Introduction to Wind Energy Systems

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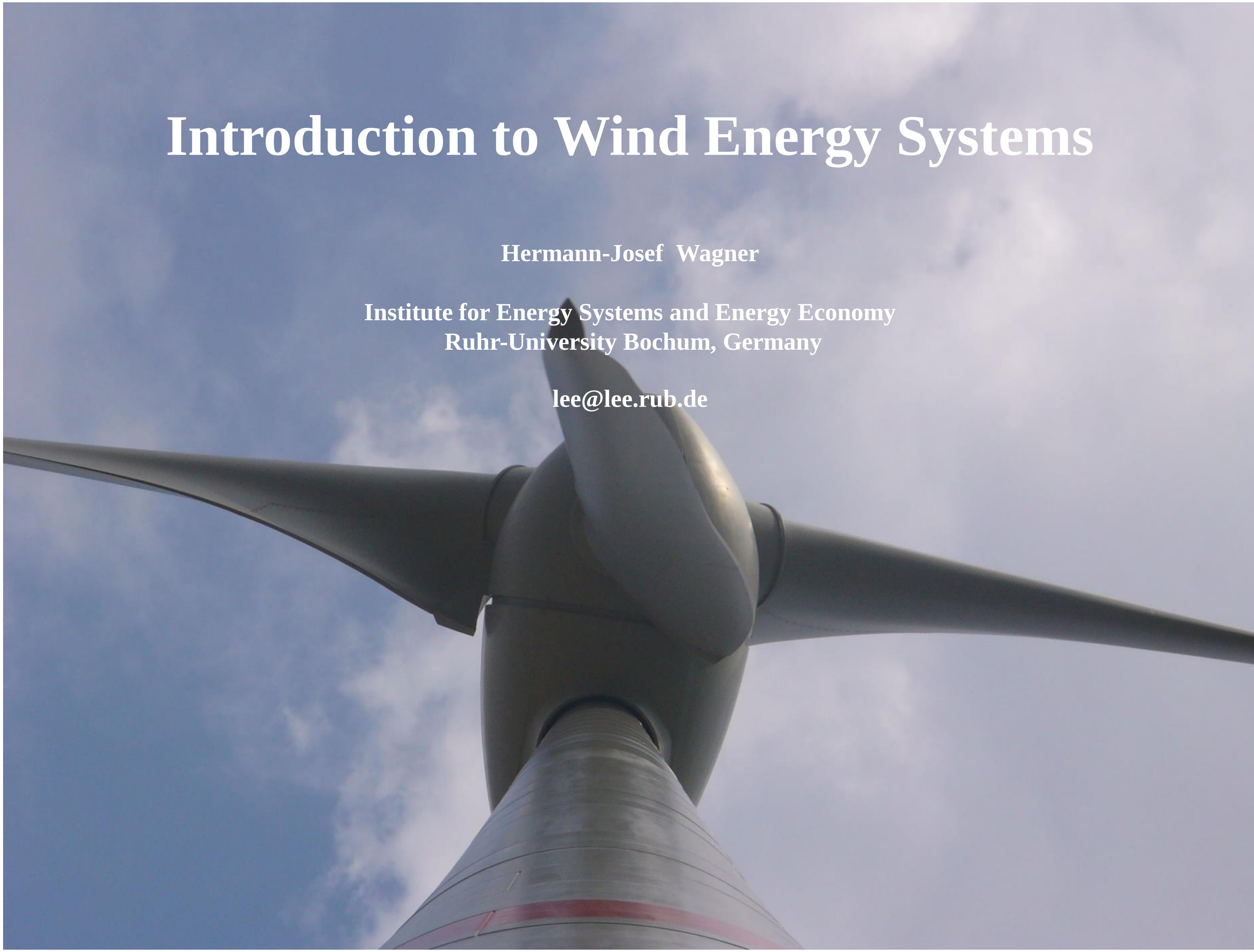

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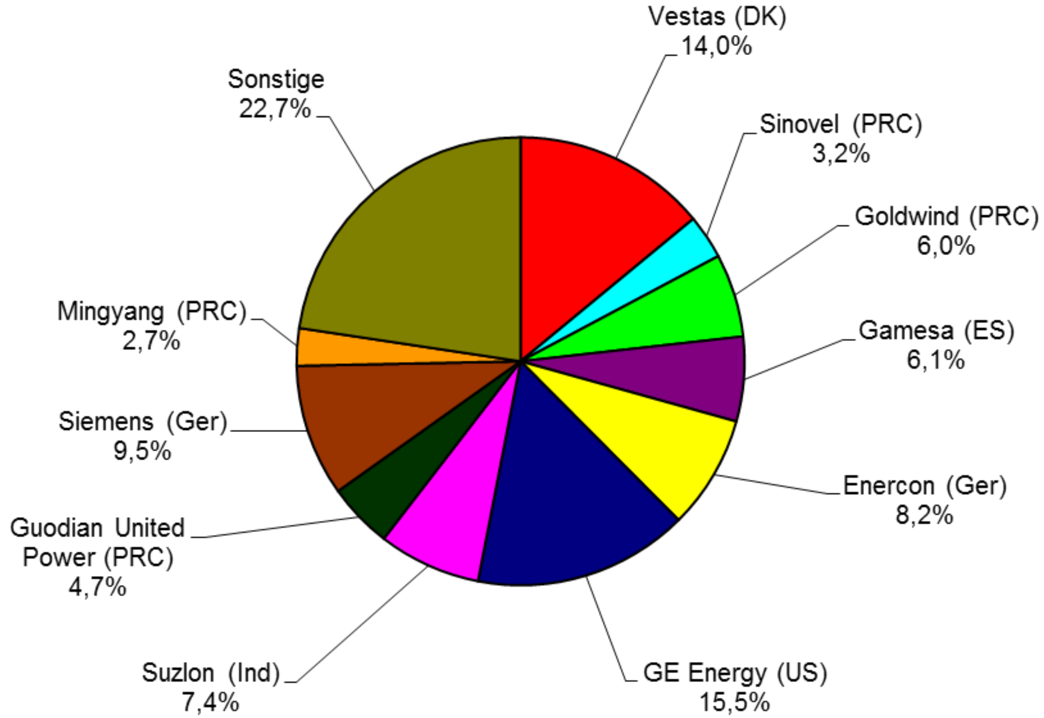
- **Present status of wind energy use**
- Physical and meteorological basics
- Techniques of wind converters
- Off shore windparks
- Wind use in Europe

Status of installed wind power		
	Rated Capacity End of 2013 [GW]	Share worldwide [%]
China	91	29
USA	61	19
Germany	35	11
Spain	23	7
India	20	6
UK	11	3
Italy	9	3
France	8	3
Canada	8	2
Denmark	5	2
Remaining countries	48	15
Total	**319**	**100**

Source: DEWI Magazin, No. 44; Feb. 2014,p.36

Electricity from wind energy



New erected capacity 2012:

44.700 MW

Source: http://de.statista.com/statistik/daten/studie/169595/umfrage/marktanteile-der-groessten-windturbinen-produzenten-weltweit/

Shares of the suppliers in the world market

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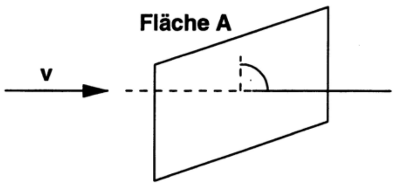
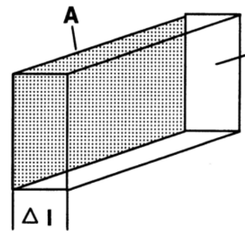
Derivative of the equation with steady velocity of wind v





$$\Delta V = A \cdot \Delta l$$

$$v = \frac{\Delta l}{\Delta t}$$

$$\Delta V = A \cdot v \cdot \Delta t$$

Kinetic energy E of a mass element Δ m

$$\Delta E = \frac{1}{2} \Delta m \; v^2$$

$$\Delta m = \Delta V \cdot \rho_L$$

$$\Delta E = \frac{1}{2} \cdot A \cdot \rho_L \cdot v^3 \; \Delta t$$

$$E = \frac{1}{2} A \; \rho_L \cdot v^3 \cdot t$$

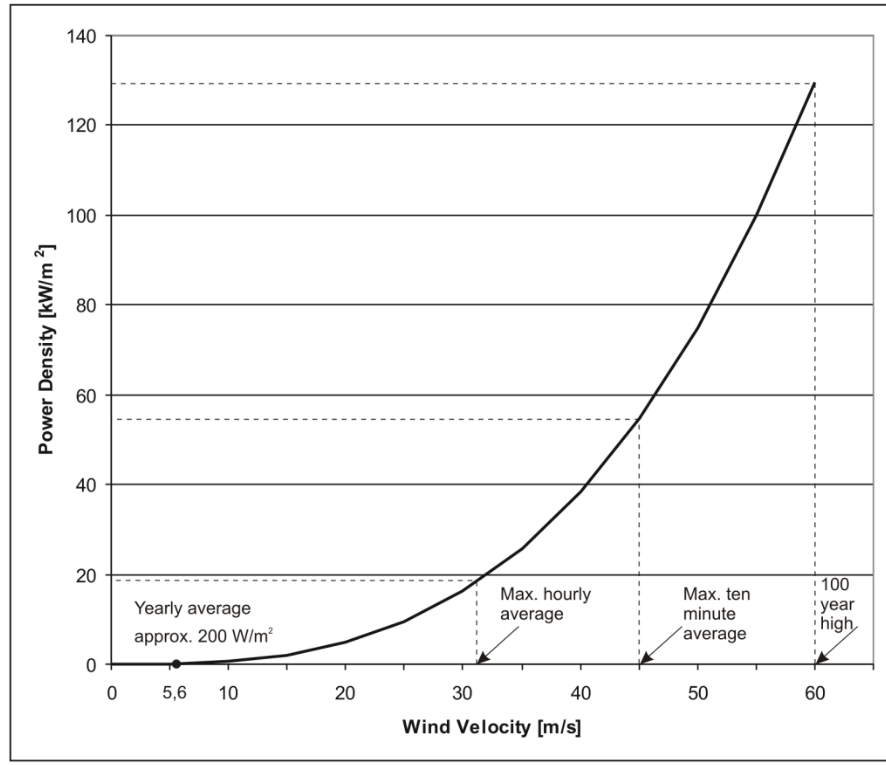
$$P = \frac{E}{t} = \frac{1}{2} \cdot A \cdot \rho_L \cdot v^3$$

V = volume

ρ_L = density of air
= 1,2 kg/m³

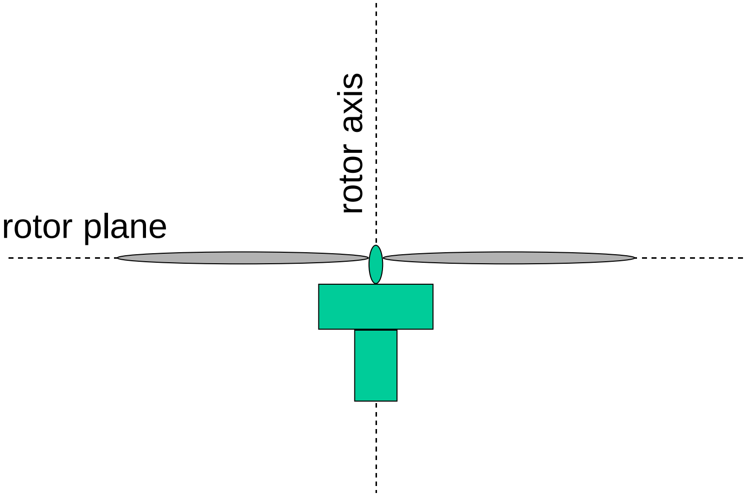
Efficiency

$$\eta = \frac{P_{el}}{\frac{1}{2} \cdot \rho_L \cdot A \cdot v^3}$$



Energy and power density of wind

Bird's eye view of horizontally positioned rotor blades



a_A = angle of attack (angle between profile chord and relative approach velocity)

b = pitch angle

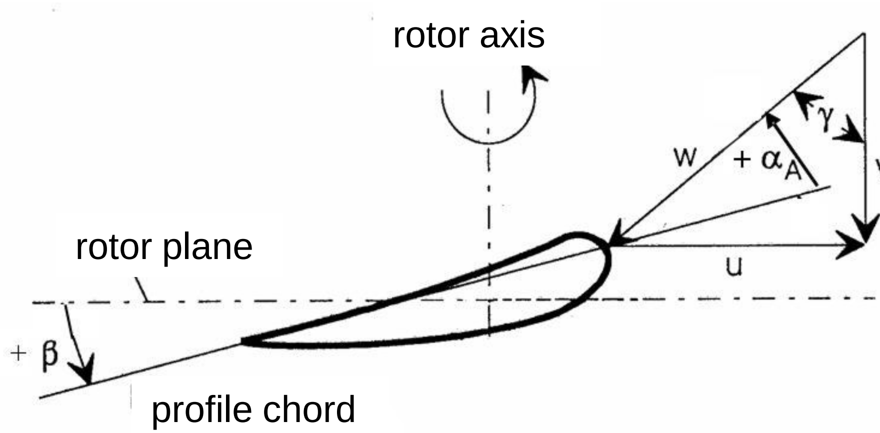
g = angle between wind velocity and approach velocity

u = circumferential velocity

v_0 = wind velocity in the rotor axis

w = relative approach velocity (Es gilt:)

Bird's eye view of vertically positioned rotor blades



for the pitch angle applies:

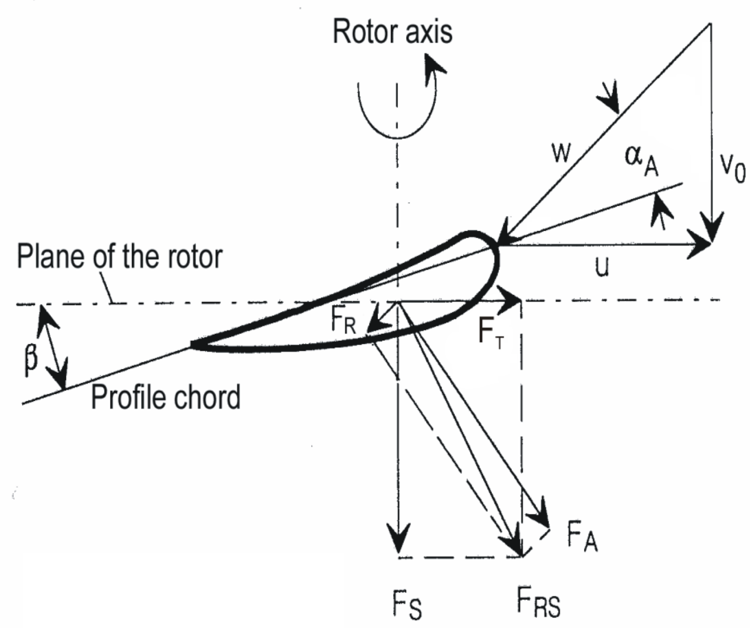
α_A should be optimal,

besides use b as a set variable in accordance to

v_0 and u (revolution)

$$\alpha_A = f(\beta, v_0, u) = \arctan(v_0/u) - b$$

Velocity triangle at the rotor blade



α_A = Angle of attack
β = Pitch Angle
u = Average circumferential velocity
v_n = Wind velocity in the rotor plane
w = Relative approach velocity
F_R = Drag force
F_A = Lift force
F_{RS} = Resultant force
F = Tagental component
F_S = Axial component

The velocities and forces acting on a blade

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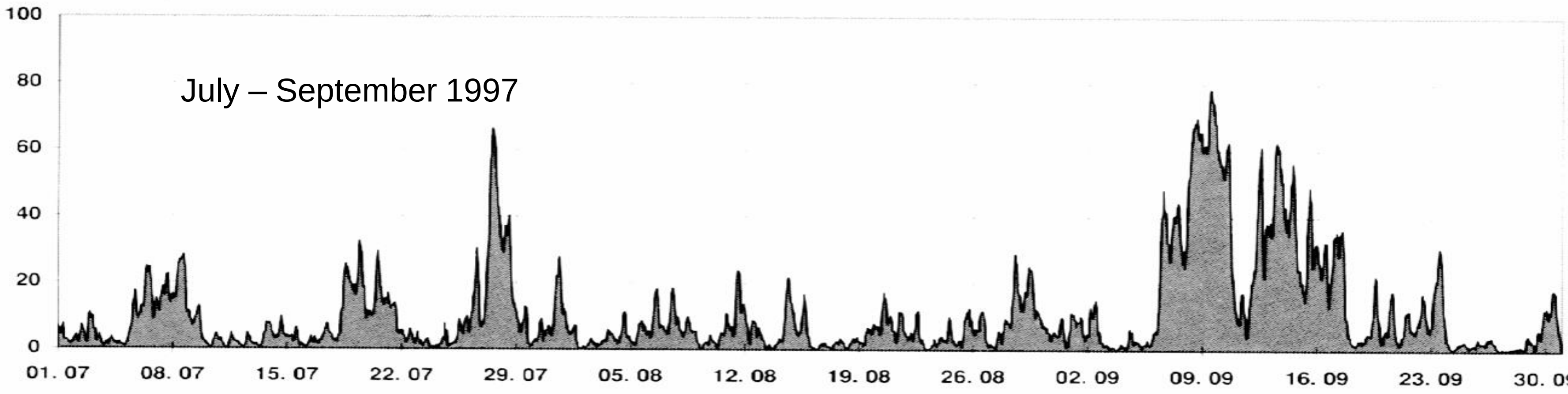
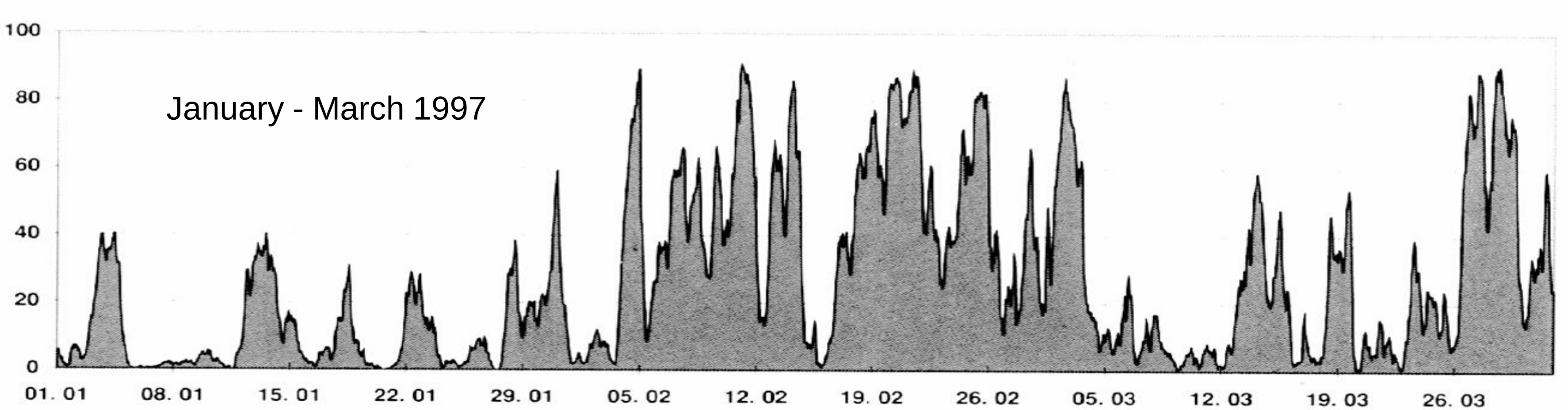
Percent of total capacity (28 MW)



Percent of total capacity (28 MW)



Source: 250 MW-Auswertebericht: zitiert nach M. Kleemann, FZ Jülich, Vortrag Dehli Januar 2002

Load distribution – Measurement 250 MW program

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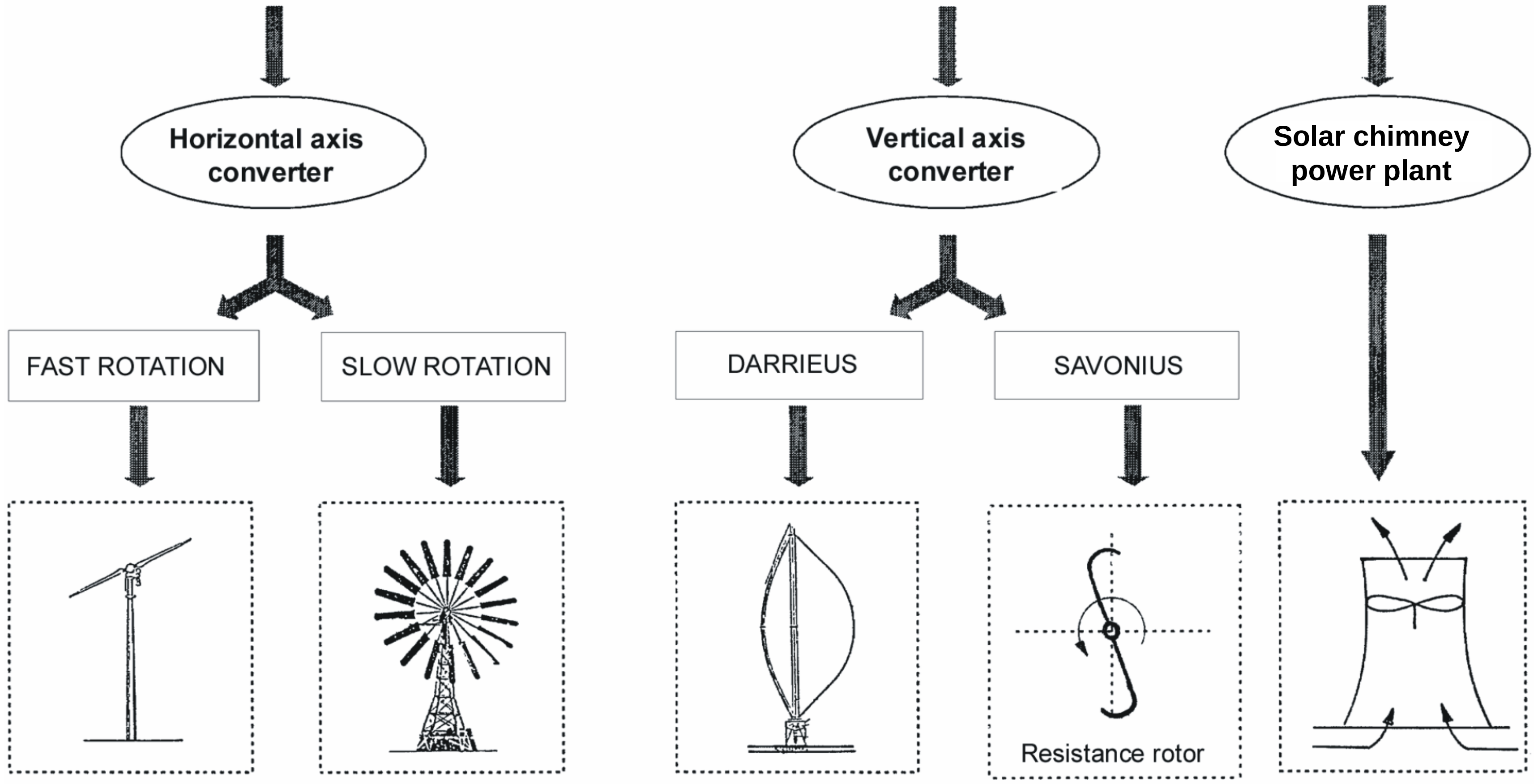


Different types of wind energy converters

Definition of the rotor power

$P = 0{,}5 \cdot c_p \cdot \rho \cdot A \cdot v^3$

v = wind velocity

A = rotor circular area = $\pi\, l^2$ with l = rotor length

ρ = air density

c_p = power coefficient

Dependence of the power coefficient c_p

c_p interdepends with three factors:

1. Blade design, i.e. ratio of buoyancy factor to friction factor = glide ratio.
   The glide ratio affects the tip speed ratio strongly.

2. Ratio blade tip velocity to wind velocity = tip speed ratio λ
   Dutchmen windmills: $\lambda = 2 - 4$
   Modern 3-blade conversion systems: $\lambda = 3 - 12$
   Limitation of the tip speed ratio in practice due to sound emissions (blade tip velocity contributes to sound emissions with the power of six)

3. Ratio of the sum of all blade areas to the rotor circular area A = solidity ratio.
   which is simplified the number of rotor blades.

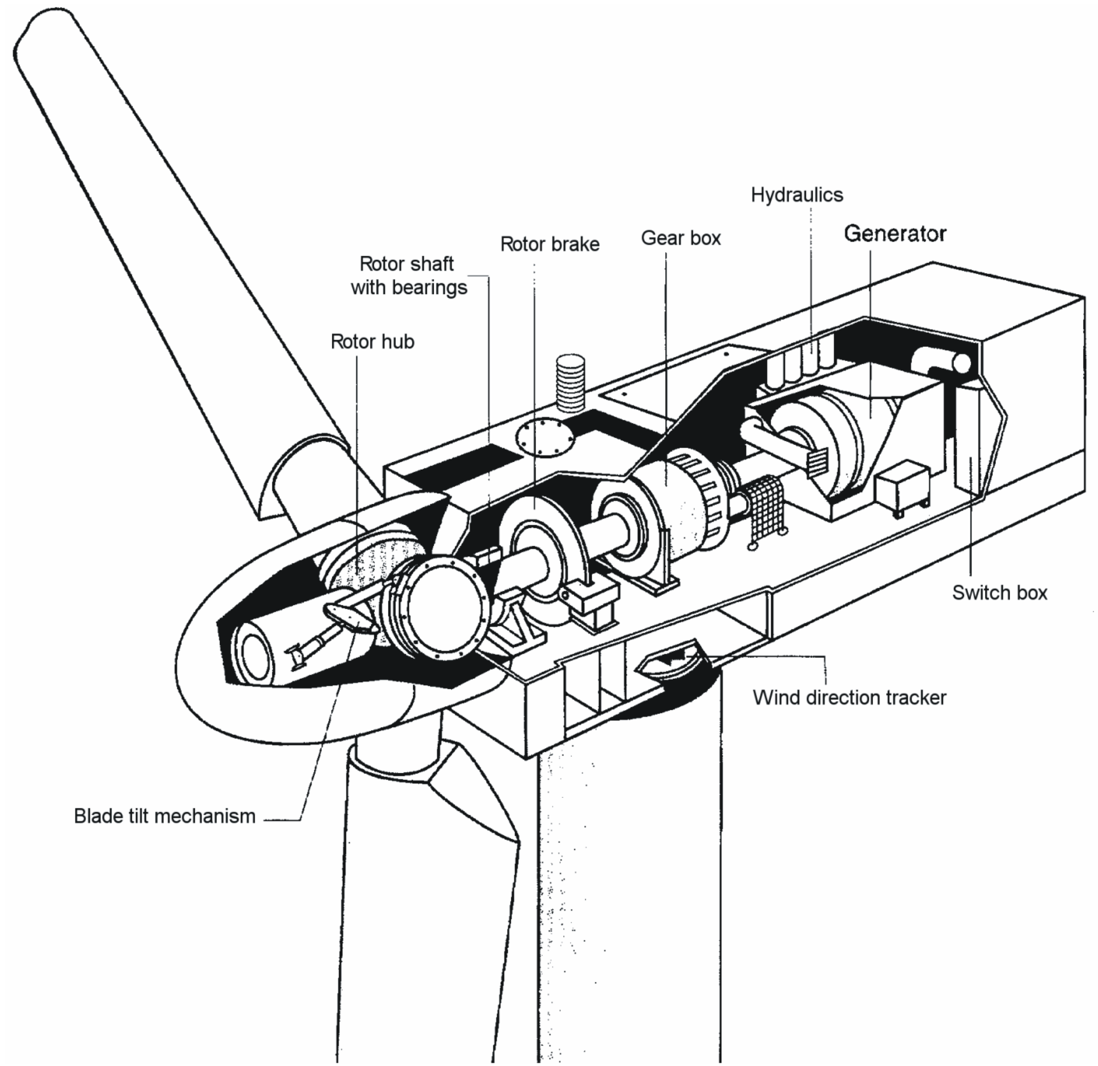
„Cooking recipes"
for dimensioning of wind energy conversion systems

1. High glide ratios lead to high tip speed ratios and therefore to a large power coefficient c_p
   → Modern converters with good aerodynamic profiles rotate quickly.

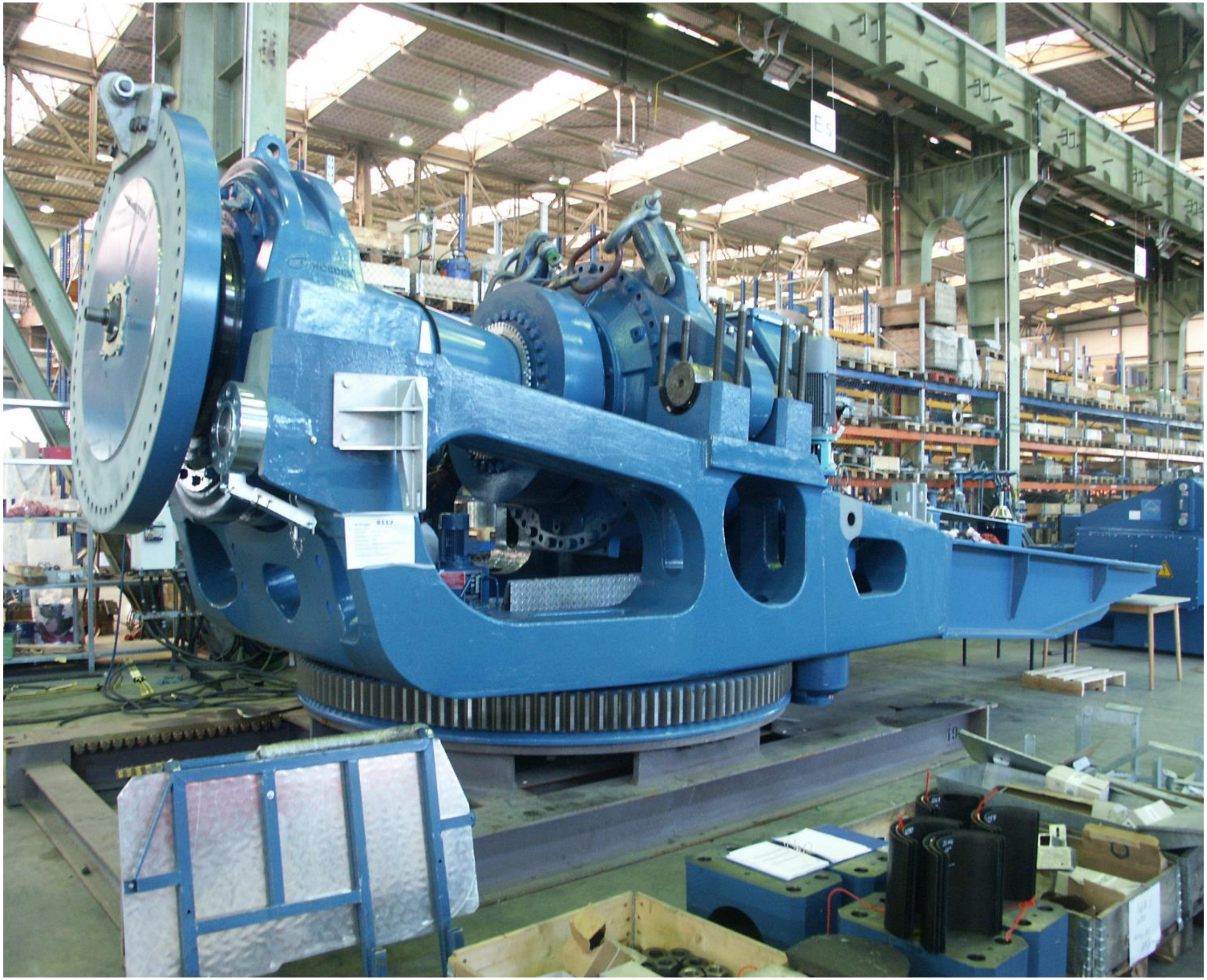
2. Simple profiles with a smaller glide ratio have smaller tip speed ratios. Therefore is a large solidity ratio required to achieve an increase of the power coefficient.
   → Slow rotating converters have poor aerodynamic profiles and a high number of blades

3. Glide ratio and tip speed ratio have a larger influence on the power coefficient than the solidity ratio.

   → Number of blades for fast rotating converters has a secondary relevance (in practice mostly 2-3).



Constructional type of a WECS with „classical“ power train



Source: Nordex AG

Assembling of a wind converter by Nordex AG

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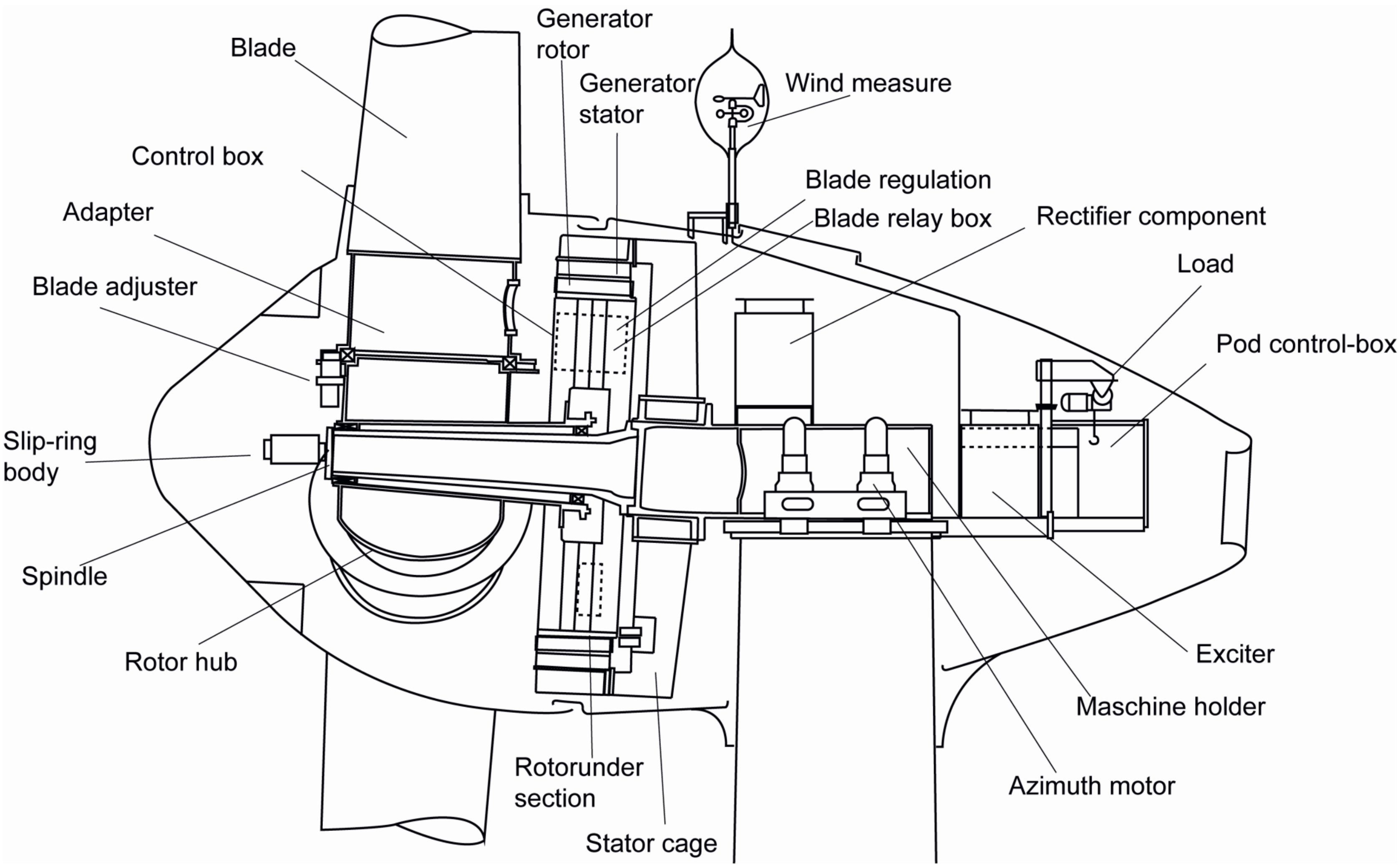
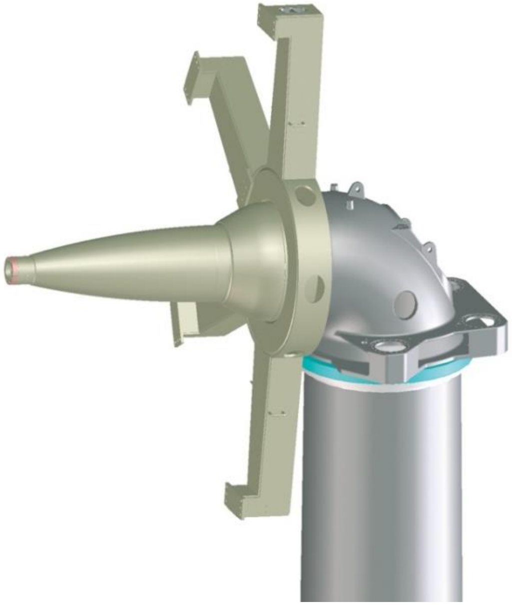
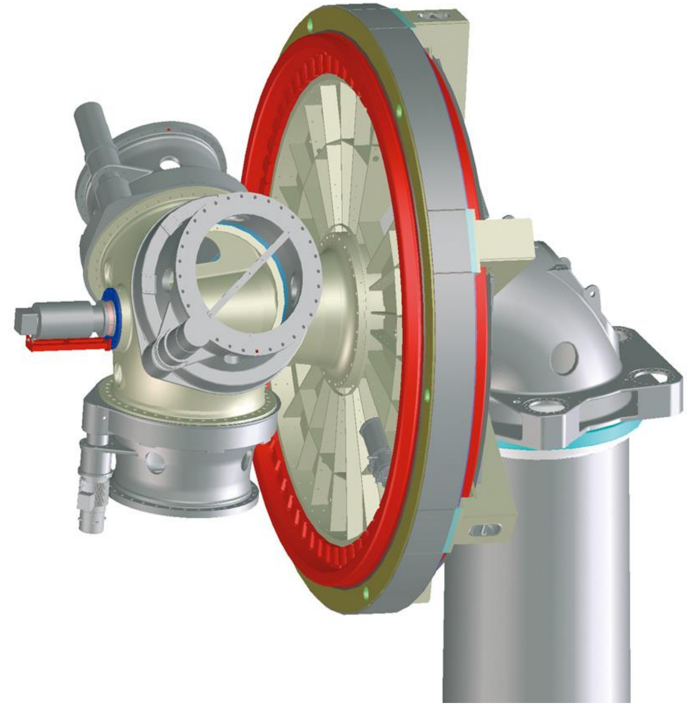
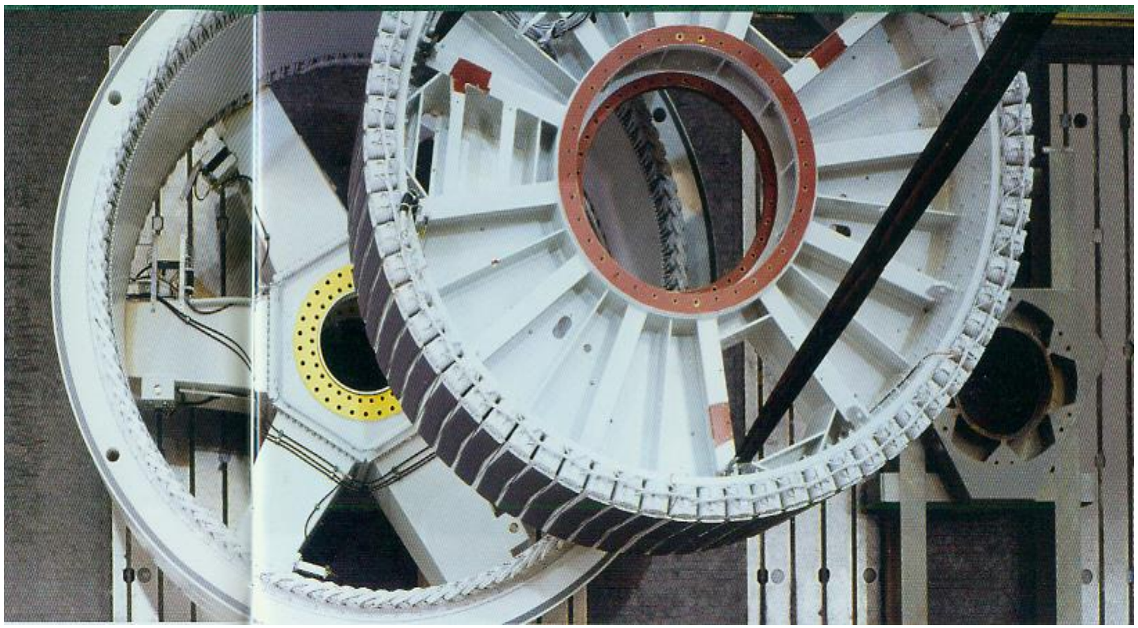


Constructional type of the WEC Enercon-66

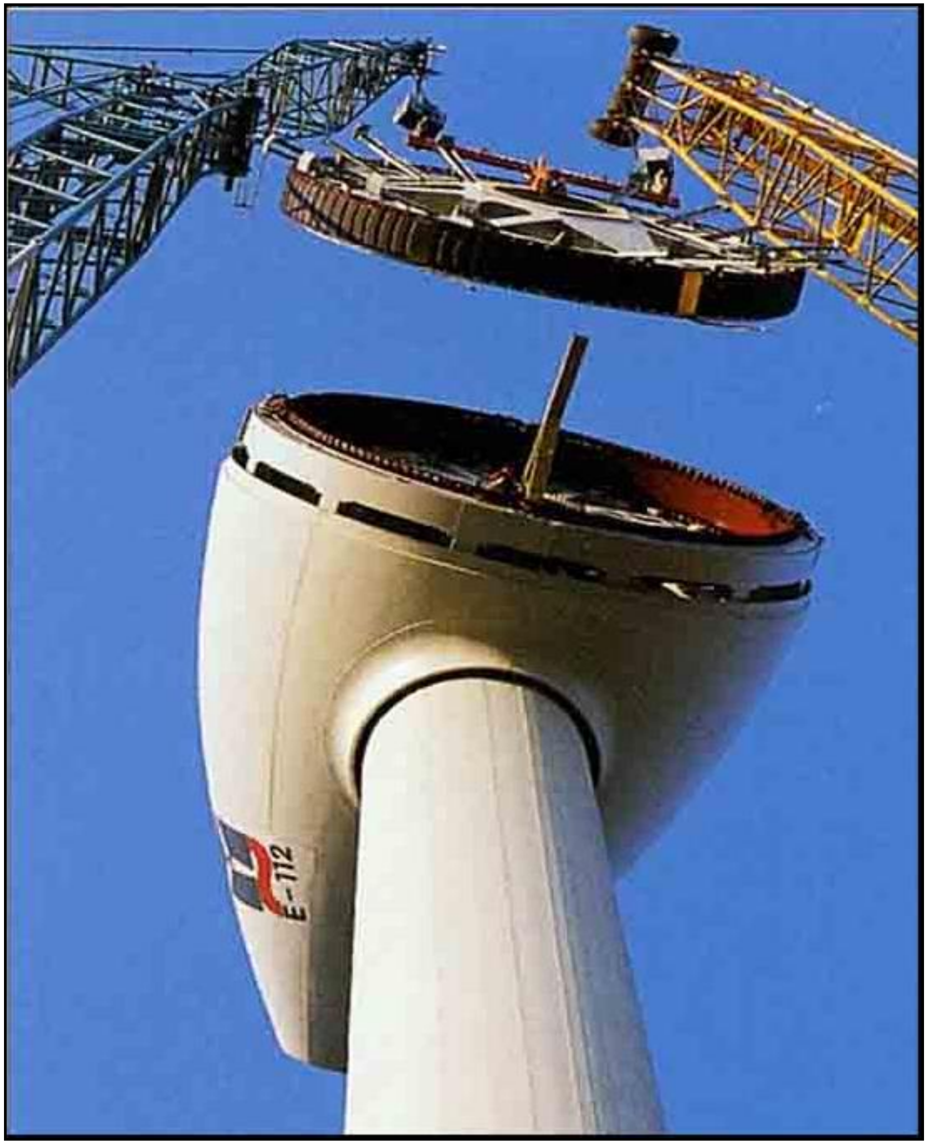




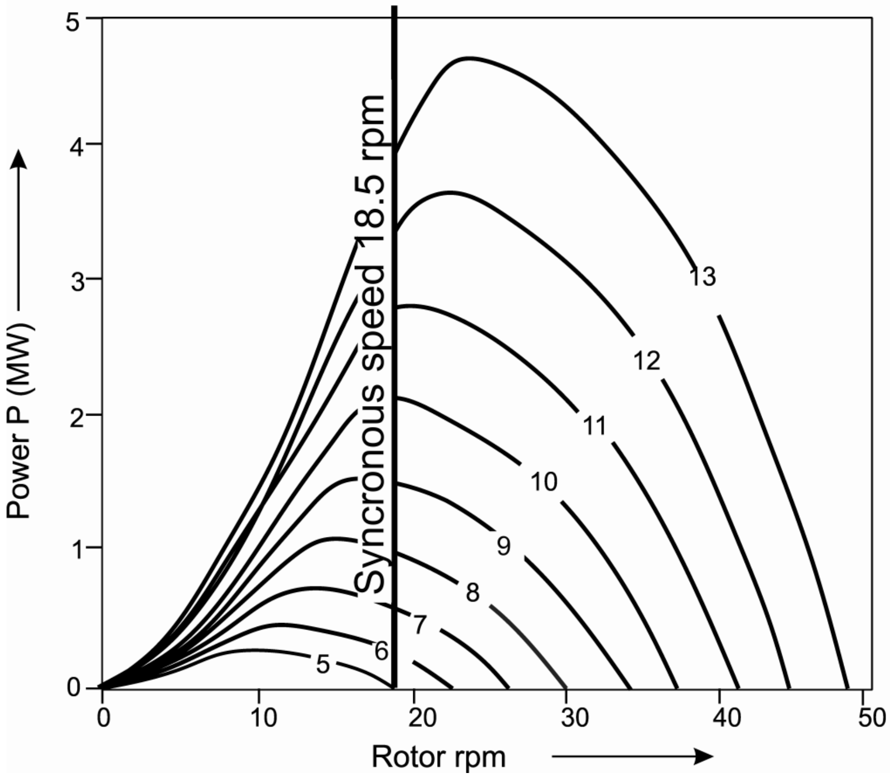


Source: ENERCON GmbH

Wind energy converter without gear box



Installation of the generator by a wind mill without gears

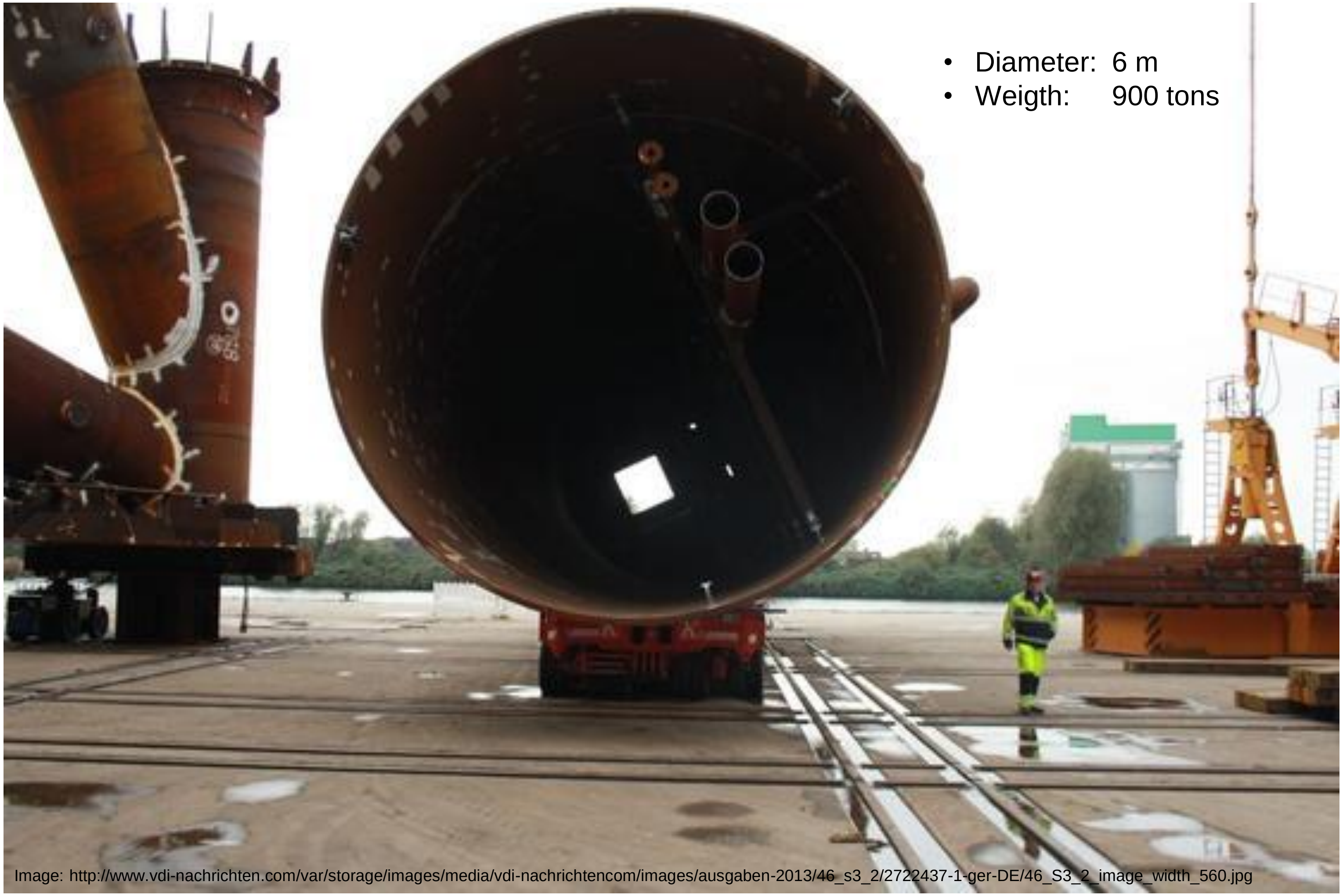


Adjusting of the revolutions and the line frequency with:

- controllable gearing or
- changeable number of pole pairs (electrical gearing) or
- asynchronous generator with extended slip or
- intermediate direct currency link

Curve family of a fast rotating rotor

Central tube of a wind power station foundation



- Diameter: 6 m
- Weigth: 900 tons

Image: http://www.vdi-nachrichten.com/var/storage/images/media/vdi-nachrichtencom/images/ausgaben-2013/46_s3_2/2722437-1-ger-DE/46_S3_2_image_width_560.jpg

Source: „Das letzte Fundament“, VDI Nachrichten No. 46, November 2013

New devices need testing: Problems with gear boxes

Image: http://ais.badische-zeitung.de/piece/04/81/34/f7/75576567.jpg

Burned off wind power station in Lahr/Schwarzwald, Germany

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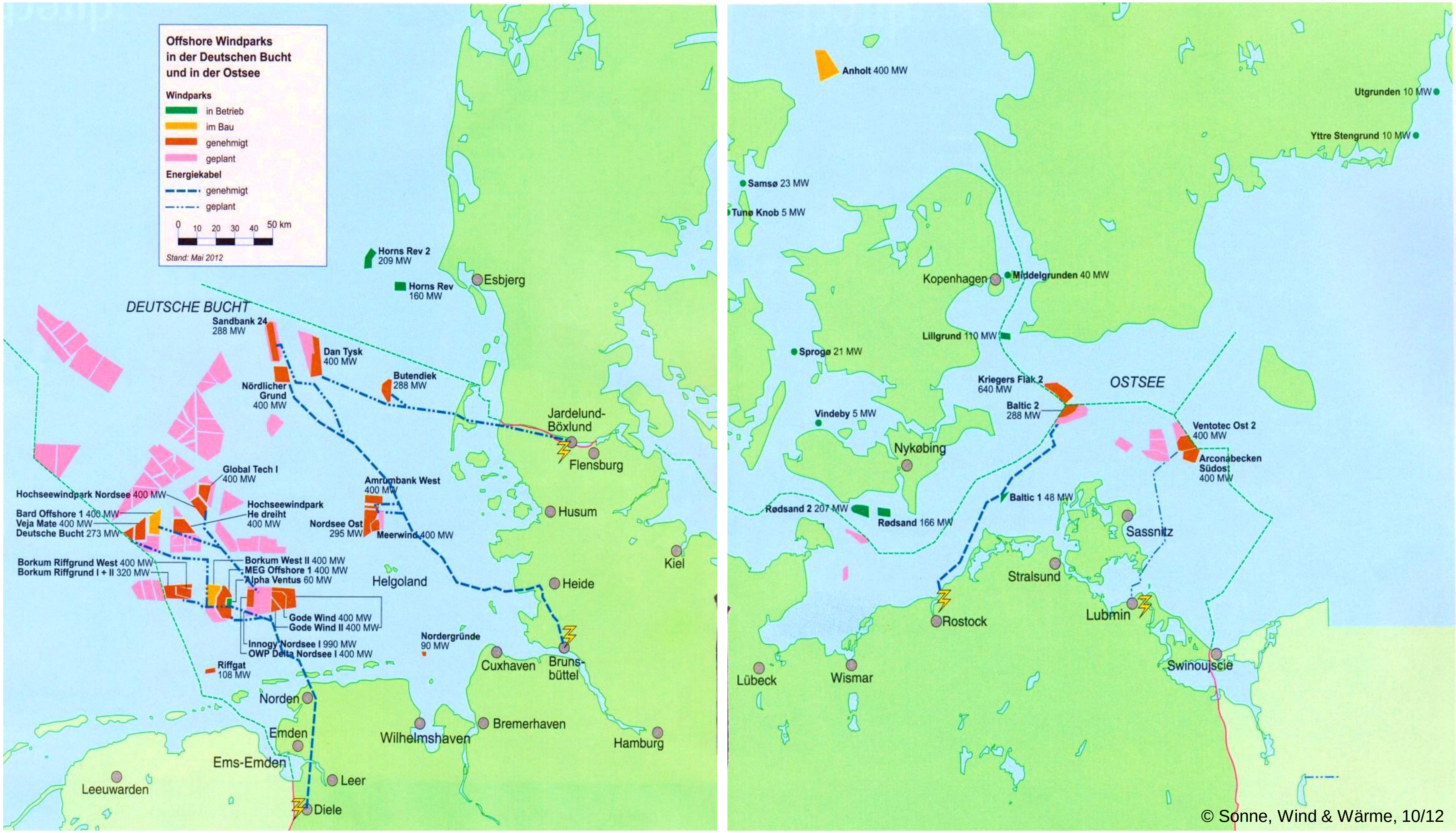

Offshore wind projects in the German part of north and east sea

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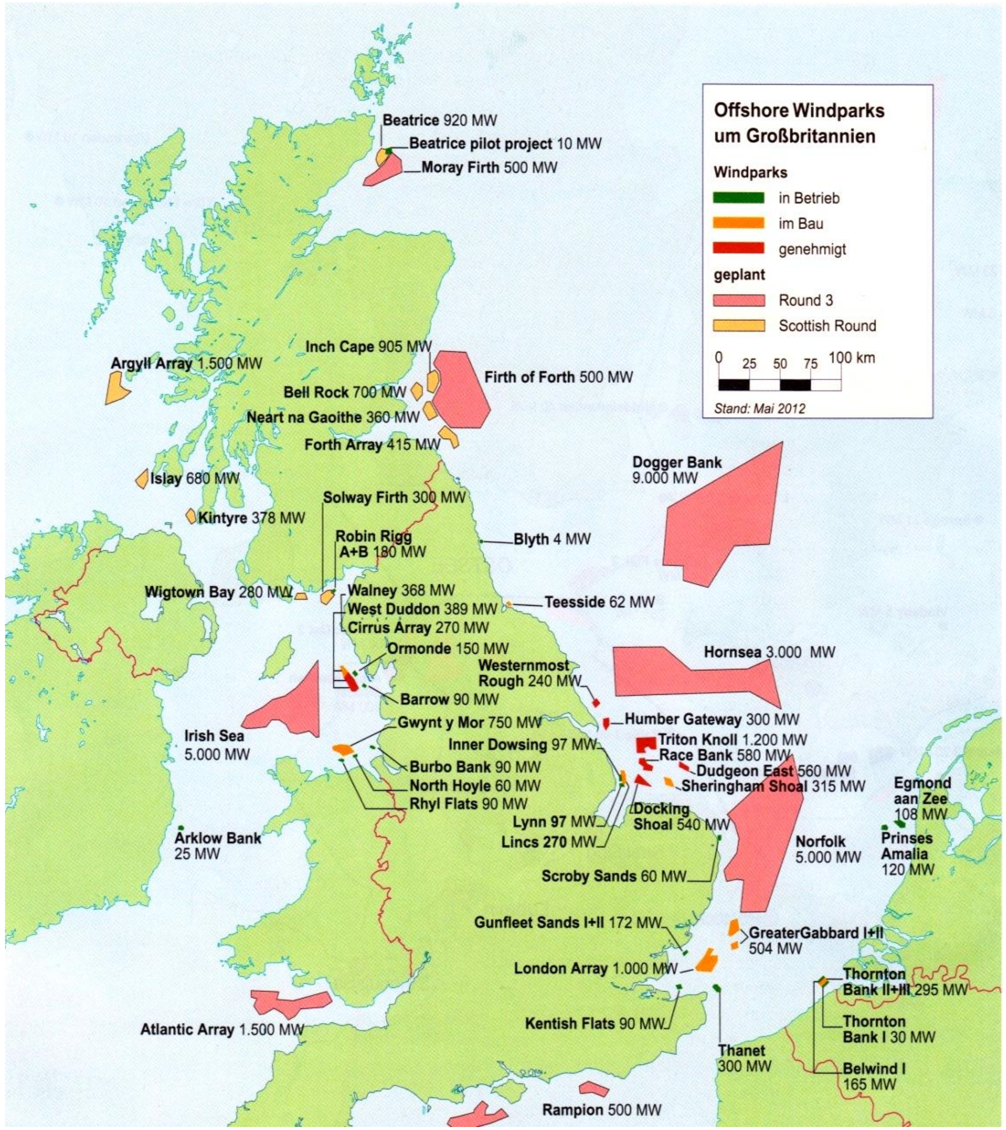

Source: Sonne, Wind und Wärme 10/2012

Offshore-wind projects in Great Britain, Ireland, France and Netherlands

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Offshore wind farm alpha-ventus: Panorama

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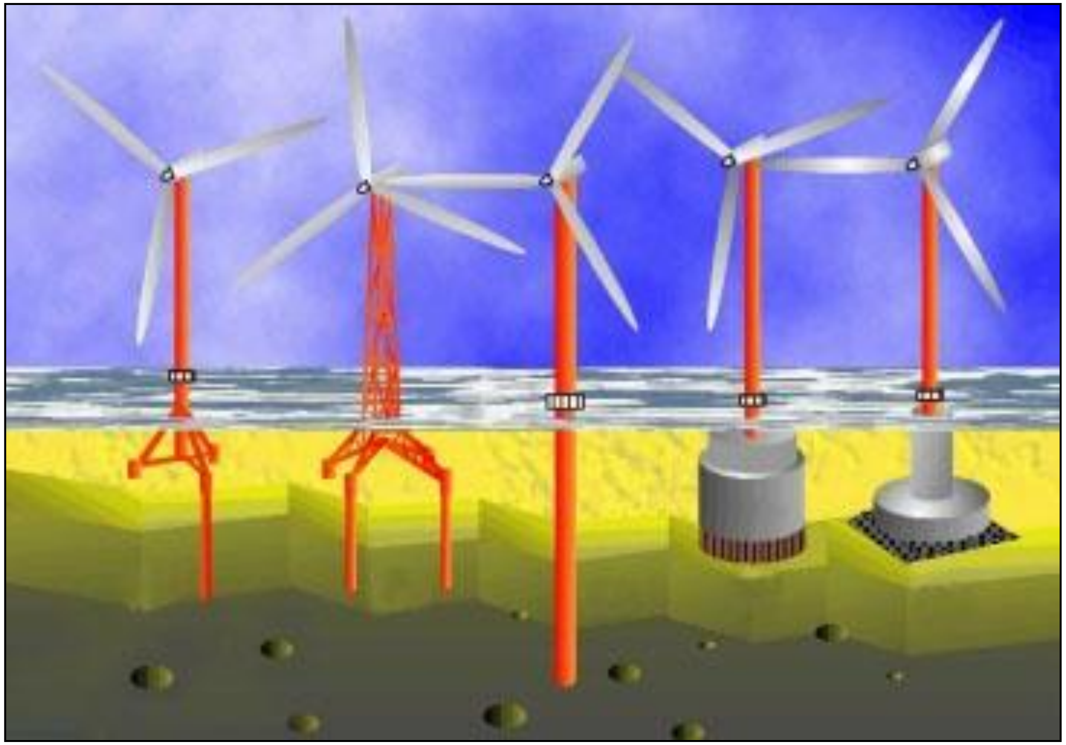
Offshore windfarm in Denmark (Malmo-Copenhagen region)



Monopile

- until 20 m deep of water
- Steel- or concrete construction

Gravity foundation

- until 10 m deep of water
- Steel- or concrete construction

Tripod, Jacket

- more than 20 m deep of water
- Steel construction

Possible foundations of offshore wind converters

Photo: Helmut Müller; Sonne, Wind und Wärme 4/2012

Repair of corrosion protection

Foto: Große Boeckmann, August 2008

Fundaments for windmills for the windward Alpha Ventus

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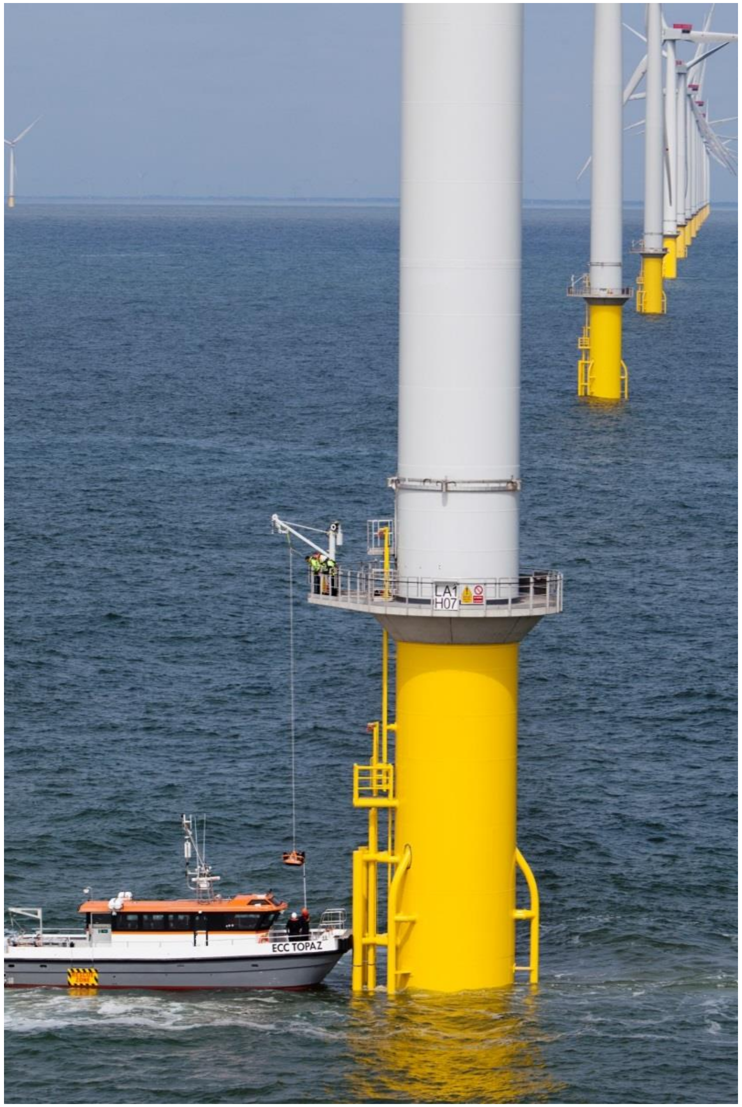
Jackets

Source: http://www.siemens.com/press/pool/de/pressebilder/2013/photonews/300dpi/PN201308/PN201308-04_300dpi.jpg



Source: http://www.siemens.com/press/pool/de/pressebilder/2013/photonews/300dpi/PN201308/PN201308-05_300dpi.jpg

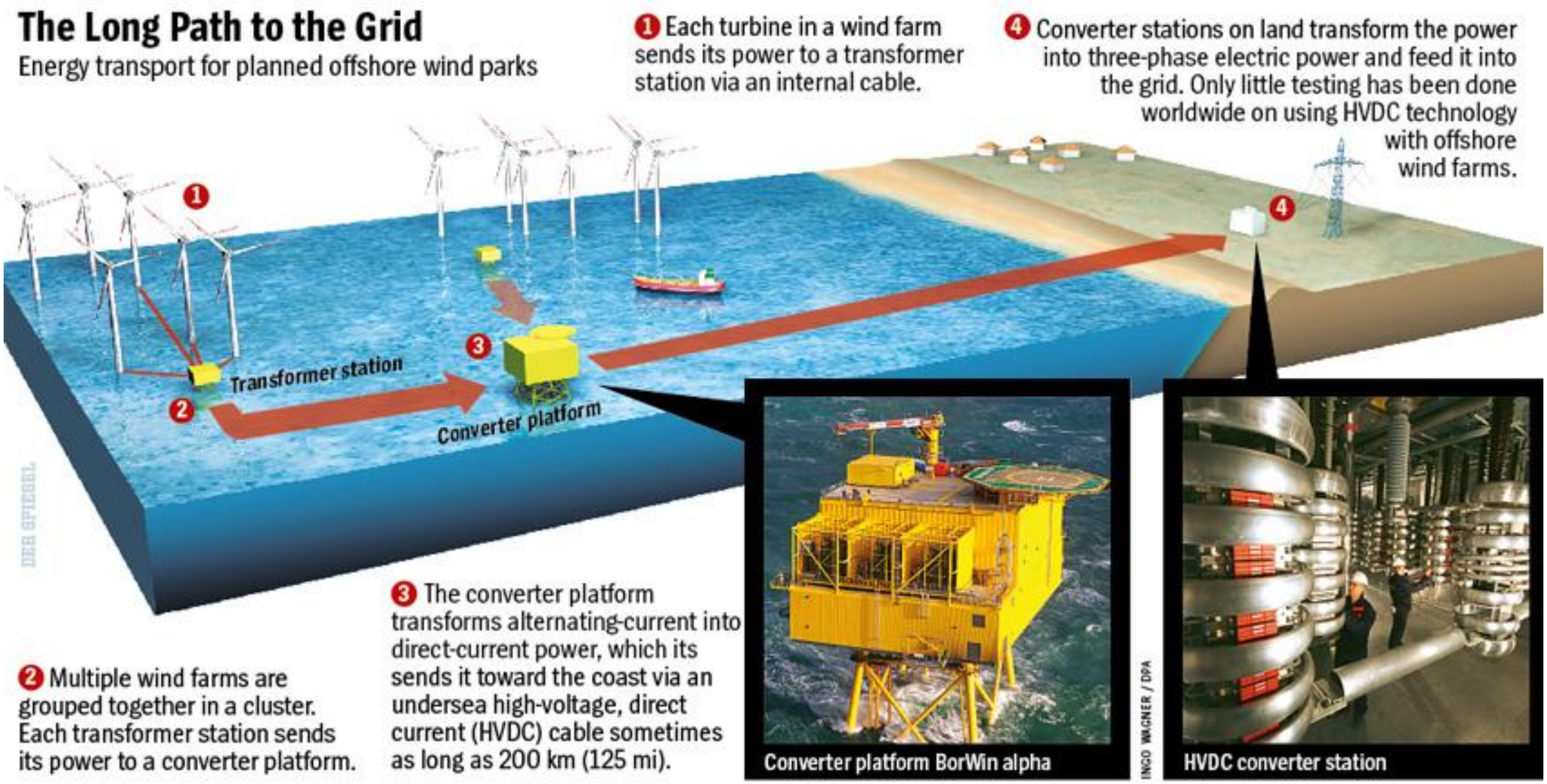
Offshore windpark, transformer station

Source: http://www.siemens.com/press/pool/de/pressebilder/2012/photonews/300dpi/PN201209/PN201209-01_300dpi.jpg

Montage of a rotor blade

Source: http://www.siemens.com/press/pool/de/pressebilder/2012/photonews/300dpi/PN201204/PN201204-06e_300dpi.jpg

Size of rotor blades



Source: „Germanys´s Troubled Offshore Wind Offensive“; Spiegel Online; http://cdn3.spiegel.de/images/image-395626-galleryV9-ynkq.jpg

Electricity transport from offshore to land

- Present status of wind energy use
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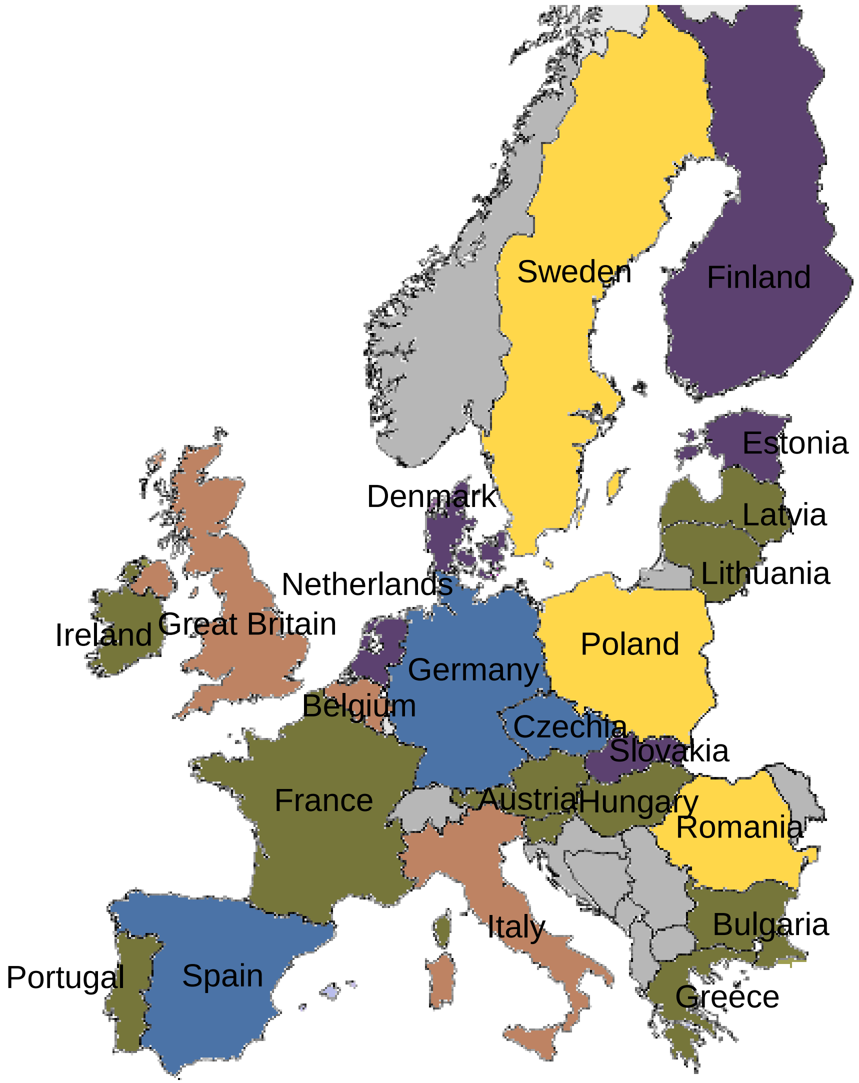
Structure of my presentation

Investment plan	Costs [€/kW]	
Hub height	< 120 m	> 120 m
Wind power station, transport, installation	1150	1340
Foundation	70	
Grid connection	70	
Site development (lanes)	40	
Planning, environmental measures, concession, others	190	
Total	**1520**	**1710**

Operating costs: 5,1 ct/kWh (Average over 20 years operating time)	
Service, reparation, others	50 %
Rent	20 %
Management (technical and business)	20 %
Reserve for unforeseen events	5 %
Insurance	5 %

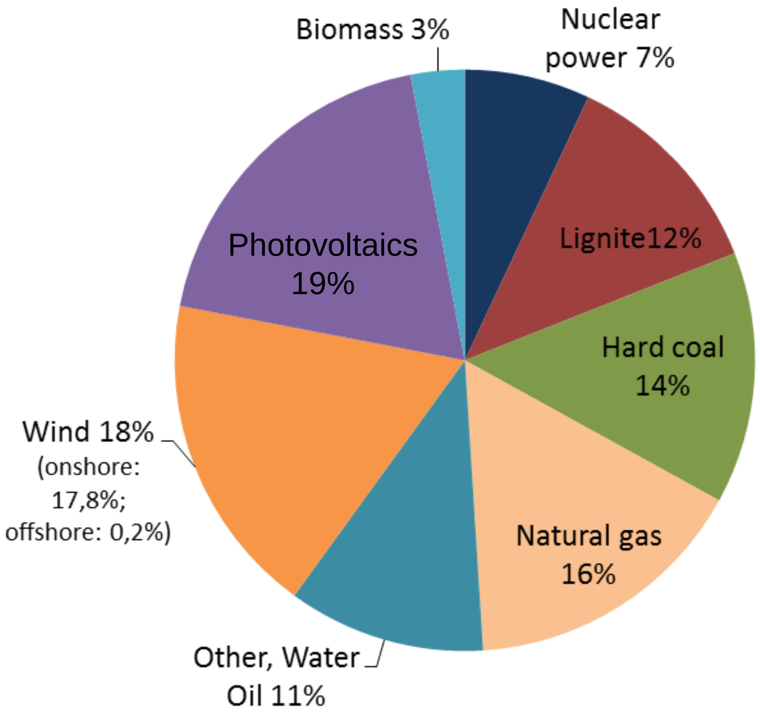
Source: Deutsche WindGuard GmbH; Kostensituation der Windenergie an Land in Deutschland, Stand 2013

- Quota system
- Feed in compensation
- Feed in premiums
- Combination of feed in compensation and quota system
- Combination of feed in compensation and premiums

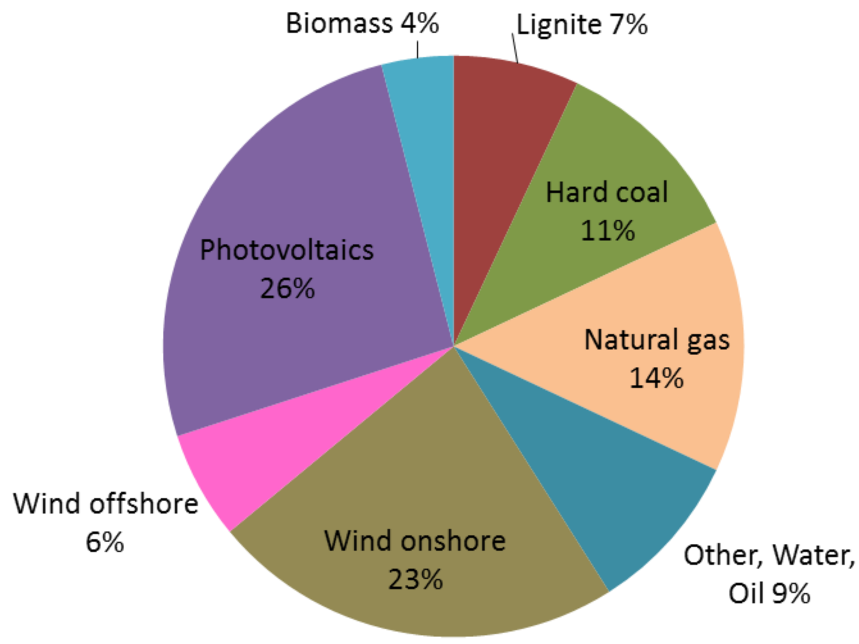


Source: Fraunhofer IST et al. ; 02/2012

Different conveying systems for electricity (renewable energies) in the EU



2012
Statistical value (175 GW)



(Nuclear power: 0,0%)

2024
Objective of government (225 GW)
(Scenario B)

Objective power station capacities in Germany 2024

Renewables and liberalisation require the grid extension europeanwide

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Thank you for your attention

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