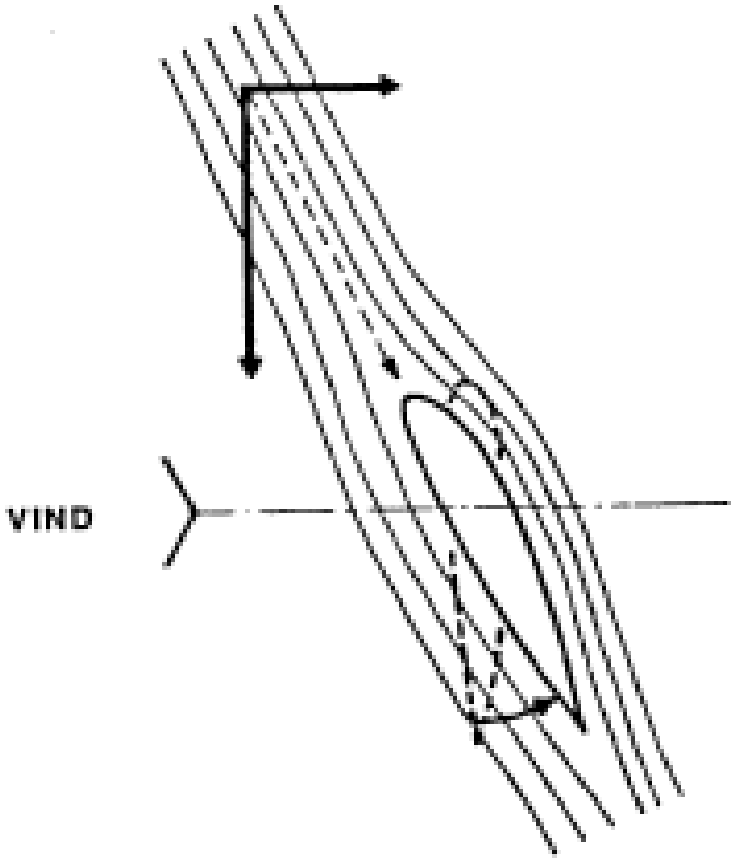
# Limitations of wind power

- Pitch control
  turn the blades
- Stall control
  Ridged blades,
  turbulence limit the power
- Active stall
  the pitch angle can be adjusted

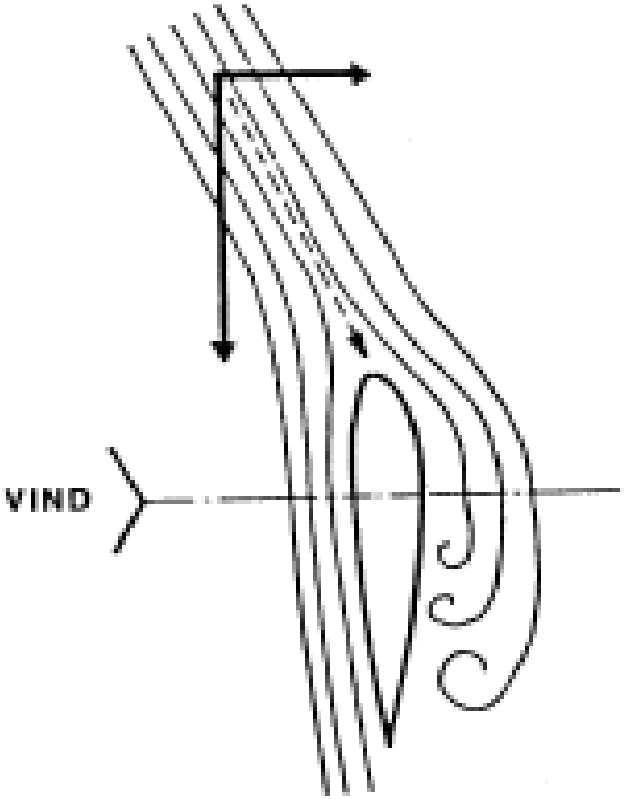
- At emergency stop will the blades turn
- At emergency stop will the outer part of the blades turn
- At emergency stop will the blades turn

# Control

## Pitch

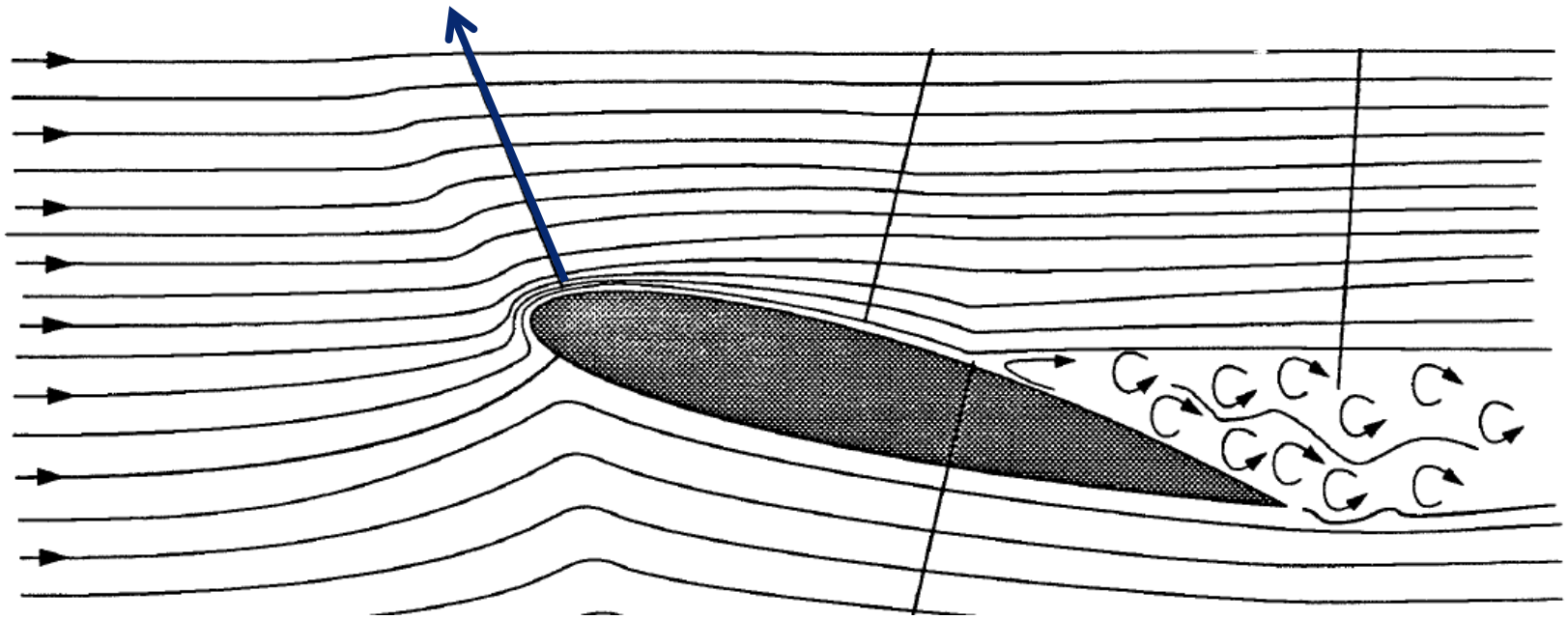



## Stall



# Stall control

Force from turbine laminar flow stalled condition



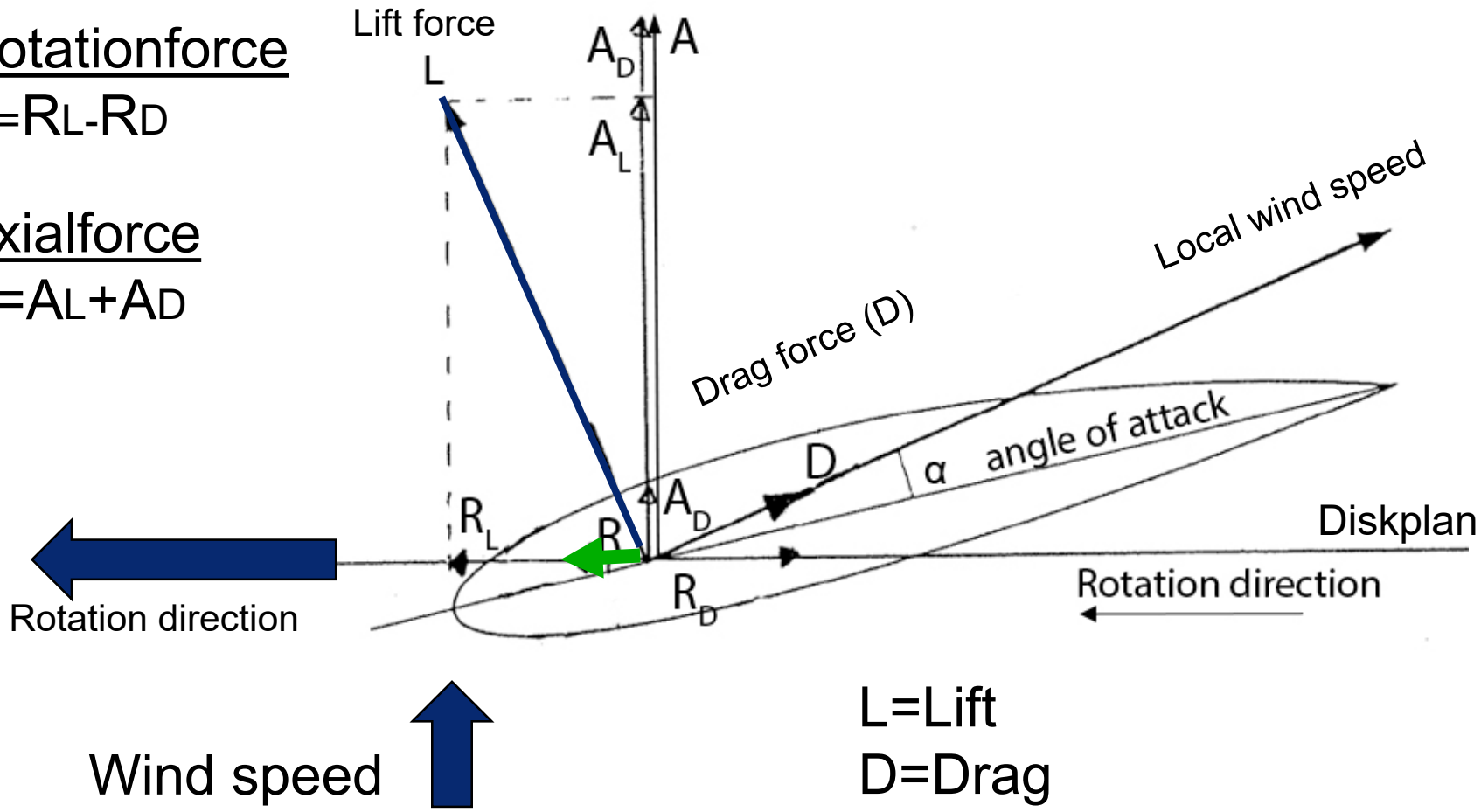
# Axial- and rotationsforces = Thrust and Torque

<u>Rotationforce</u>

$R = R_L - R_D$

<u>Axialforce</u>

$A = A_L + A_D$




L=Lift

D=Drag

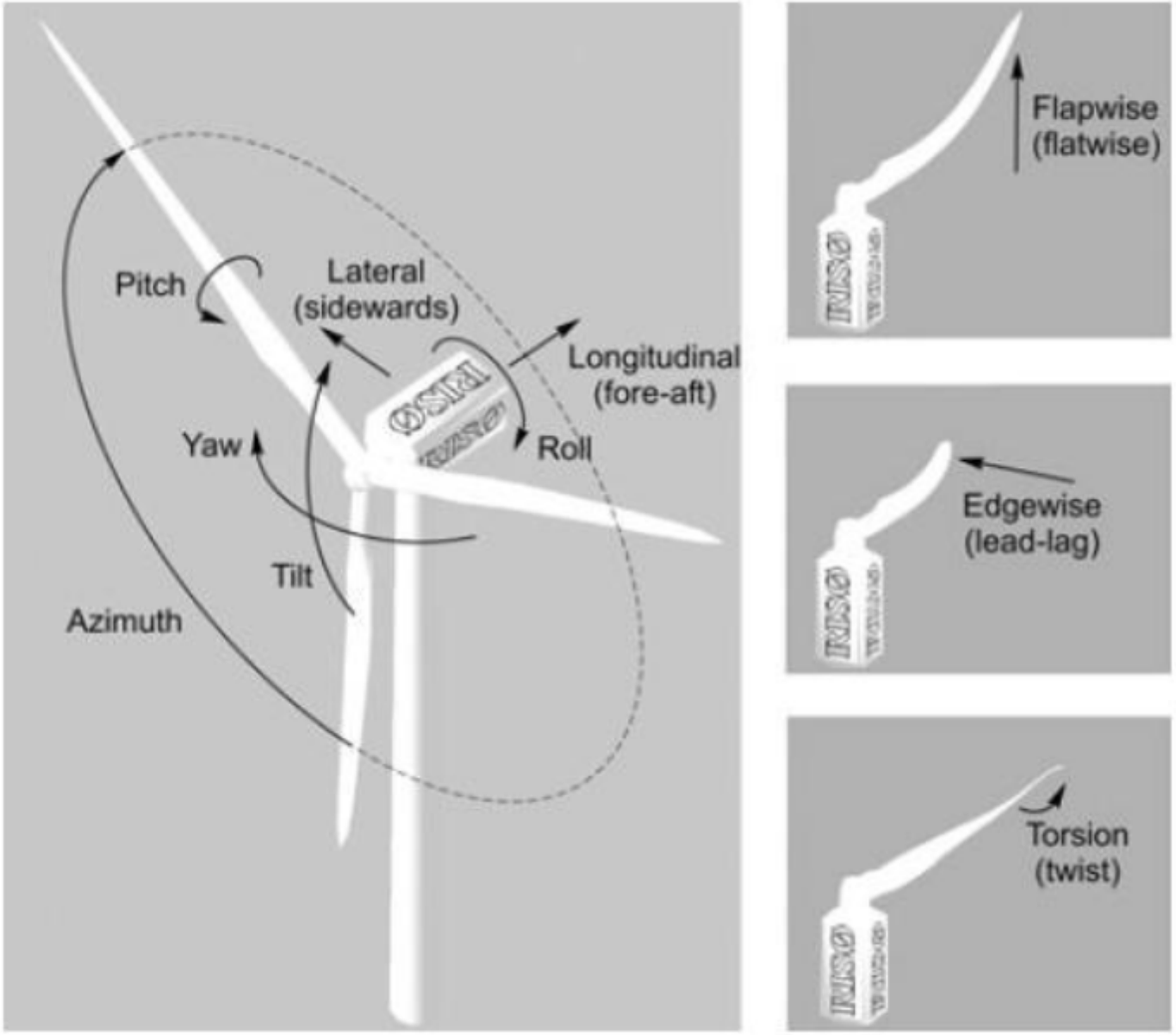
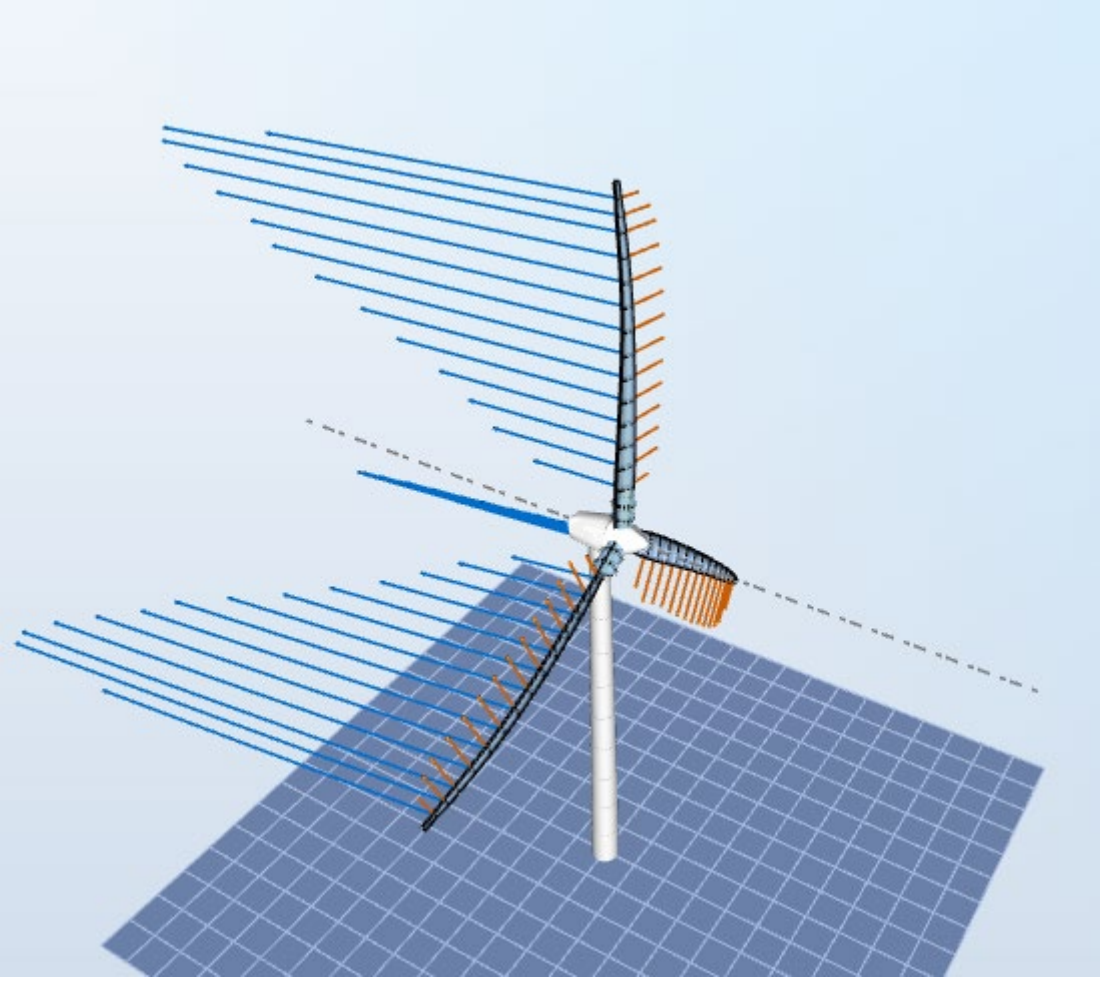



**Fig. 1** Terminology for degree-of-freedom of wind turbines [6]

# Thrust and Torque



The simulations in this computer lab will be done in the software Ashes, see Figure 1. To your help you have a prepared Excel file which you will find in Course Documents/SPPT Mechanics lab at the desktop.

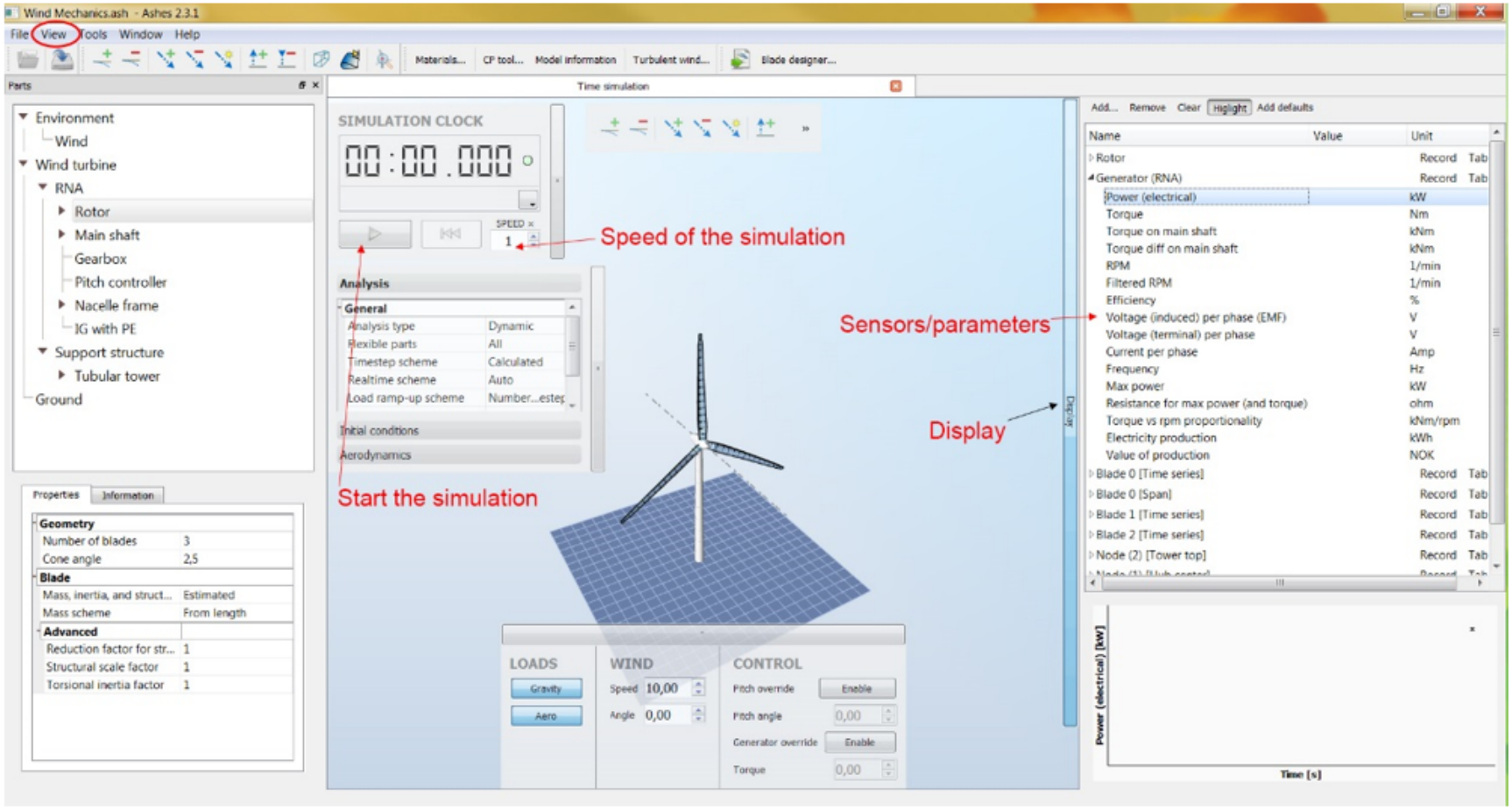



Figure 1 View of Ashes

If you like you can download Ashes to your own computer and try it out.
You will find the link to download at http://www.simis.io/. You need to register before downloading, but the software is free to try.

# Assignment Wind 2

Wind turbine control and $T = f(n)$

$T$ = Turbine torque as a function of turbine speed at optimal operation.

$$P_{mech} = \frac{1}{2}\rho \cdot C_p \cdot A \cdot {v_w}^3$$

$$\omega = \frac{2\pi n}{60} \qquad \lambda = \frac{v_{tip}}{v_w}$$

$$P_{mech} = T \cdot \omega$$

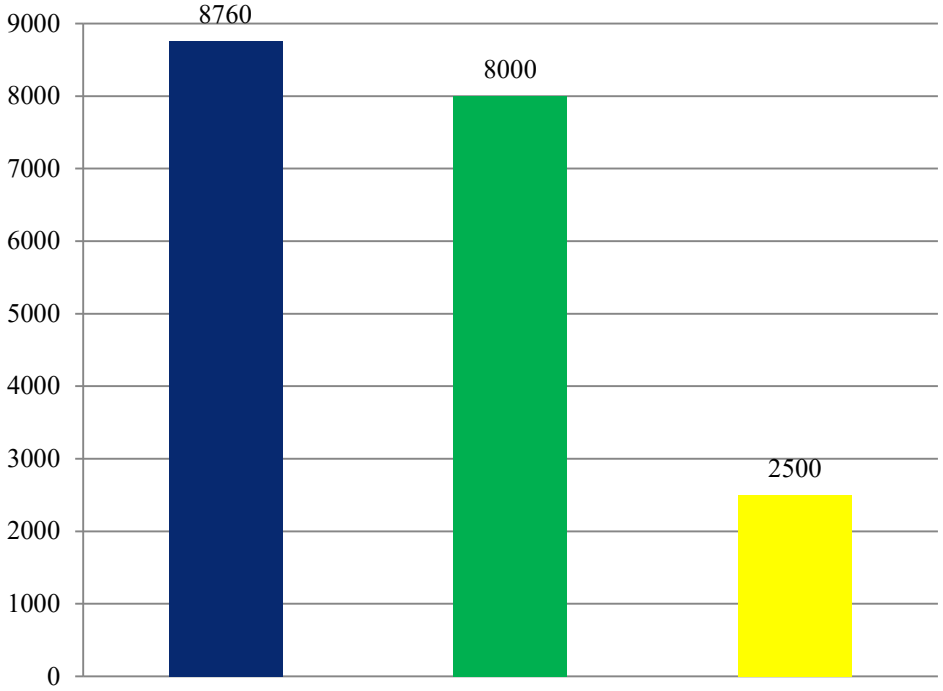
$$v_{tip} = r \cdot \omega$$

# Operation of the wind turbine

Hours in a year: 8760 — 100% of the year

Operation hours: 8000 — 91% of the year (at 4-25 m/s)

Equivalent Rated Power hours: 2500 — 29% of the year




Accessibility =
Part of the operation hours that the wind turbine is in operation (Sweden)

2009: 95,8%
95,5%

| | |
|---|---|
| Årstimmar | Hours in a year |
| Driftstimmar | Operation hours |
| Fullasttimmar | Equivalent Rated Power hours |

# Size and weight

Blade
Length: 45-107 m
Weight: ca 7-30 ton

# Size and weight

Nacelle Vestas
Weight: 70 ton
Size: 10*3*4 m

Nacelle Enercon
Weight: 120 ton

# Vestas

The 4 MW platform covers all wind segments enabling you to find the best turbine for your specific site.

**WINDCLASSES**

| TURBINE TYPE | Low Wind Speeds | Medium Wind Speeds | High Wind Speeds |
|---|---|---|---|
| **4 MW TURBINES** | | | |
| V105-3.45 MW™ IEC IA | | | ■ |
| V112-3.45 MW® IEC IA | | | ■ |
| V117-3.45 MW® IEC IB/ IEC IIA | | | ■ |
| V117-4.2 MW™ IEC IB-T/ IEC IIA-T/ IEC S-T | | | ■ |
| V126-3.45 MW® IEC IIA/ IEC IIB | | ■ | ■ |
| V136-3.45 MW® IEC IIB/ IEC IIIA | | ■ | ■ |
| V136-4.2 MW™ IEC IIB/ IEC S | | ■ | ■ |
| V150-4.2 MW™ IEC IIIB/ IEC S | ■ | ■ | |
| V155-3.3 MW™ IEC S | ■ | | |

| | |
|---|---|
| **POWER REGULATION** | Pitch regulated with variable speed |

**OPERATING DATA**

| | |
|---|---|
| d power | 3,300 kW |
| Cut-in wind speed | 3m/s |
| Cut-out wind speed | 18m/s |
| Re cut-in wind speed | 16m/s |
| Wind class | IEC S |

Standard operating temperature range from -20°C* to +45°C with de-rating above 30°C

*subject to different temperature options

**SOUND POWER**

| | |
|---|---|
| Maximum | 107.7dB(A)** |

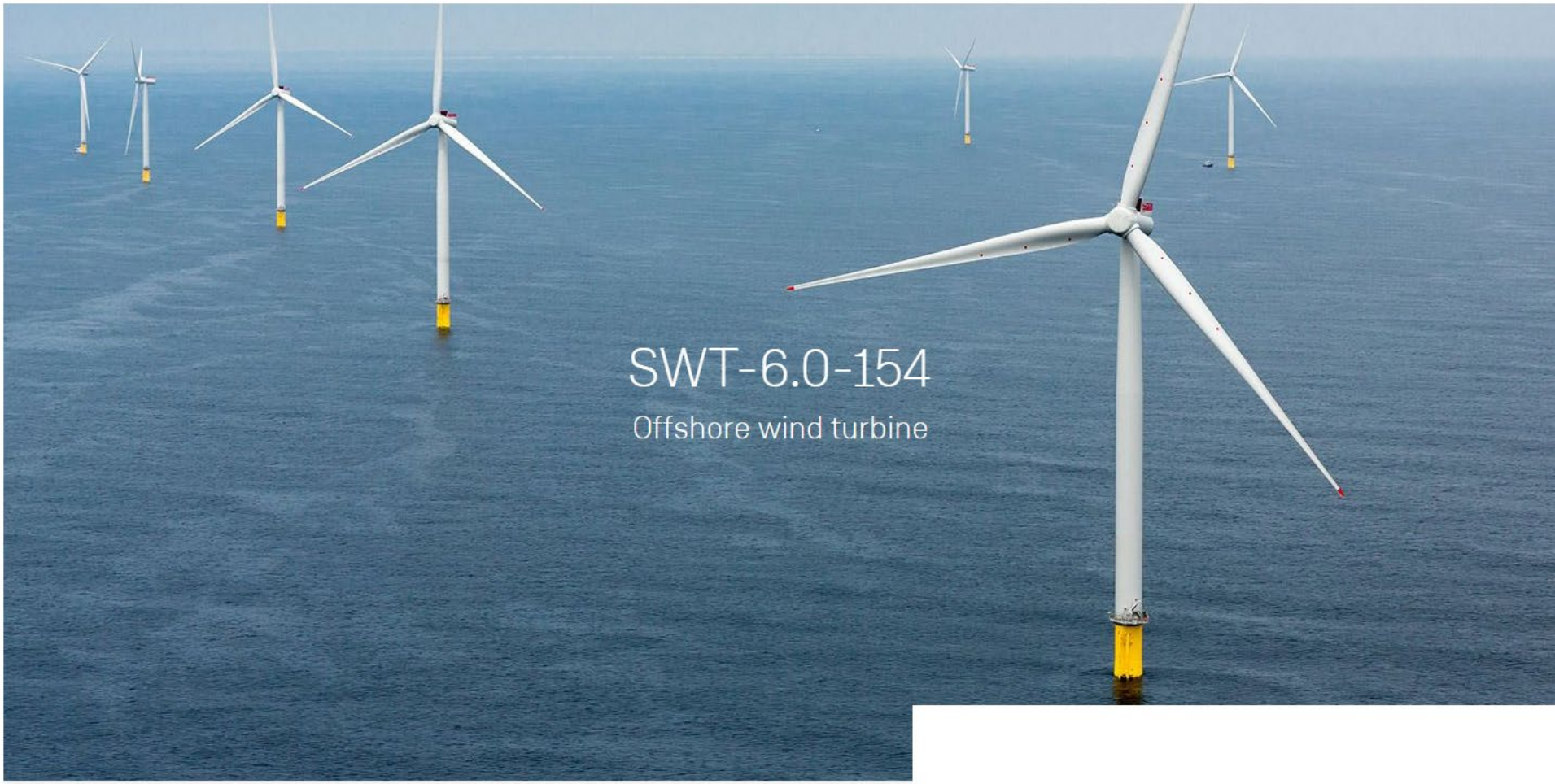
**Sound Optimised modes dependent on site and country

**ROTOR**

| | |
|---|---|
| Rotor diameter | 155m |
| Swept area | 18,869m² |
| Air brake | full blade feathering with 3 pitch cylinders |

**ELECTRICAL**

| | |
|---|---|
| Frequency | 50/60Hz |
| Converter | full scale |




Contact Siemens Gamesa

Siemens Gamesa 5.X

## SG 5.8-170

As a part of our Siemens Gamesa 5.X onshore platform, the SG 5.8-170 comes with high performance and proven reliability at medium and low wind.

170 m

5.8 MW

Geared

OptimaFlex

SG 14-222 DD

## Strong winds of change

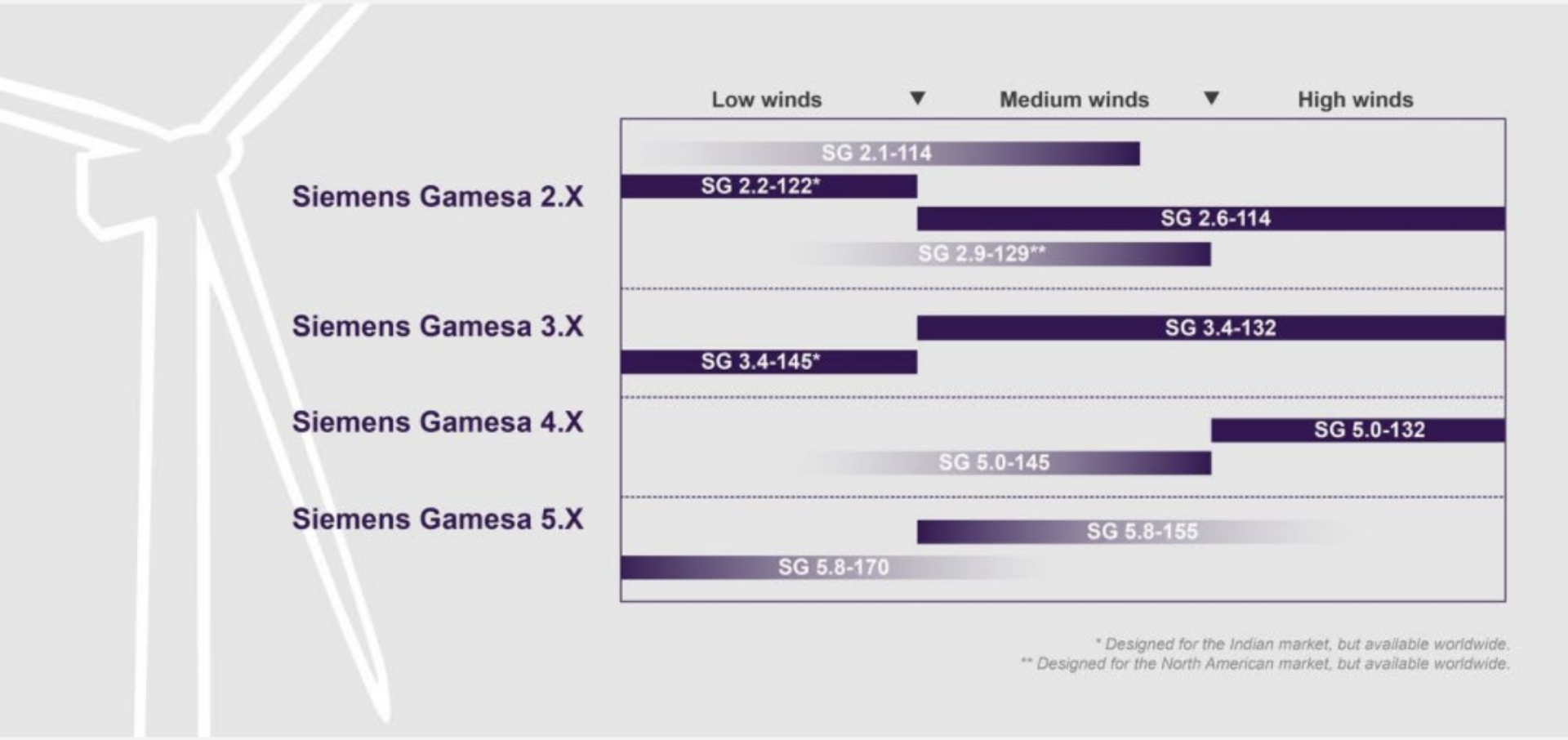
The SG 14-222 DD is based on proven technology and will deliver safe and clean energy for a sustainable future.

I, S

222 m

2024

14 MW


Low winds
Medium winds
High winds
Siemens Gamesa 2.X
SG 2.1-114
SG 2.2-122*
SG 2.6-114
SG 2.9-129**
Siemens Gamesa 3.X
SG 3.4-132
SG 3.4-145*
Siemens Gamesa 4.X
SG 5.0-132
SG 5.0-145
Siemens Gamesa 5.X
SG 5.8-155
SG 5.8-170
* Designed for the Indian market, but available worldwide.
** Designed for the North American market, but available worldwide.

## ENERCON E-160 EP5

# Overview of technical details

| | |
|---|---|
| Rated power | 4,600 kW / 5,500 kW |
| Rotor diameter | 160 m |
| Hub height in meter | 120 / 166 |
| Wind class (IEC) | IEC IIIA |
| WEC concept | Gearless, variable speed, full power converter |

# E-160 EP5

Overview of technical data

Complete view