Physics and engineering of wind power systems

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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

Structure of my presentation

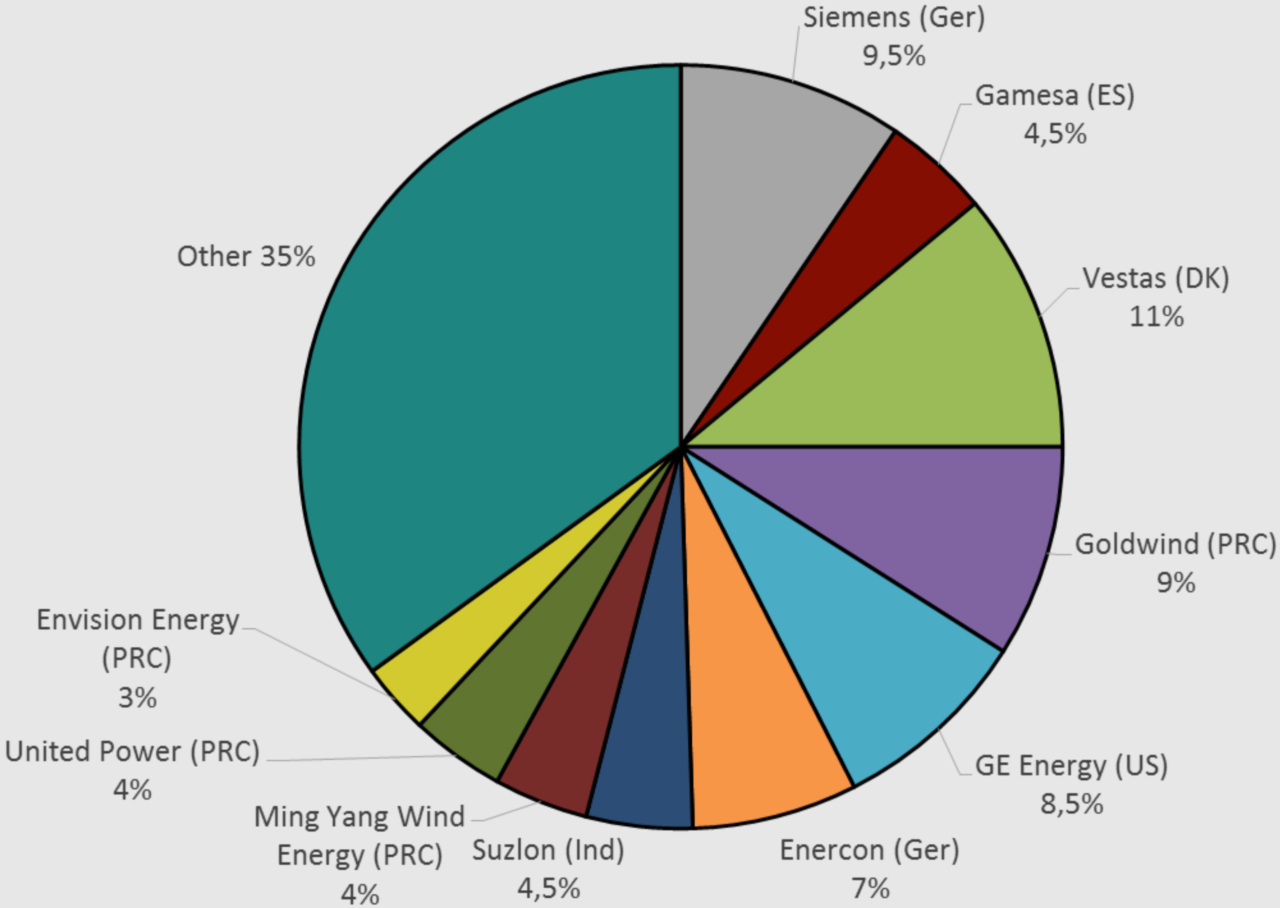
Wind energy use – a good idea since a lot of years

Wind energy use worldwide (values rounded)		
	Rated Capacity [GW]	Share worldwide [%]
	the end of 2016	worldwide 2016
China	169	35
USA	82	17
Germany	50	10
India	29	6
Spain	23	5
United Kingdom	15	3
France	12	2
Canada	12	2
Brazil	11	2
Italy	9	2
Remaining countries	76	16
total	**487**	**100**

Germany at beginning of 2016 about 50 GW, 46 Onshore and 4 Offshore.
For comparison:
At the end of 2003: world about 40 GW, Germany about 15 GW

Source: http://www.gwec.net/global-figures/graphs/

Worldwide wind use – present status



New erected capacity 2015:

56.000 MW

Source: http://www.ingenieur.de/Fachbereiche/Windenergie/Das-9-groessten-Windradhersteller-Welt

Shares of the suppliers in the world market in 2015

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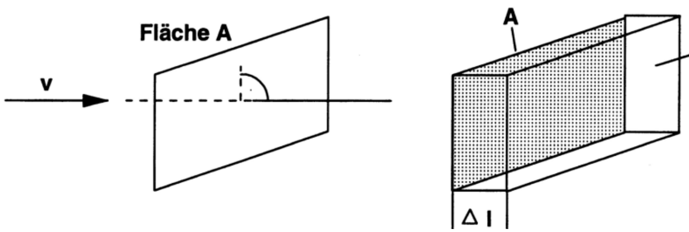
Derivative of the equation with steady velocity of wind v



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

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

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

Kinetic energy E of a mass element Δ m

$$\Delta E = \tfrac{1}{2} \Delta m \, v^2$$

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

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

$$E = \tfrac{1}{2} A \, \rho_L \cdot v^3 \cdot t$$

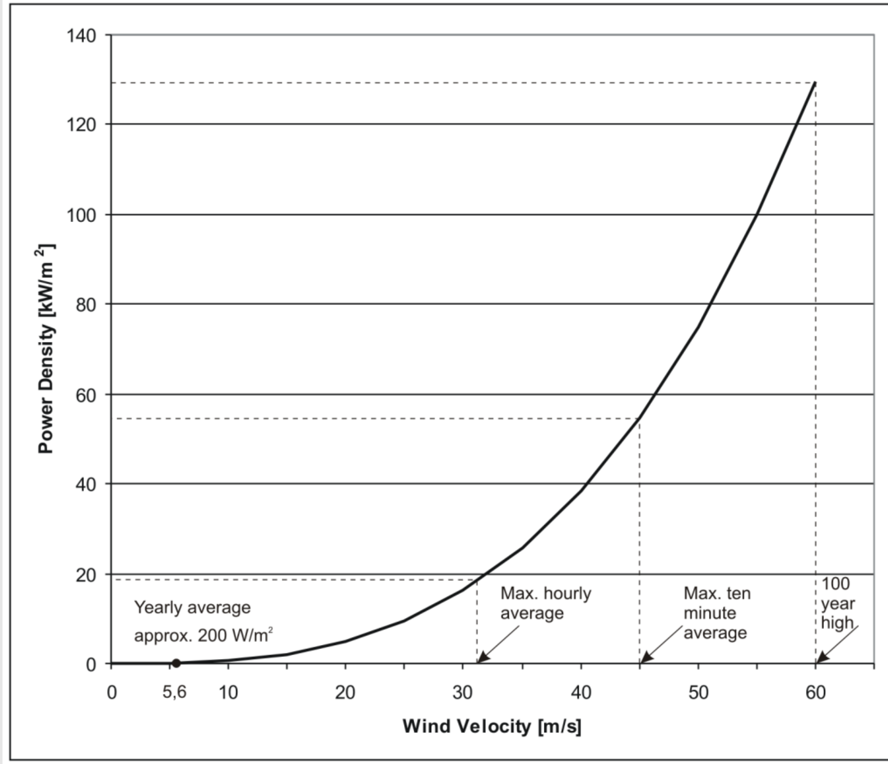
$$P = \frac{E}{t} = \tfrac{1}{2} \cdot A \cdot \rho_L \cdot v^3$$

V = volume

ρ_L = density of air = 1,2 kg/m³

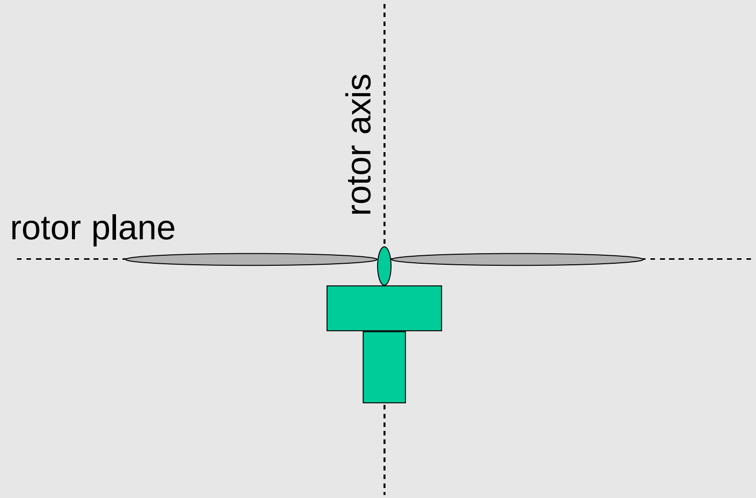
Efficiency

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



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)

β = pitch angle

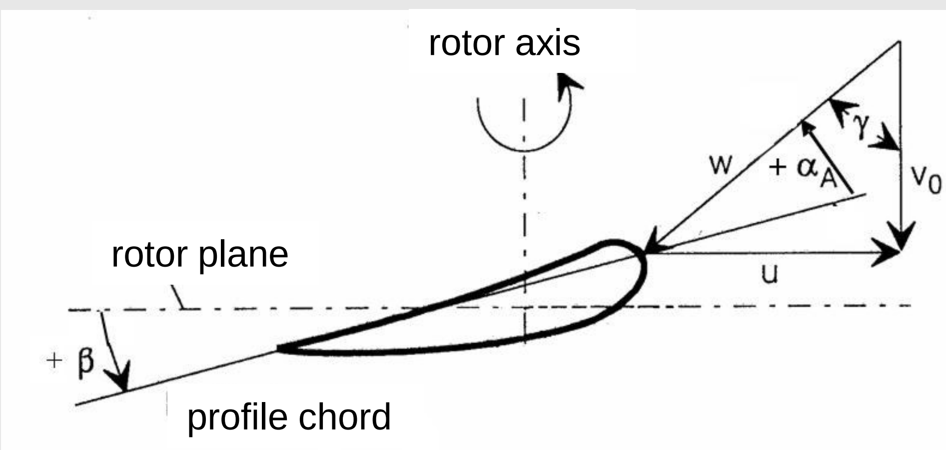
α = angle between wind velocity and approach velocity

γ = circumferential velocity

v_0 = wind velocity in the rotor axis

w = relative approach velocity

Bird‘s eye view of vertically positioned rotor blades

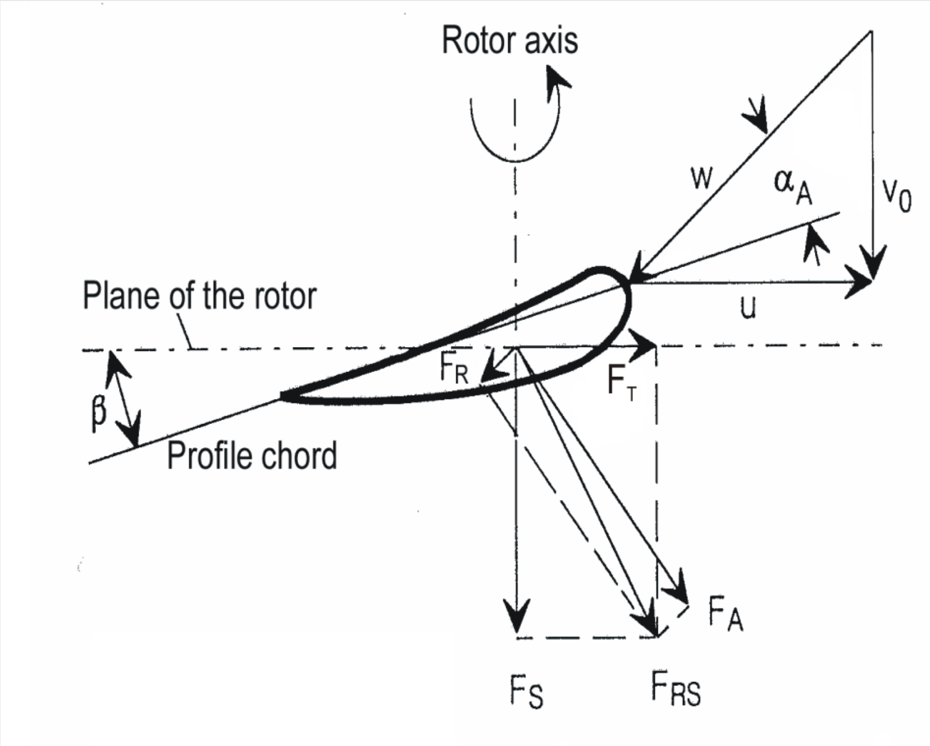


for the pitch angle applies:

α_A should be optimal,
besides use b as a set variable in accordance to v_0 and u (revolution)

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

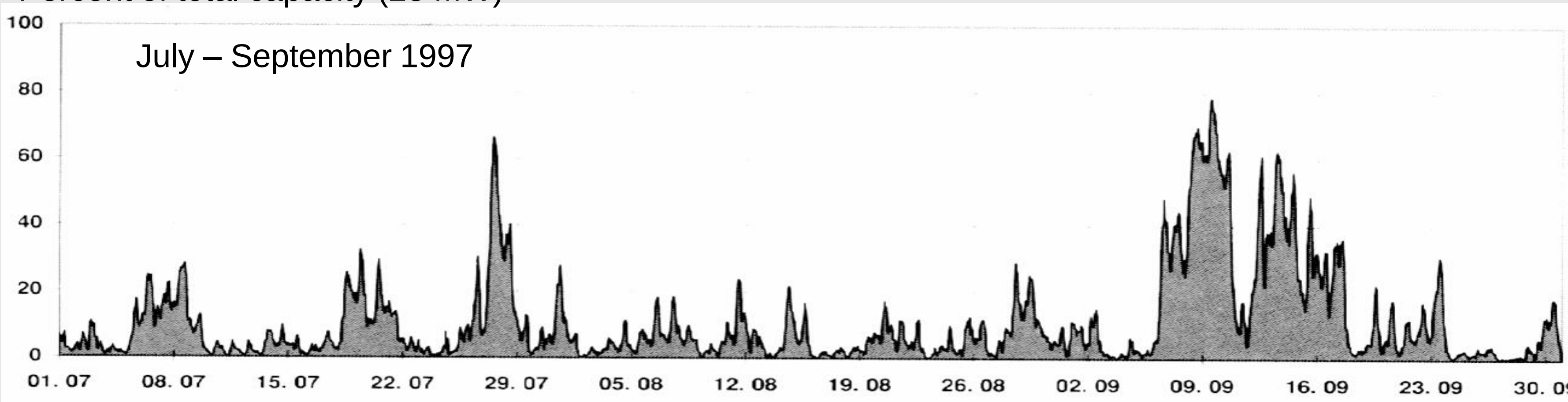
Velocity triangle at the rotor blade



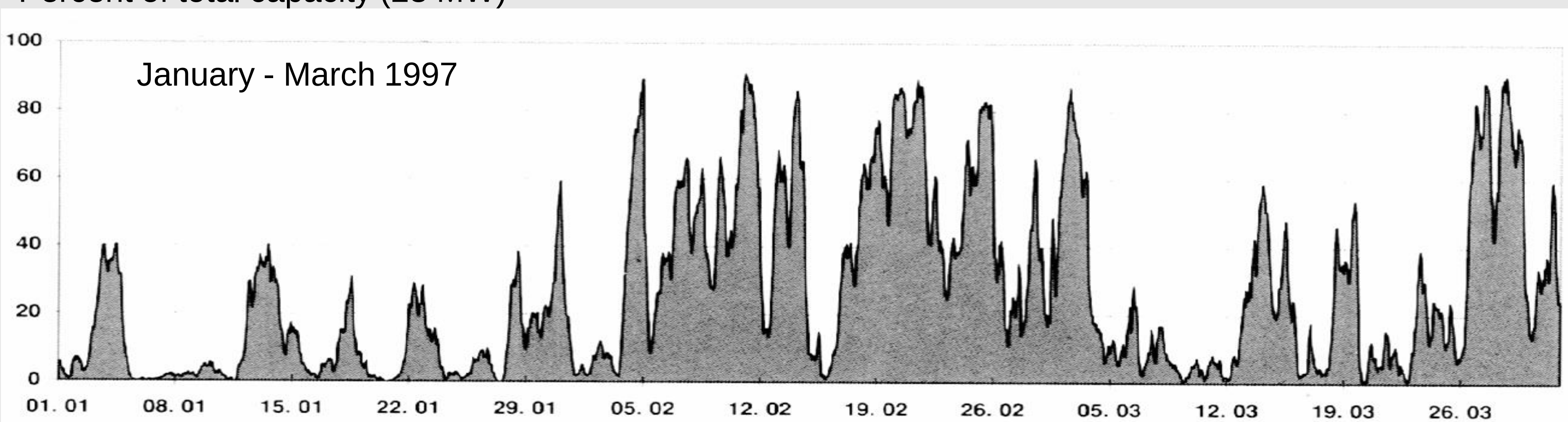
α_A	= Angle of attack
β	= Pitch Angle
u	= Average circumferential velocity
v_n	= Wind velocity in the rotor plane
w	= Relative approach velocity
F_R	= Drag force
F_A	= Lift force
F_{RS}	= Resulant force
F_T	= Tangential component
F_S	= Axial component

The velocities and forces acting on a blade

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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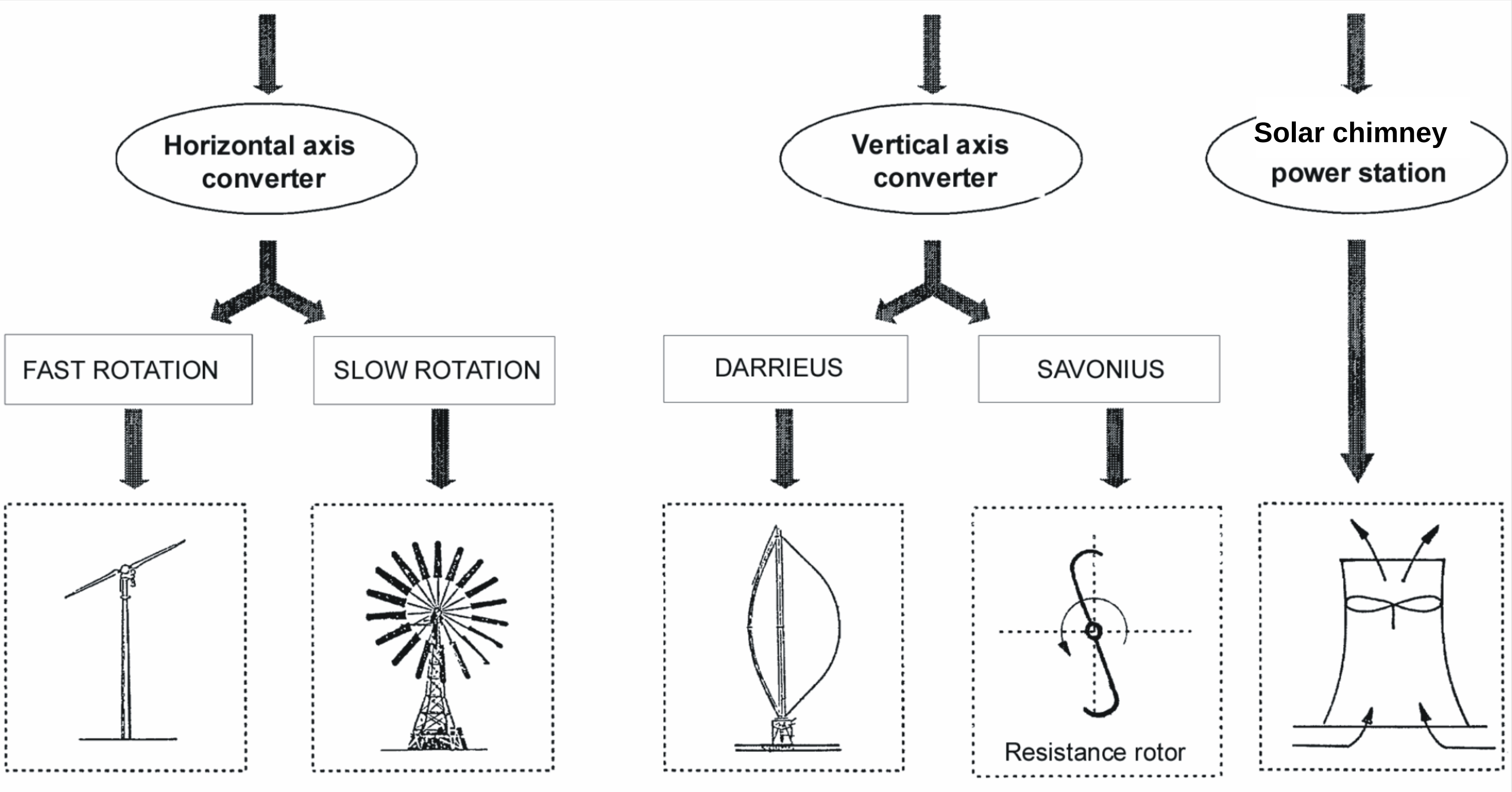
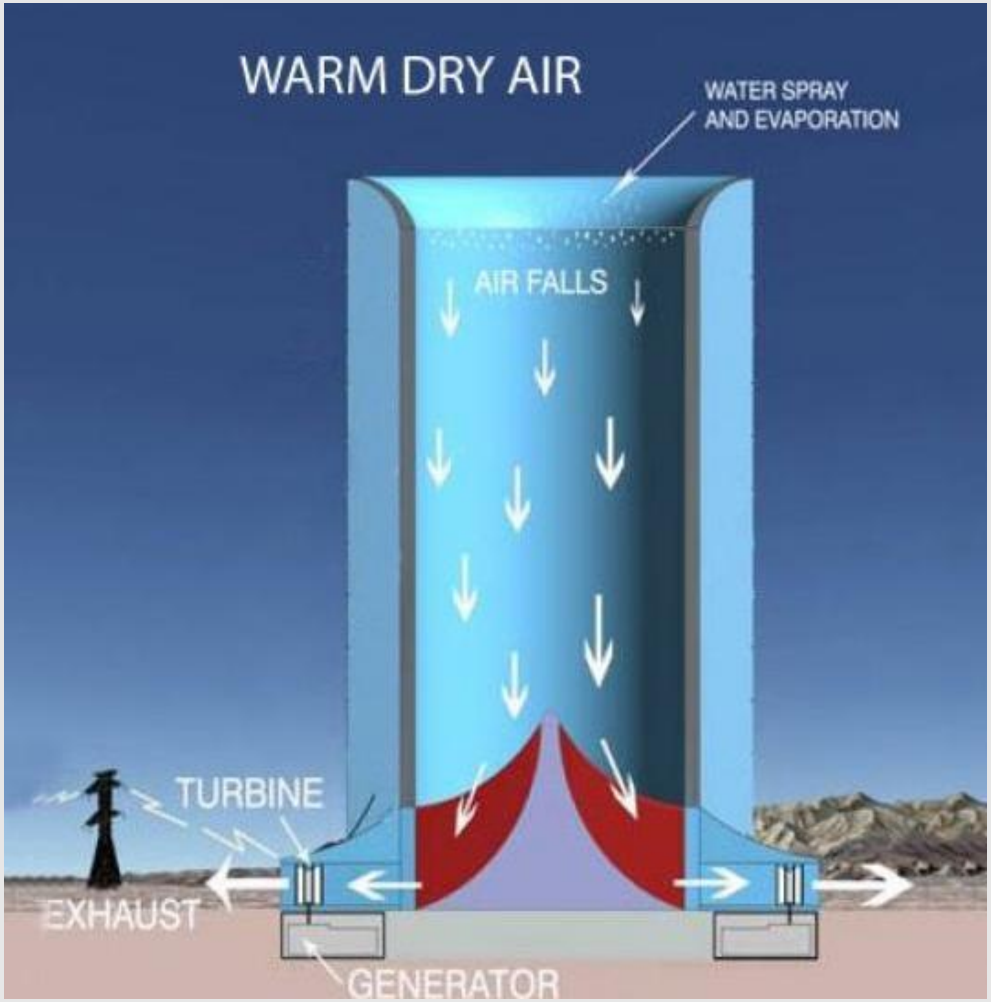
Structure of my presentation



Different types of realised wind energy converters **(Solar chimney only 1 prototype)**



Warm air flows up into the tower, at the top of the tower water is sprayed into the air. The water evaporates and cools the air. By the ensuing convection the air sinks toward the ground and drives a vertical axis turbine. Subsequently, the cold air flows back into the environment.

Suitable locations are hot and dry areas with nearby large water supplies. The independent time of day electricity production is advantageous.

Source: (Information and graphic): http://www.solarwindenergytower.com/the-tower.html

Planned Energy Tower (solar - wind hybrid power plant) in Arizona , USA

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: λ = 2 -4
   Modern 3-blade conversion systems: λ = 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

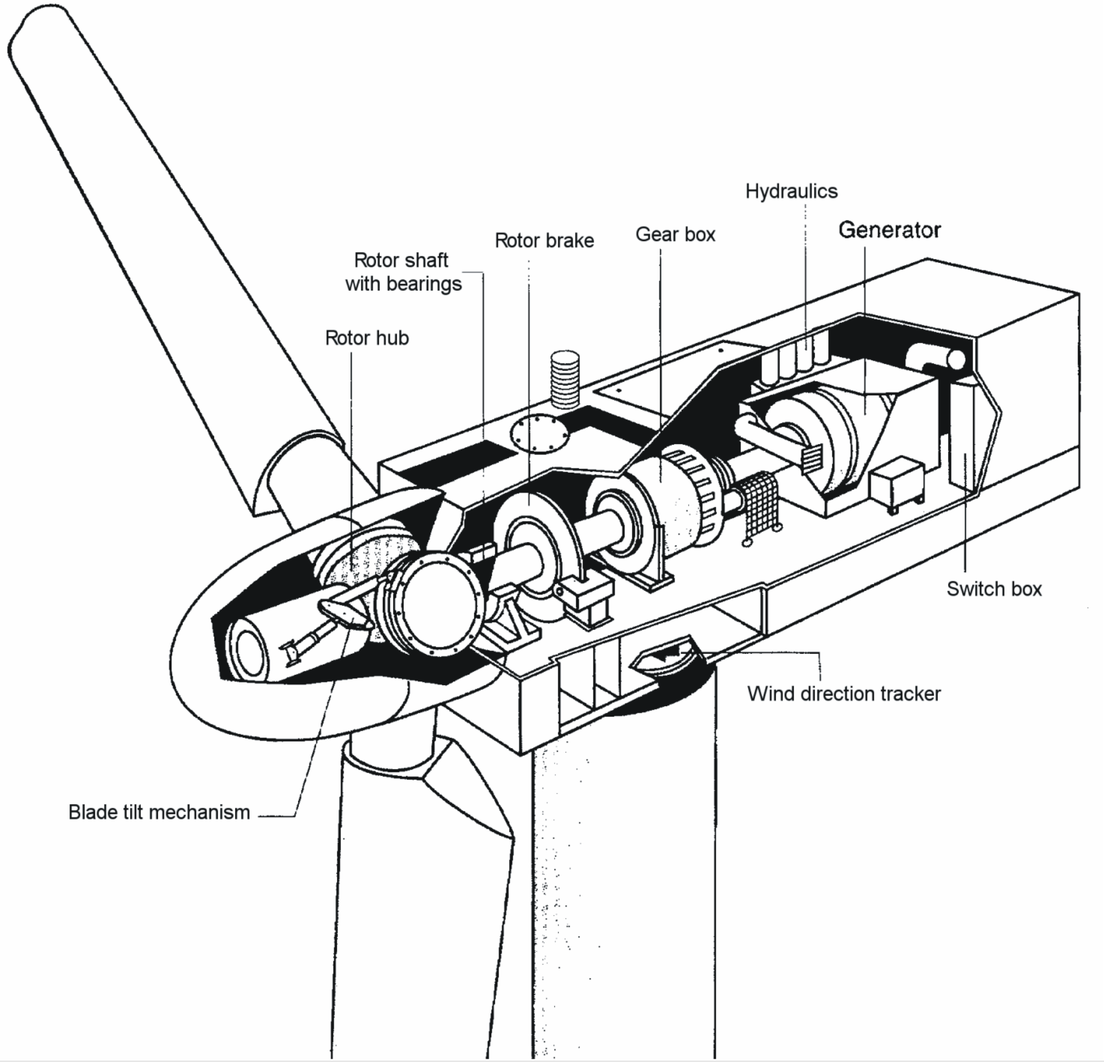
1. High glide ratios lead to high tip speed ratios and therefore to a large power coefficient c_p
   → Modern converters with good aerodynamic profiles rotate quickly.

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

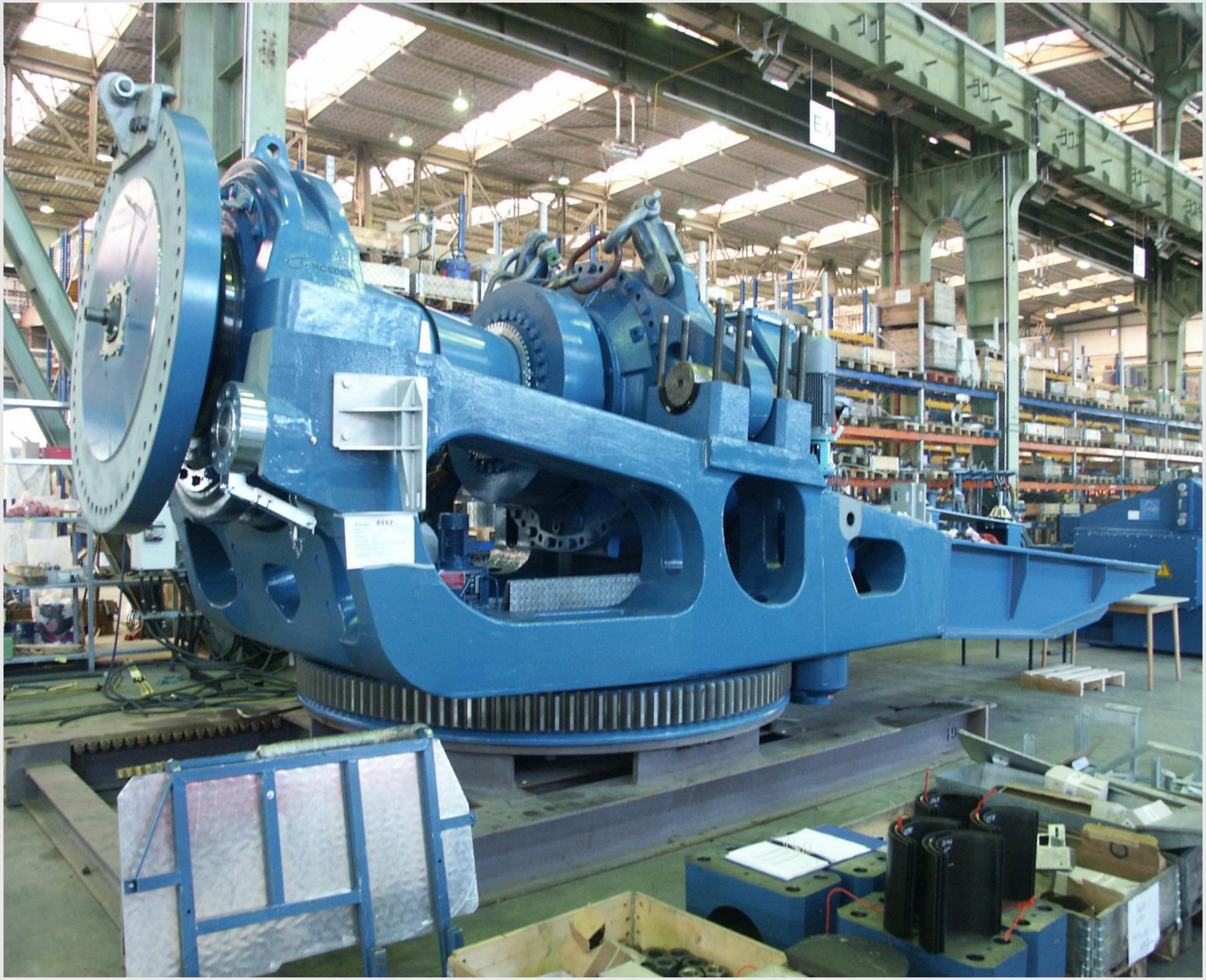
3. Glide ratio and tip speed ratio have a larger influence on the power coefficient than the solidity ratio.

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

Dimensioning of wind energy conversion systems

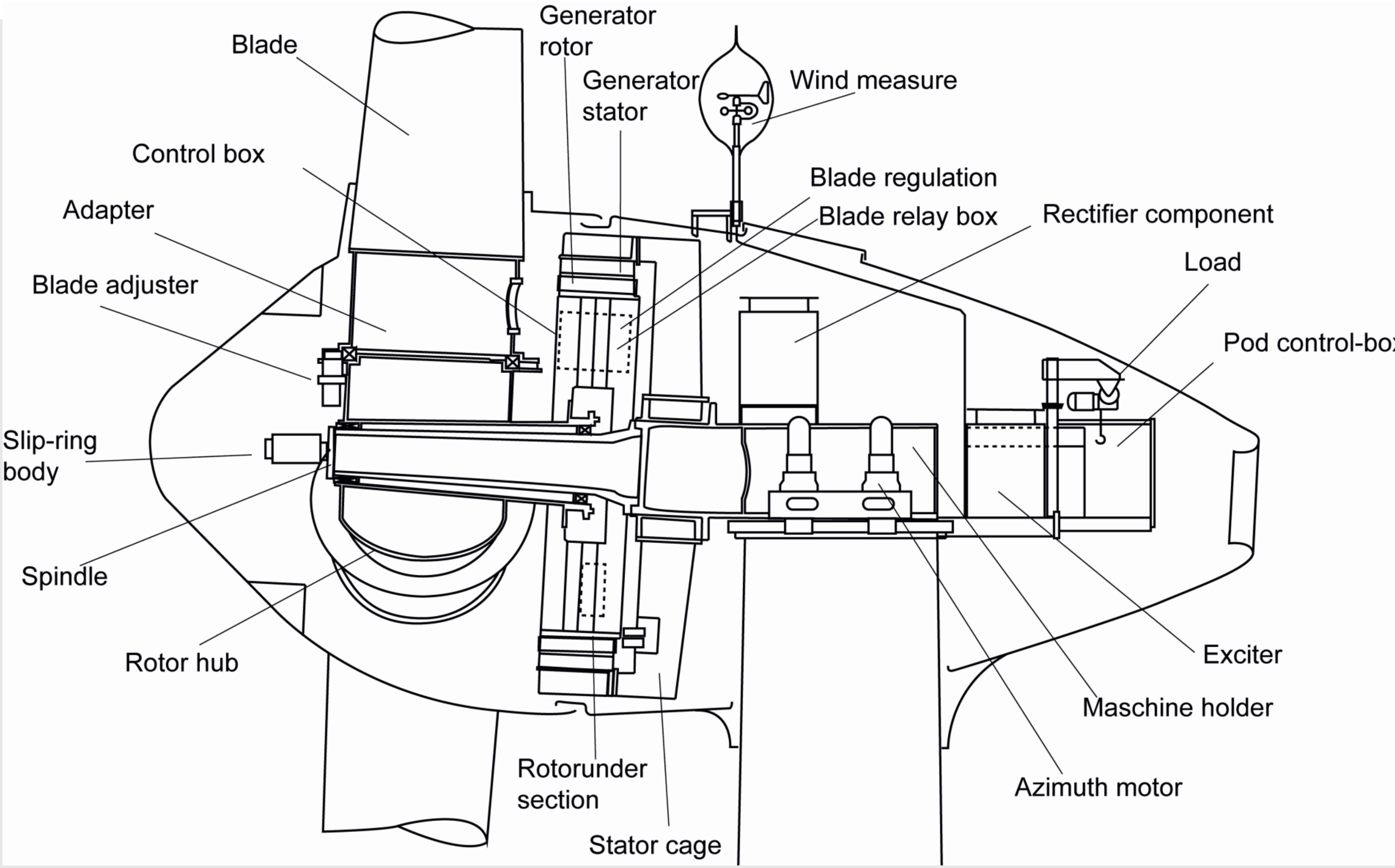


Constructional type of a WECS with „classical“ power train

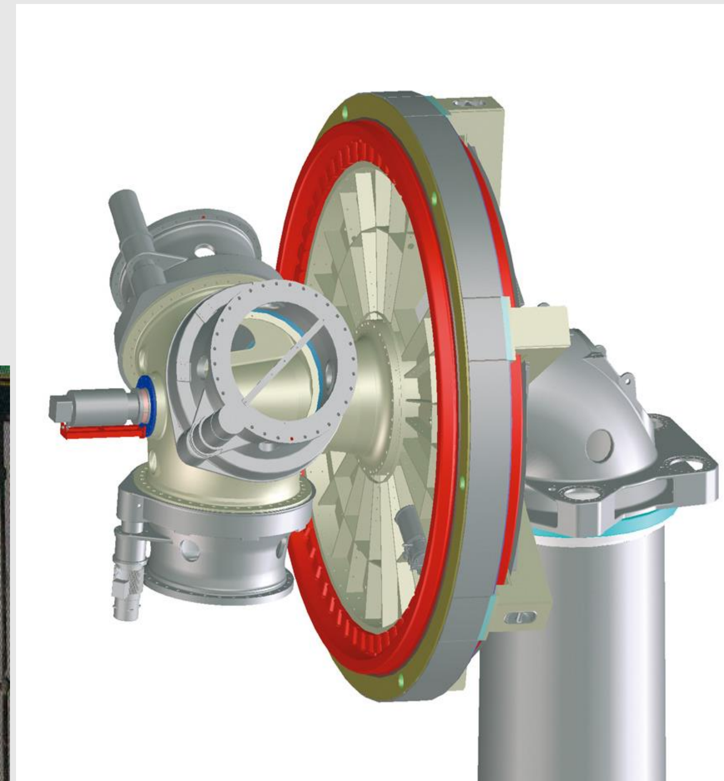


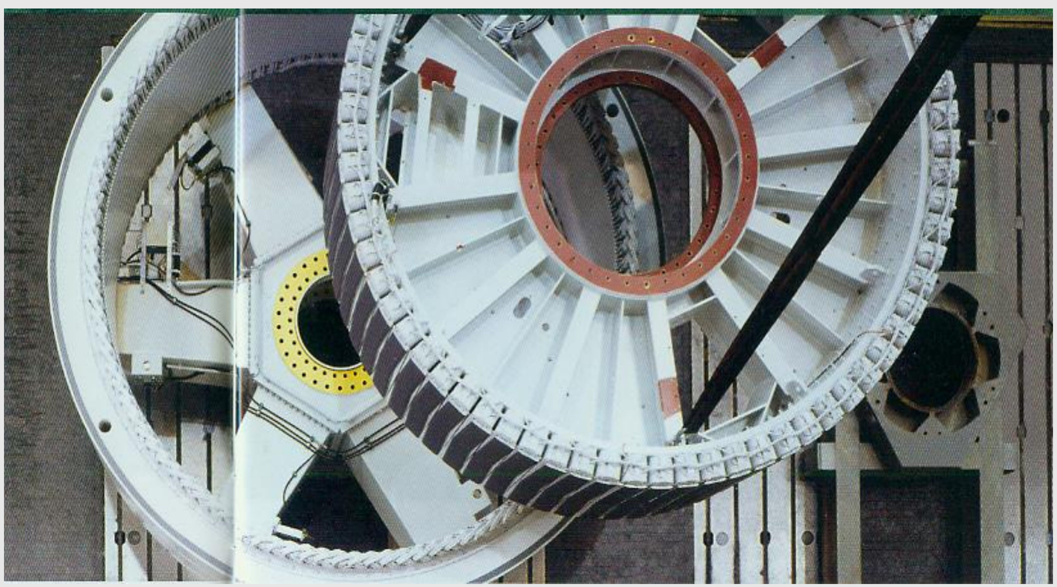
Source: Nordex AG

Assembling of a wind converter by Nordex AG



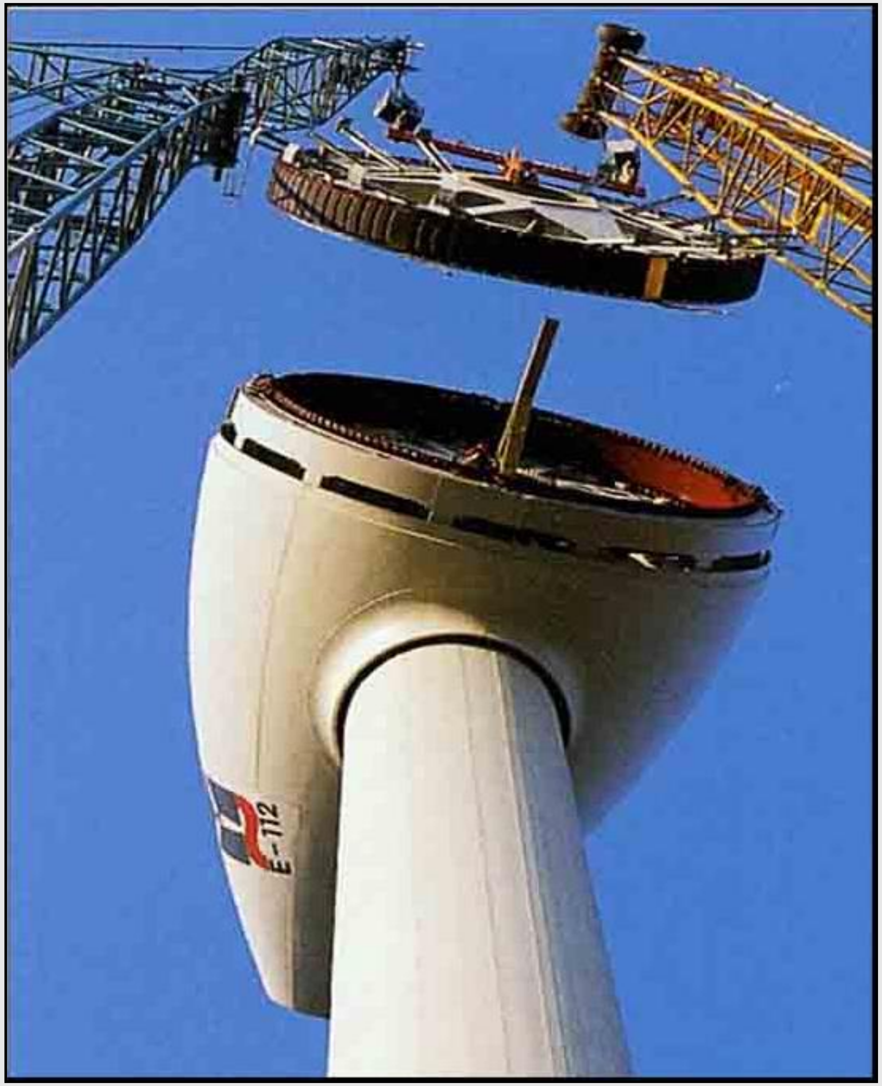
Constructional type of the WEC Enercon-66





Source: ENERCON GmbH

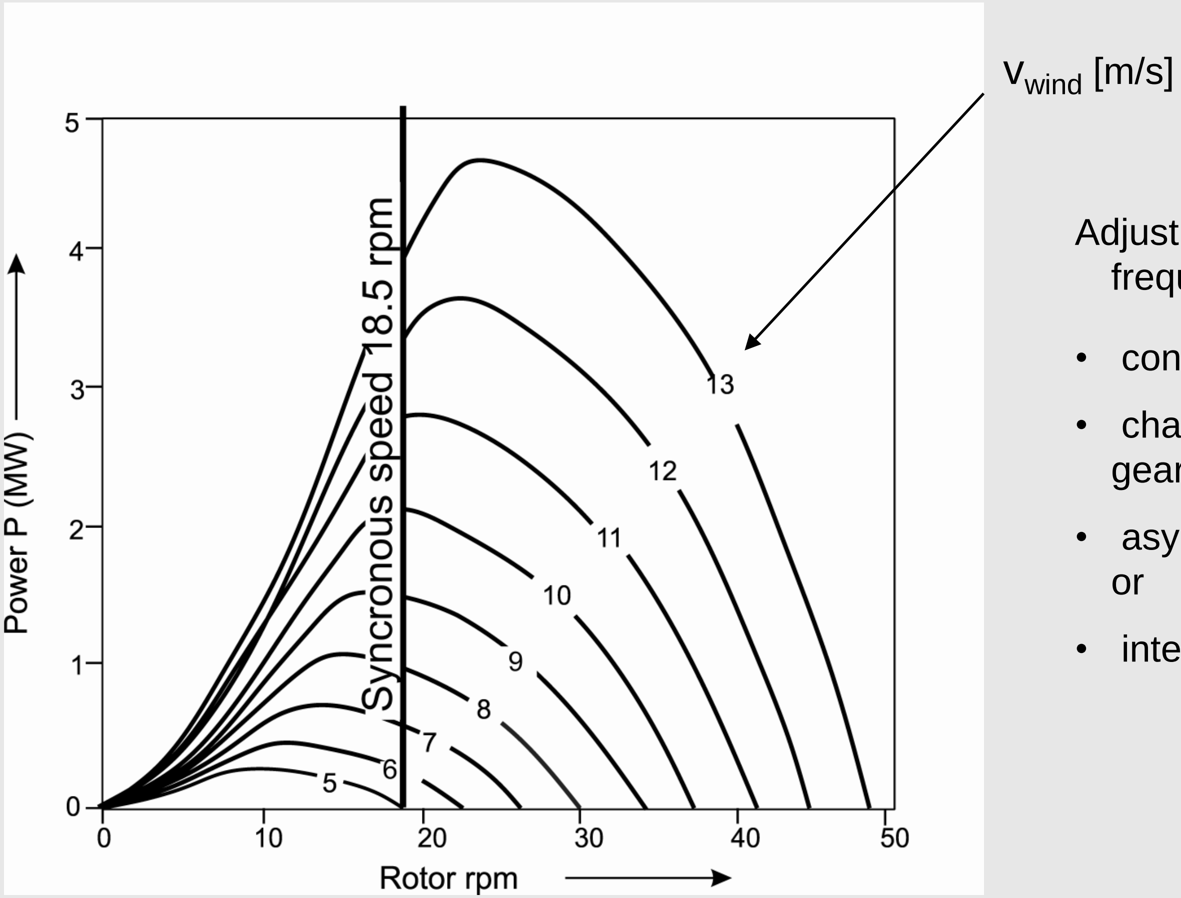
Wind energy converter without gear box



Installation of the generator by a wind mill without gears

	Enercon E-182 E3	REpower 3,2 MW
Design	without gearbox	with gearbox
Hub height	80 - 130 m (onshore)	100 - 130 m (onshore)
No. of blades	3	3
Rotor speed	6-18 rpm	6.7 -12 rpm
Rotor diameter	82 m	114 m
Material of blade	Fibreglass (reinforced epoxy)	Fibreglass (reinforced epoxy)
Blade regulation	Pitch	Pitch
Rated power	3 MW	3.2 MW
Transmission ratio of gearbox	None	approx. 99
Generator	Multi-pole	Asynchronous, few poles
Grid connection	Via frequency converters	Via frequency converters

The technical figures of two different multi-megawatt wind turbines for onshore



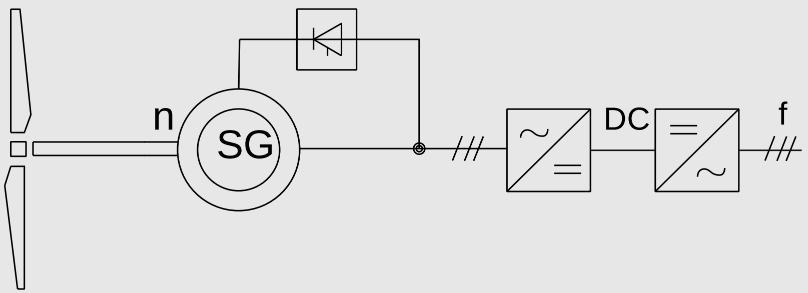
Adjusting of the revolutions and the line frequency with:

- 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 development of wind velocity

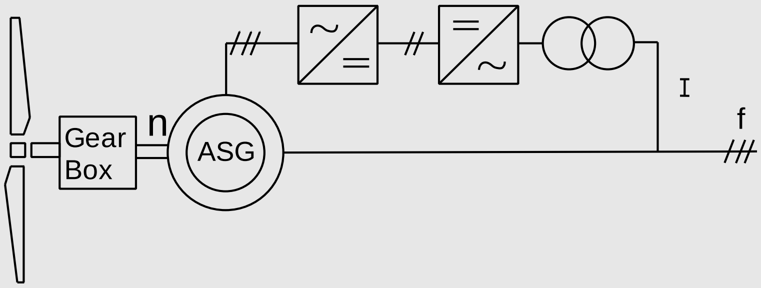
New devices need testing: Problems with gear boxes

Grid connection for synchronous generators (SG)
without gear box



n= 0.5 to 1.2 (f/p) (controllable)
Inductive reactive load
Controllable reactive power

Grid connection of asynchronous generators (ASG)
Double excited asynchronous generator



n= (1+s) f/p, s= 0 to 0.3 (controllable)
Controllable reactive power

n= rotation number [1/min]
f= frequency [1/s]
p= number of polepairs
s= slip between the mechanical and magnetical rotation

Source: Intrduction to Wind Energy Systems, Hermann-Josef Wagne & Jyotirmay Mathur

Example of grid connection

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

Safety - Burned off wind power station in Lahr/ Germany

Generators	-Copper? Permanent Magnet? -Rare earths? -Superconductors?
Rotor Blades	-Cost reduction? -Utilization? -Legal situation? -Active control elements in rotor blades?
Operations Monitoring	-Drive train monitoring (CMS) for onshore plants? -Tower- and foundations vibrations – Number of Sensors, also Onshore? -Periodic Inspections- Scope, Number?
Technical Uncertainties	-Handling of new developments?
Offshore Foundations technologies	-Steel? Concrete? -Gravity Foundations? -Environment, under water noise protection during the piling for the foundation?

Technical developments in Wind Turbines

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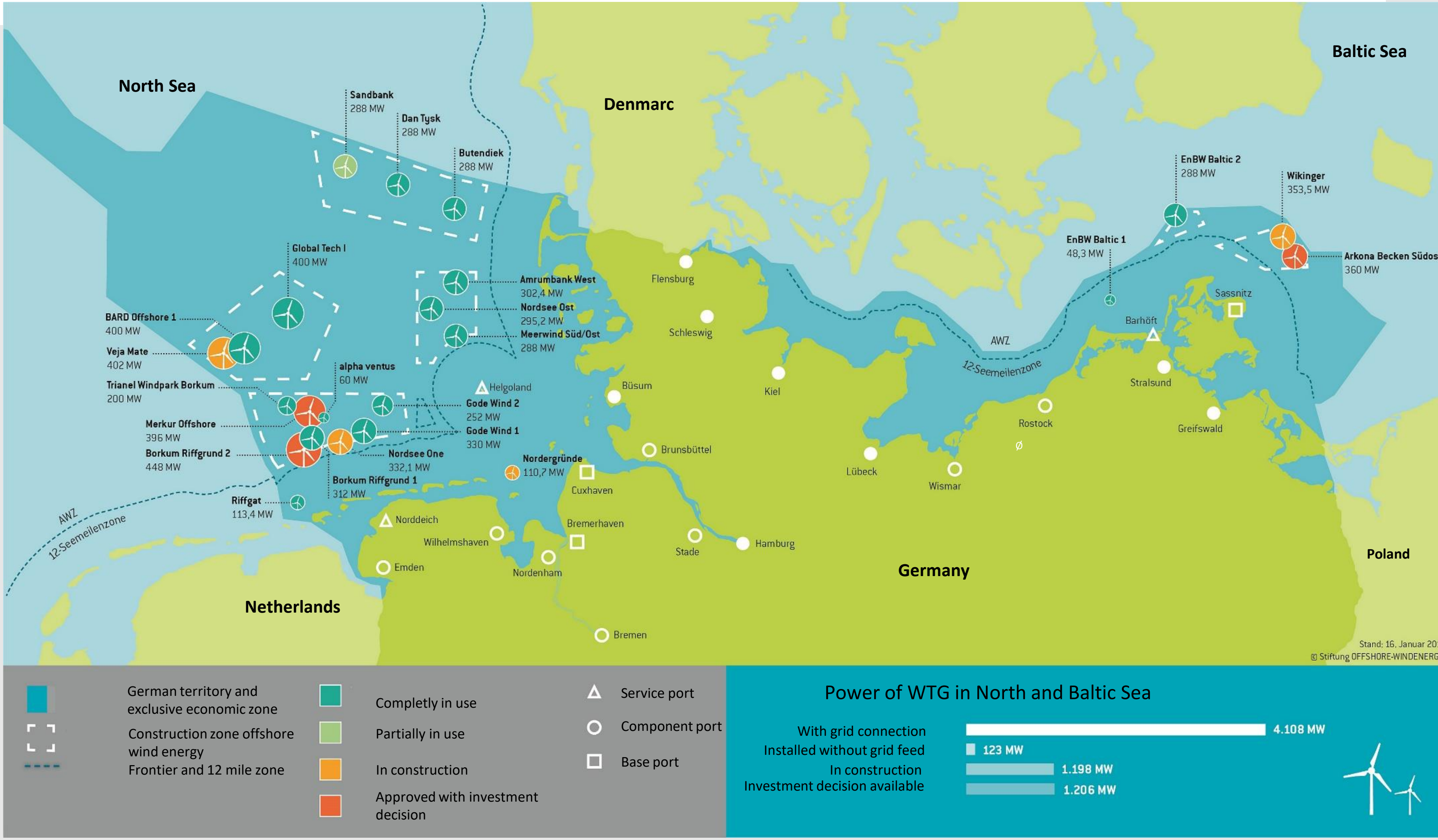
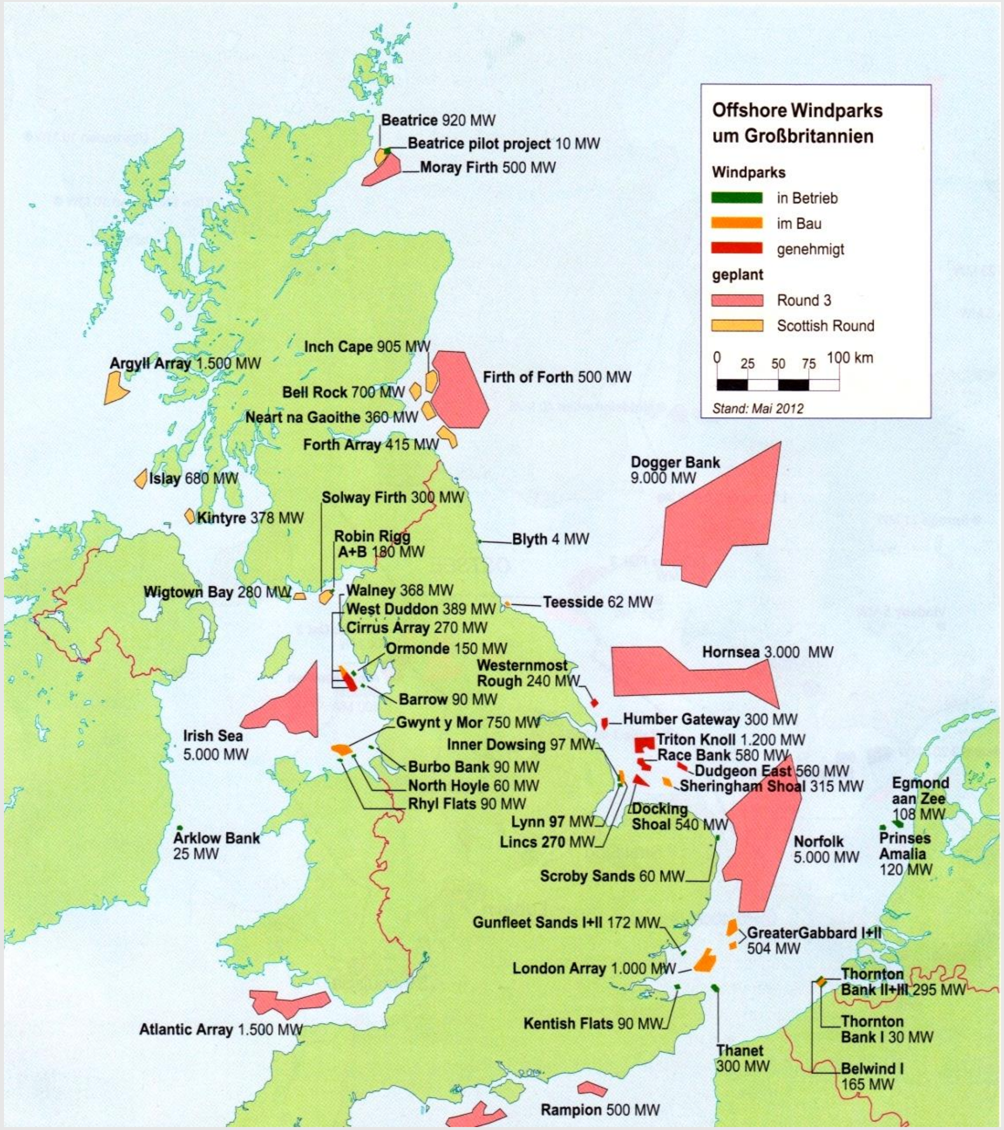
Structure of my presentation



Source: offshore-stiftung.de/sites/offshorelin.de/files/mediaimages/uebersichtoffshorewindparks

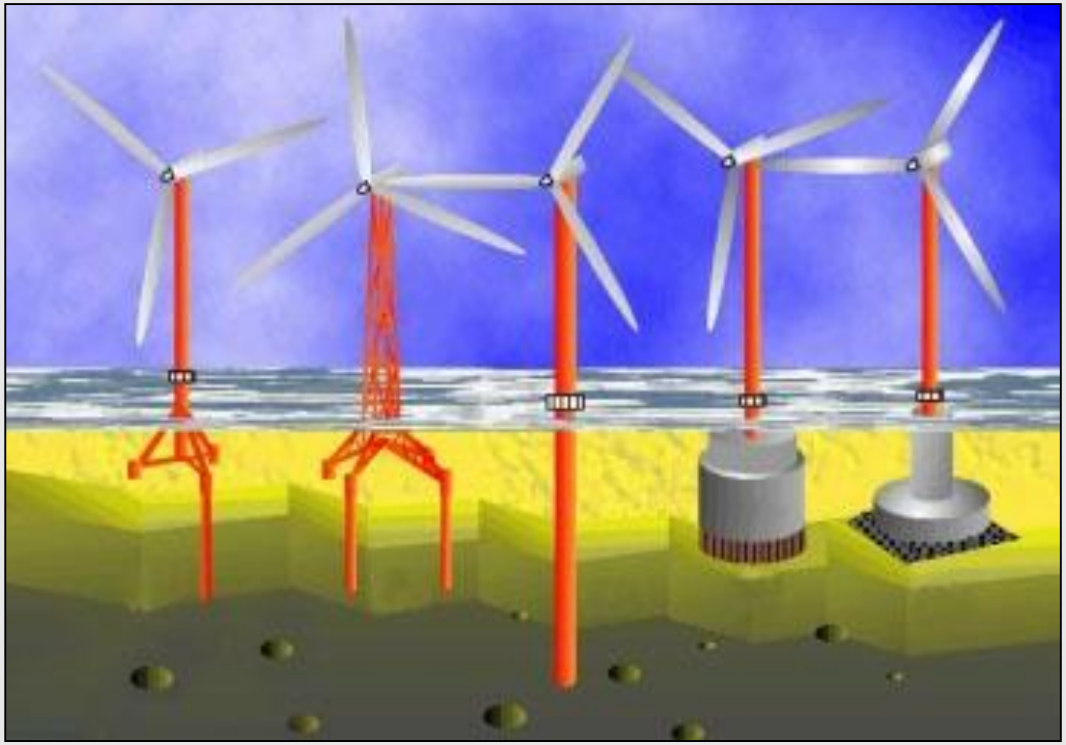
Offshore wind energy in Germany in 2017



Source: Sonne, Wind und Wärme 10/2012

Offshore-wind projects in Great Britain

Offshore wind farm alpha-ventus: Panorama



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

Photo: Große Boeckmann, August 2008

Fundaments for windmills for the windward Alpha Ventus

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

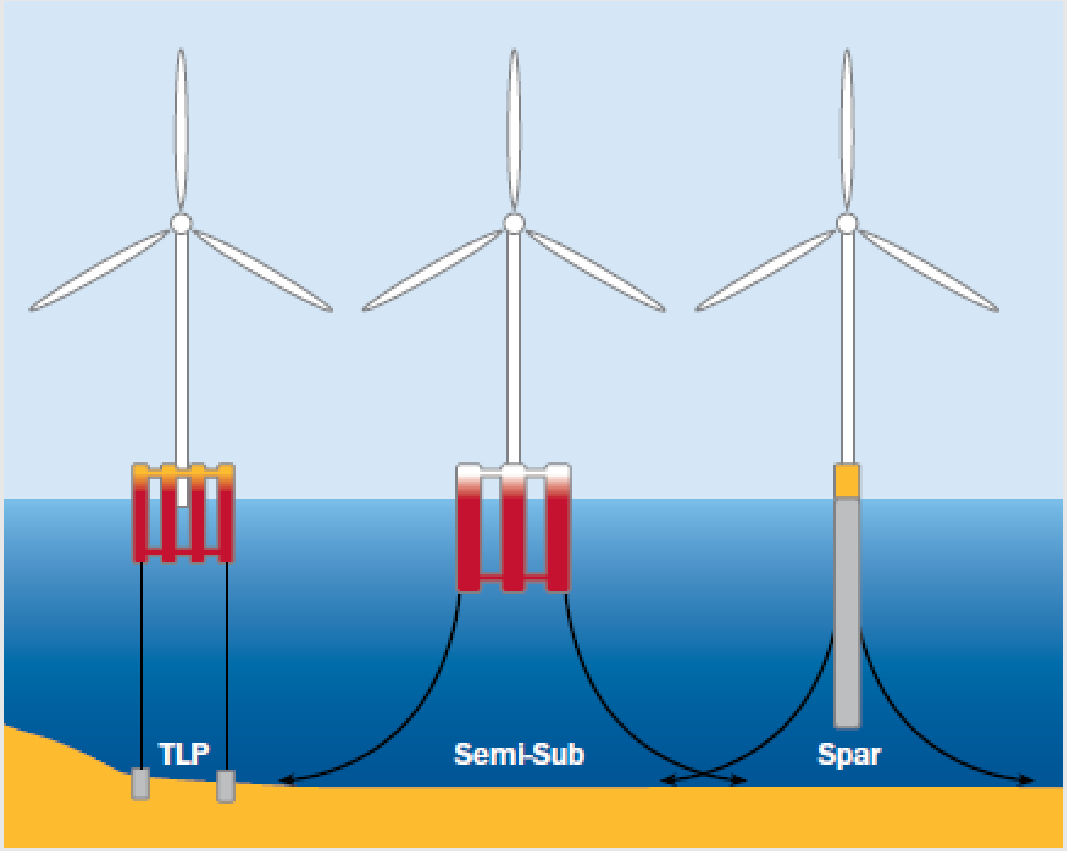
Structure of my presentation
Offshore windpark, transformer station and entrance

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



TLP = Tension-leg-platform
Semi-Sub = Semi-submersible platform

Source: Deep Water The next step for offshore wind energy, EWEA

Floating offshore windparks

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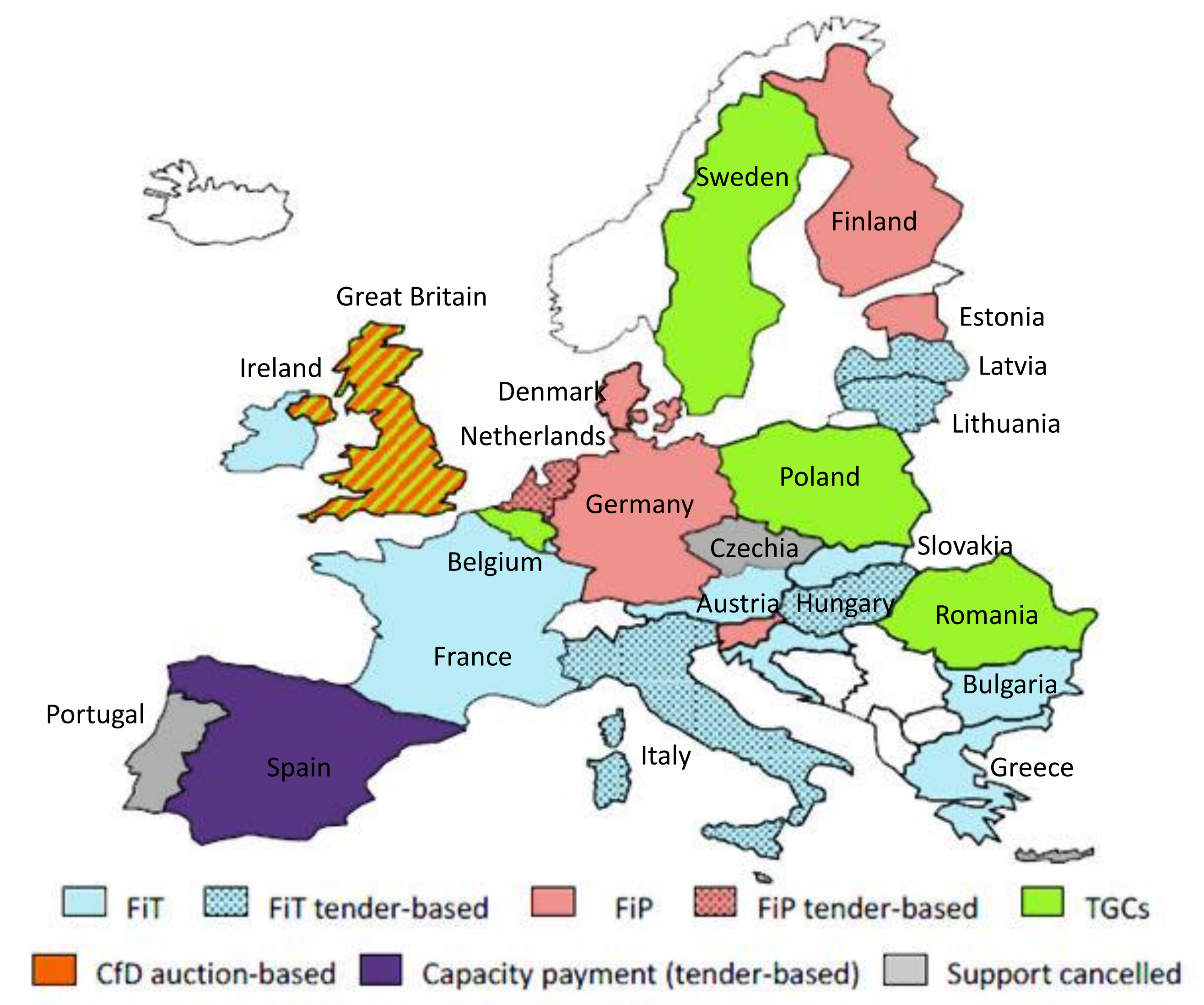
Structure of my presentation

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

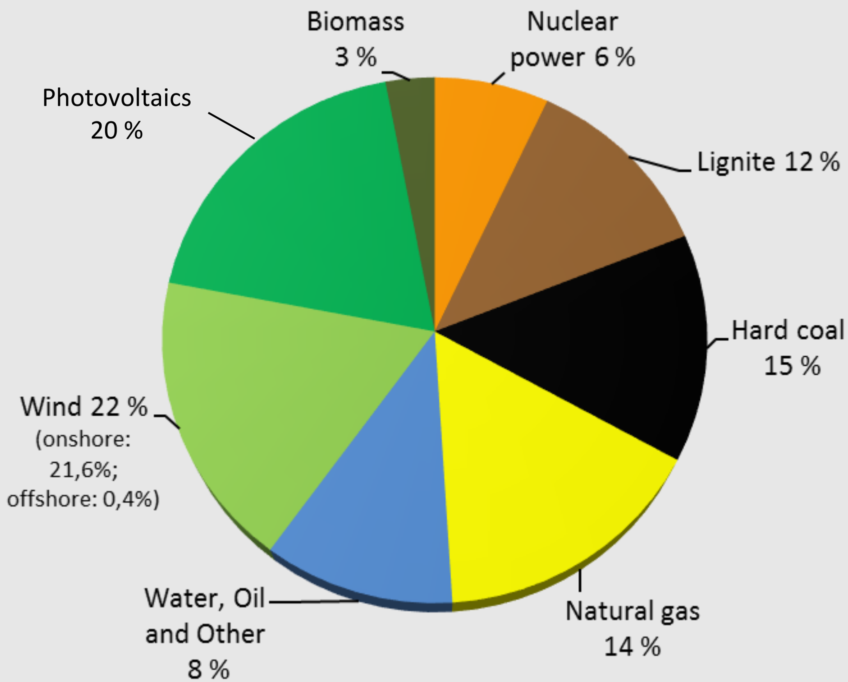
Costs of a 2 MW onshore wind power station in Germany



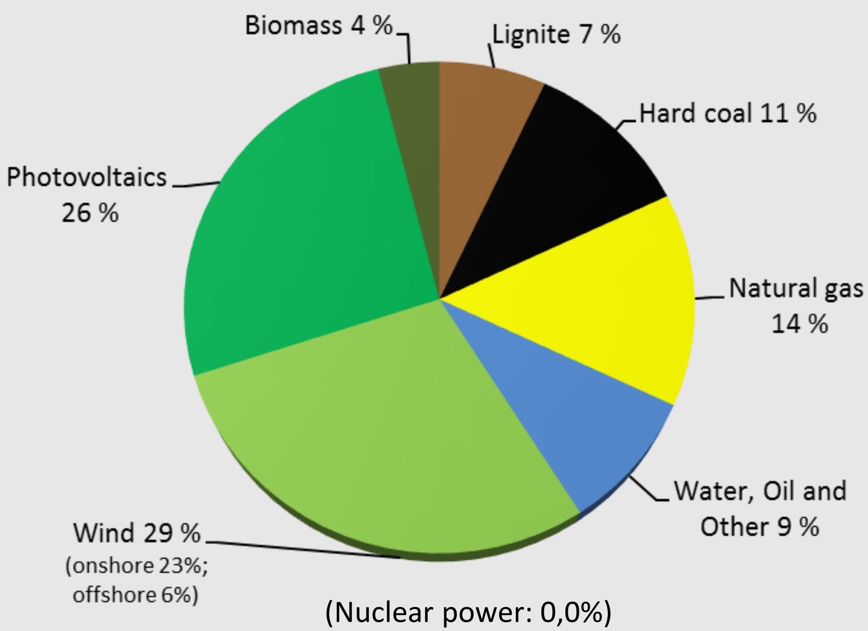
FiT = Feed-in tariffs
FiP = Feed-in premium
TGCs= Tradable green certificates
CfD= Contract for Difference

Source: 2014 JRC wind status report

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



2012
Statistical value (175 GW)



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

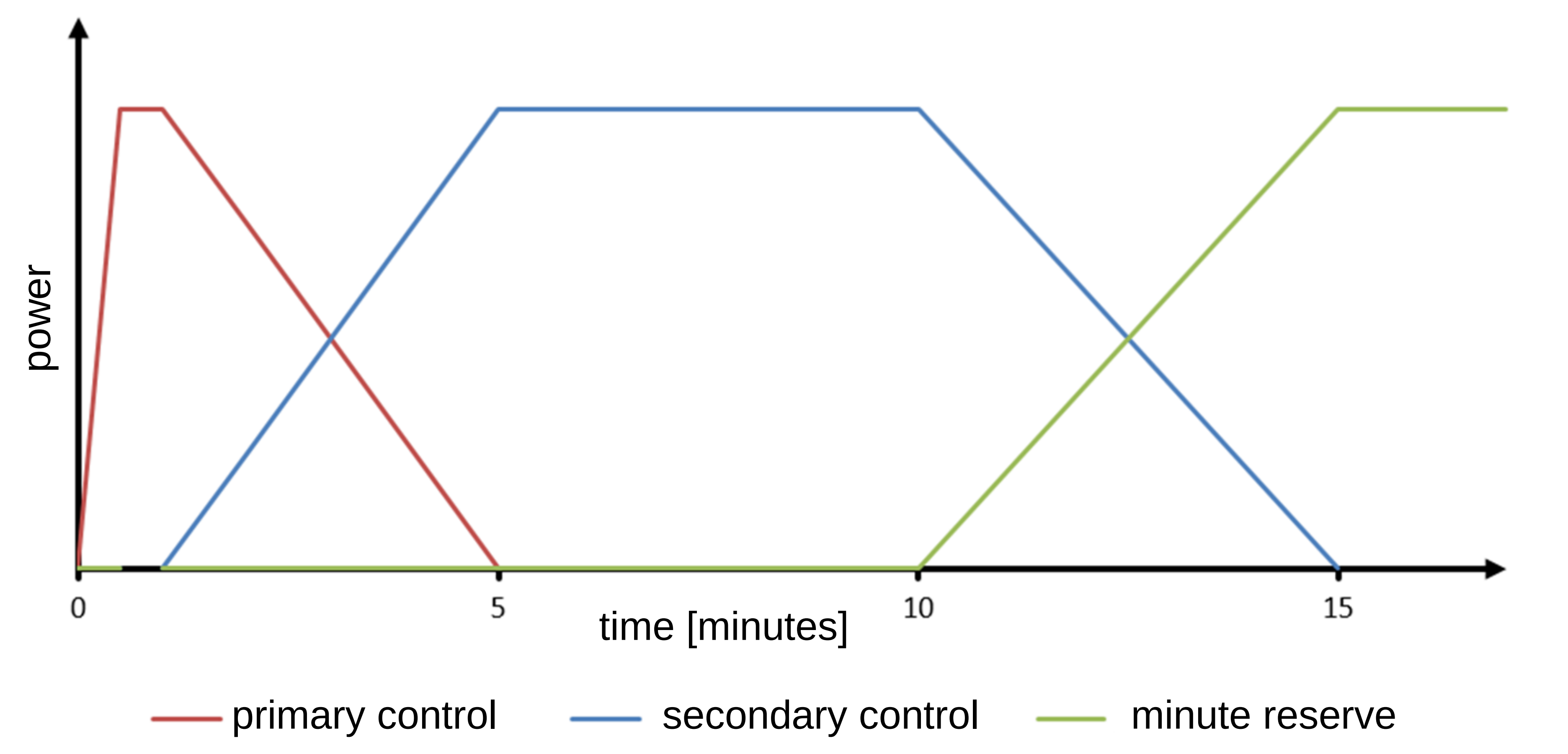
Objective for the power station capacities in Germany in the year 2024

Renewables and liberalisation require the grid extension europeanwide

Source: bi-baunatal.de

Network development plan for the german electricity system (2013/2014)

Bild: http://www.cpmax.com/tl_files/content/leistungen/inspektionen/galerie/100629%20097_klein.jpg



Control power