Wind generators

Darmstadt University of Technology
Institute for Electrical Energy Conversion

Andreas Binder

abinder@ew.tu-darmstadt.de

Lecture at HITACHI Yamate Works, Ibaraki
26 Oct. 2012

Source: Vestas, Denmark

Wind generators

1. Fixed speed wind energy conversion
2. Variable speed wind turbines: Doubly induction fed machines
3. Gearless wind turbines
4. Wind turbines with two-stage gear
5. First German off-shore wind park

Wind generators

- Fixed speed drives: super-synchronous speed $n_{Gen} = (1\text{-}s)\cdot f_s/p$, s ~ -0.5 ... -1 %

  Cage induction generators, directly grid operated, super-synchronous speed

  geared wind turbines $n_T = n_{Gen}/i$ (i: gear ratio, typically 50 ... 100)

  stall turbine power control

  Rated unit power up to 1 MW

- Variable speed drives: speed varies typically n_T 50% ... 100%

  a) Geared doubly fed induction generators

  b) Gearless electrically or permanent excited synchronous generators

  c) Geared synchronous generators

  pitch turbine power control

  Rated unit power 1 ... 5 MW

1. Fixed speed wind energy conversion

- Generator speed: super-synchronous speed $n_{Gen} = (1-s)\cdot f_s/p$, s ~ -0.5 ... -1 %

  Small load dependent slip s, so speed is almost constant.

- As wind speed v varies, power varies, too: $P \sim v^3$

- Coarse and cheap adjusting of wind turbine speed by pole changing wind generator:

  Small 6-pole winding: $2p = 6$: $n_{syn} = f_s/p = 1000$/min at 50 Hz

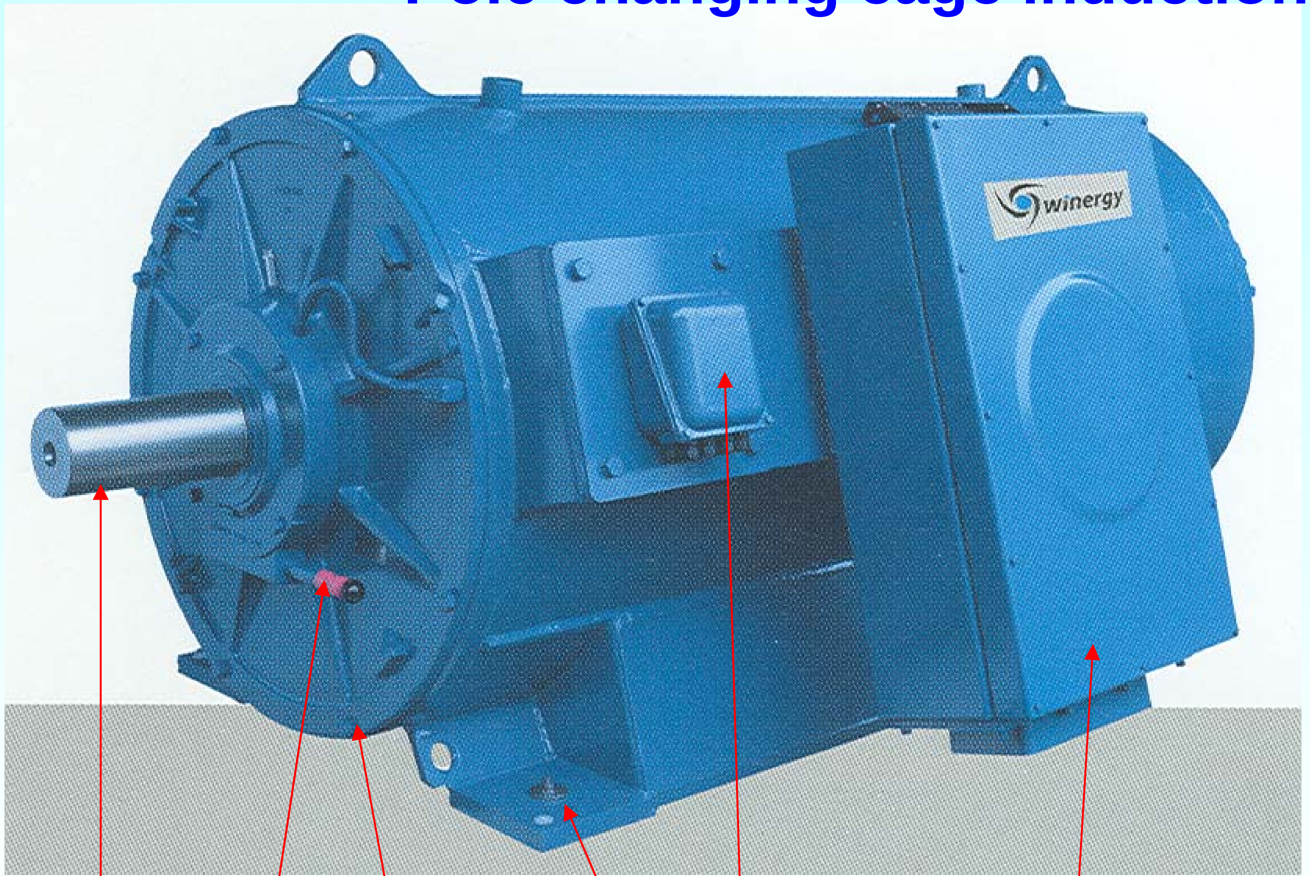
  Big 4-pole winding: $2p = 4$: $n_{syn} = f_s/p = 1500$/min at 50 Hz

- Power variation: 4 poles: 100%, 6 poles: 30 %

- Two independent three phase windings in slots of stator, switched via mechanical pole changing power switch.

Wind generators

Pole changing cage induction generator



Rated power: 1.3 MW

4-pole winding:

1500/min at 50 Hz

1800/min at 60 Hz

Water jacket cooling stator housing allows closed generator operation for outdoor use

Shaft end Housing feet terminal box Power terminal box

Bearing with lubrication opening

Source:

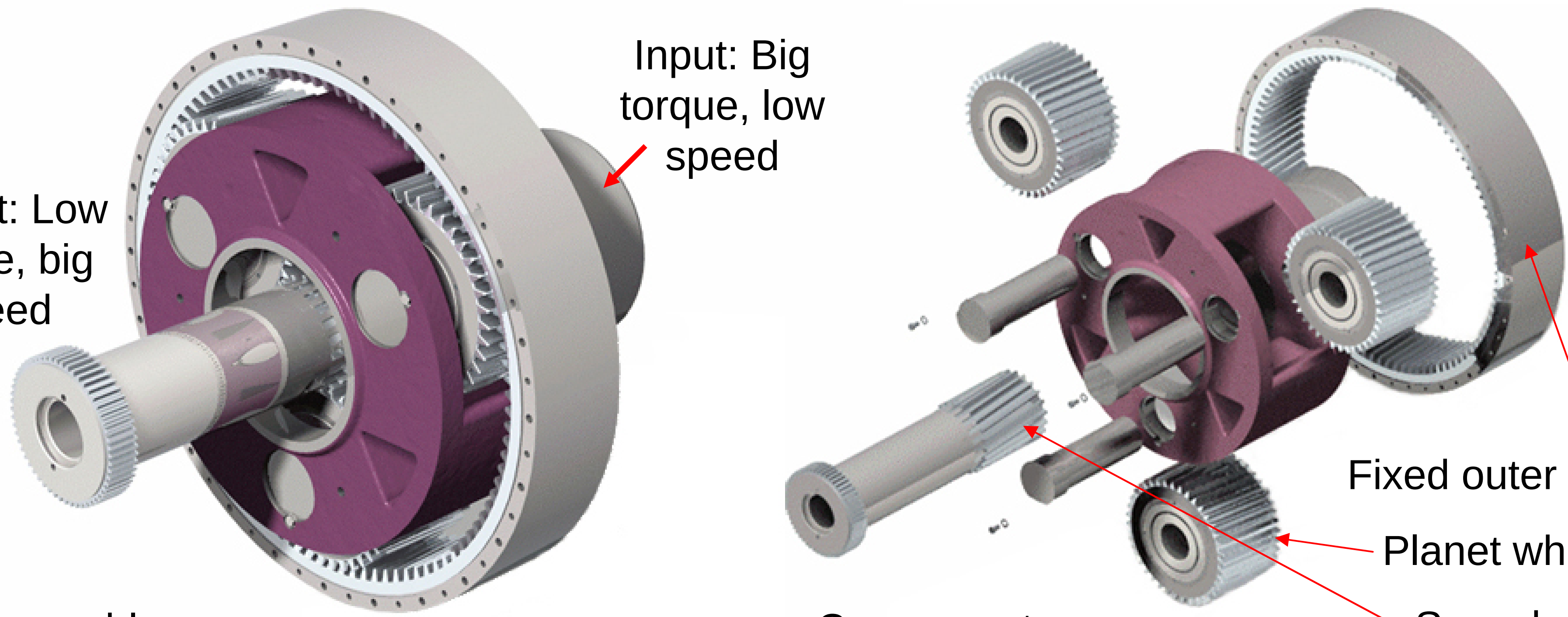
Winergy, Germany

Wind generators

Principle of planetary gear

- First stage of a two- or three-stage gear is a planetary gear

- Input and output shaft are aligned, transmission $i < 8 \ldots 9$: $M_{out} = M_{in}/i$, $n_{out} = i \cdot n_{in}$

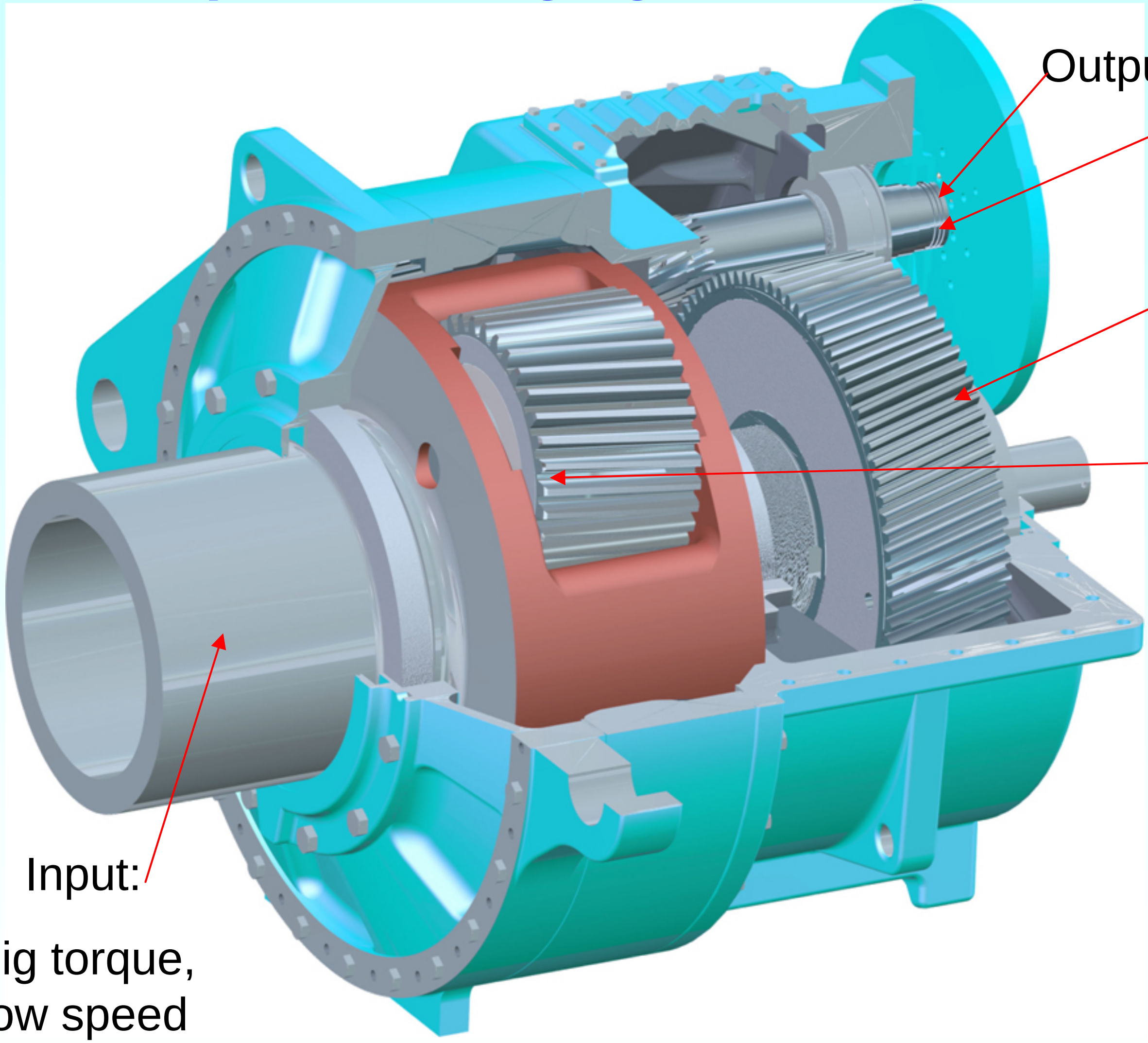


Assembly Components

Source: GE Wind, Germany

Wind generators

Principle of 3 stage gear with planetary gear as 1st stage



Source: GE Wind, Germany

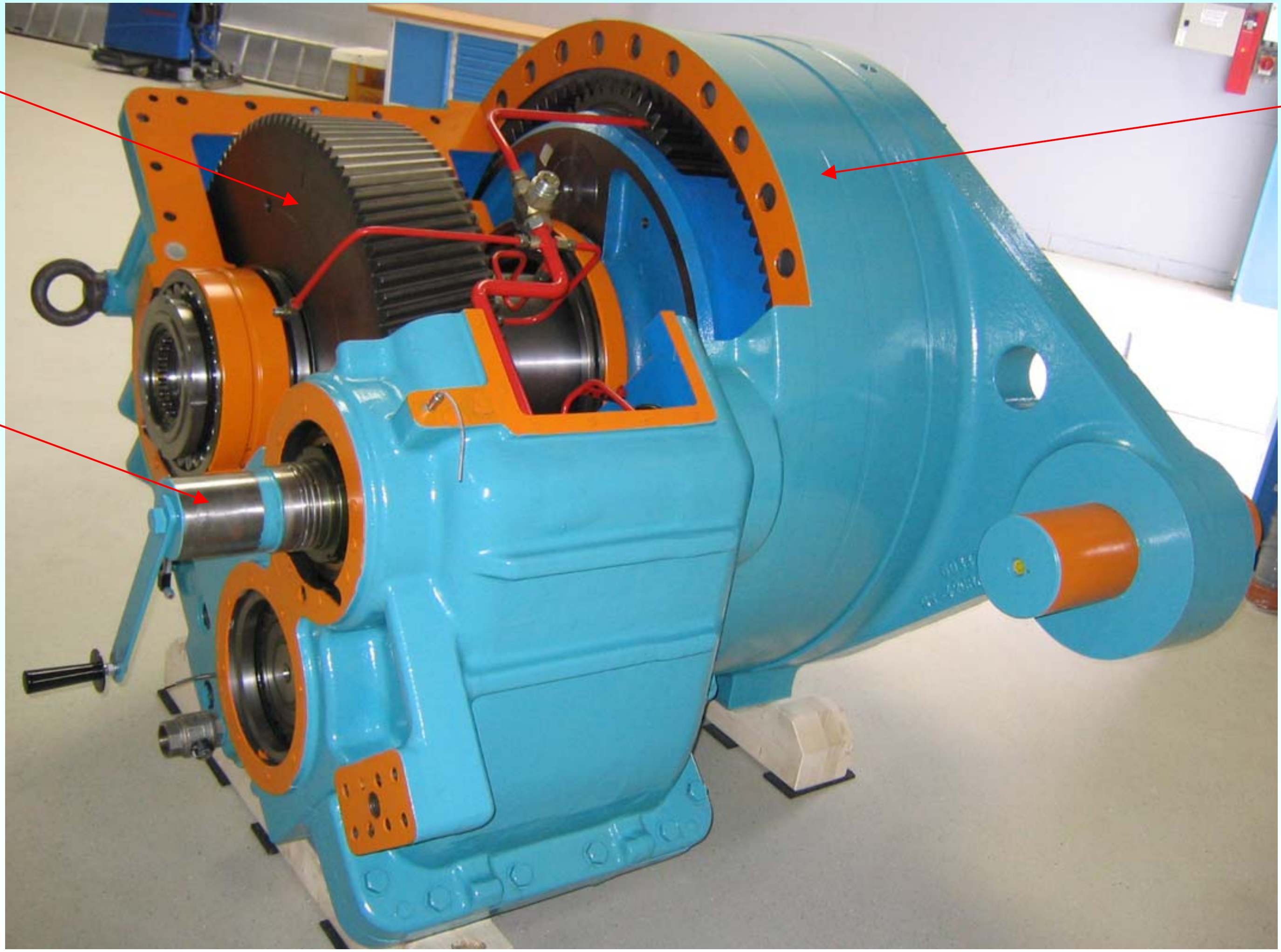
Wind generators

Planetary gear with two helical stages = 3 stage gear, *i* = 100

Second stage
= helical gear

Third stage:
helical gear at high speed e.g. 1500/min, low torque

Cut-view demonstration object



First stage:

Planetary gear: Input at low speed , e.g. 15/min

Source: GE Wind, Germany

Wind generators

Finishing work on rotor blades of wind converter with fixed speed induction generator

Source:

Vestas, Denmark

Wind generators

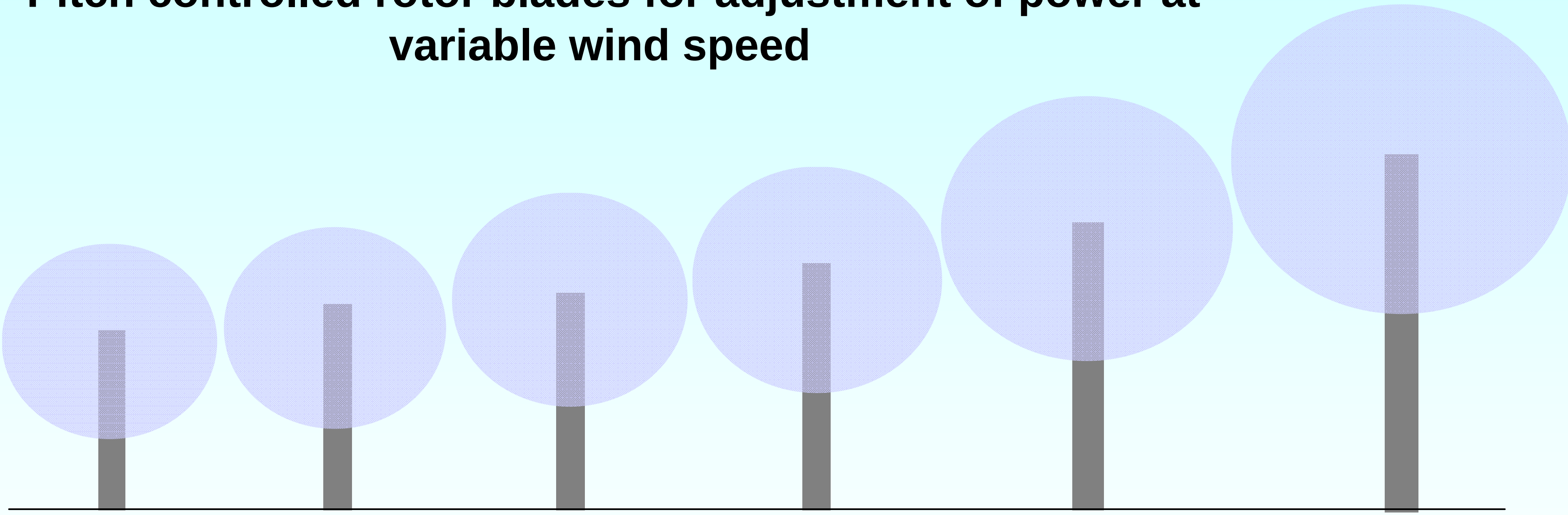
2. Variable speed wind turbines: Doubly induction fed machines

- Fixed speed drives:
  - Speed variation only by slip: $n_{Gen} = (1-s) \cdot f_s / p$, s ~ -0.5 ... -1 %
  - Cage induction generators: Big variation of torque with slip (*Kloss* function)
  - Wind power depends on speed: $P \sim n^3$
  - Local wind speed fluctuation leads turbine speed fluctuation, which causes big power fluctuation, when wind turbine blade is shadowing centre pole
  - Frequency of power fluctuation: $f = z \cdot n$ (z = 3: number of blades of wind rotor)
- Advantage of variable speed drives:
  - "Stiff" *Kloss* function is replaced by speed controlled drive via inverter feeding.
  - No big power fluctuations with 3-times turbine speed
  - Turbine blades may be operated for optimum air flow angle, getting maximum turbine efficiency below rated speed

Wind generators and high power drives

Wind generators – Power data

- **Pitch controlled rotor blades for adjustment of power at variable wind speed**



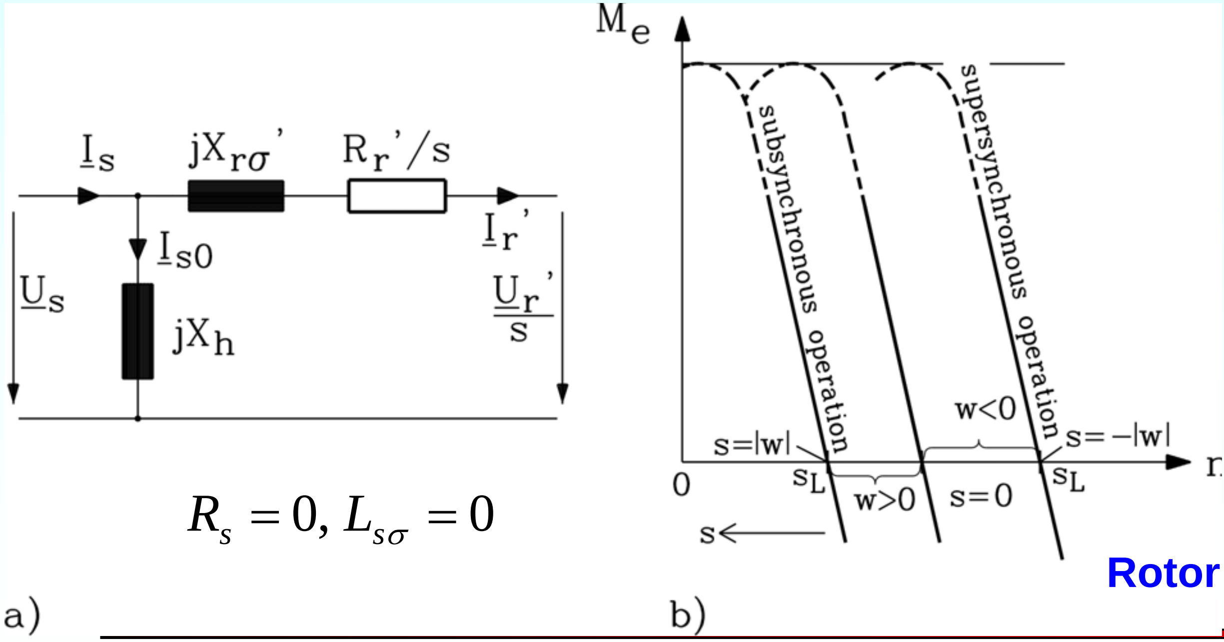
Wind generators

Principle of doubly fed induction machine

- *Aim*: Speed variable operation with small inverter:
  inverter rating less than motor rating $S_{Umr} < S_{Mot}$
- *Solution:* Line-fed slip-ring induction machine, fed by small inverter in the rotor via slip rings
- **but:** Speed range $n_{\min} \leq n_{syn} \leq n_{\max}$ small. If we want $n_{min} = 0$, we get $S_{Umr} = S_{Mot}$.
- **Inverter feeds with rotor frequency an additional rotor voltage $\underline{U}'_r$ into rotor winding.**

  \- Via variable **amplitude** of $\underline{U}'_r$ the speed is changed,

  \- Via **phase shift** of $\underline{U}'_r$ the reactive component of stator current $\underline{I}_s$ is changed



$R_s = 0, L_{s\sigma} = 0$

Explanation with simplified T-equivalent circuit per phase:

$$\underline{U}_s = jX_h(\underline{I}_s - \underline{I}'_r) = jX_h \underline{I}_{s0}$$

$$\underline{U}'_r = -(R'_r + jsX'_r)\underline{I}'_r + jsX_h \underline{I}_s$$

Rotor current: $$\underline{I}'_r = \frac{\underline{U}_s - \frac{\underline{U}'_r}{s}}{\frac{R'_r}{s} + jX'_{r\sigma}}$$

Rotor additional voltage: $\underline{U}'_r = \underline{U}_s \cdot (w - jb)$

Wind generators

Simplified torque-speed curve of doubly fed machine

- **Electromagnetic torque M_e** : Approximation for small slip s << 1:

$$\underline{I}'_r = \frac{s\underline{U}_s - \underline{U}'_r}{R'_r + jsX'_{r\sigma}} \approx \frac{s\underline{U}_s - \underline{U}'_r}{R'_r} = \frac{U_s}{R'_r}(s - w + jb) \qquad s \ll 1$$

$$P_{in} = P_\delta = m_s \operatorname{Re}\left\{\underline{U}_s \cdot \underline{I}'^*_r\right\} = m_s \frac{U_s^2}{R'_r}(s - w) \Rightarrow \boxed{M_e = \frac{P_\delta}{\Omega_{syn}} = \frac{m_s U_s^2}{\Omega_{syn} R'_r}(s - w)}$$

By real part of additional rotor voltage w the ***M_e-n-curves are shifted in parallel !***

- Torque is ZERO at **no-load slip $s_L = w$**.
  - If no-load slip s_L is positive (**SUB-synchronous no-load points**) ⇔ Active component of additional rotor voltage IN PHASE with stator voltage
  - If s_L is negative (**SUPER-synchronous no-load points**) ⇔ Active component of additional rotor voltage is in PHASE OPPOSITION with stator voltage

$$M_e = 0 \quad \Rightarrow \quad s - w = 0 \quad \Rightarrow \quad \boxed{s_L = w = \frac{U'_{r,active}}{U_s}}$$

- **Inverter rating:** $S_{Inv} = 3U_r I_r$
- At n_{min} (⇔ $s_{L,max}$) both U_r and S_{Umr} are at maximum, defining inverter rating.

Wind generators

Doubly fed induction machine as wind generator

- Wind turbine **with variable speed** allows to extract **maximum possible wind power** at each wind velocity ***v*** .
- $$P_{Wind} \sim v^3 \Rightarrow \boxed{P_{Turbine} \sim n^3}$$
- Doubly fed induction machine used as **variable speed generator, operating at grid with constant grid frequency !**
- Additional rotor voltage with rotor frequency generated by 4-quadrant PWM inverter via slip ring fed into rotor winding.

- *Example:* Wind velocity varies between $0.65v_{max}$ and v_{max}:
- Generator and gear to turbine are designed hence for speed range $n_{syn} \pm 20\%$ ($s = \pm 0.2$):

Wind velocity	Generator speed	slip	add. voltage	power
v_{max}	$n = 1.2n_{syn} = n_{max}$	$s = -0.2$	$w = -0.2$	$P = 100\%$
$v_{min} = 0.65v_{max}$	$n = 0.8n_{syn} = 0.65n_{max}$	$s = +0.2$	$w = +0.2$	$P = 30\%$

- Rated power of inverter at steady state operation and rated torque:

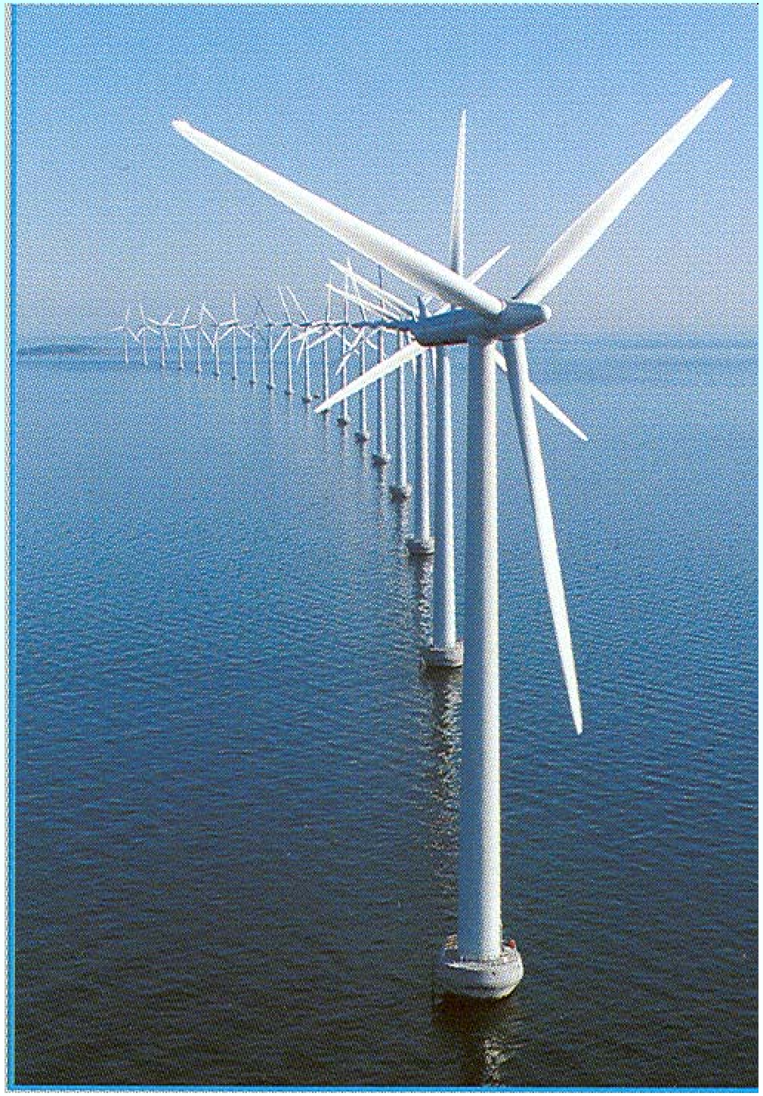
$$P_{Inverter} = sP_\delta \approx sP_N = 0.2P_N$$

Here inverter rating is only 20% of generator rating, thus it is a very cheap solution, which is used nowadays widely at big wind turbines 1.5 ... 5 MW.

Wind generators

Off-shore wind park near *Denmark*

- Variable speed wind turbines
- Pitch control
- Doubly-fed induction generators
- Yaw control to align wind direction



Source:

Winergy, Germany

Wind generators

Wind rotor:

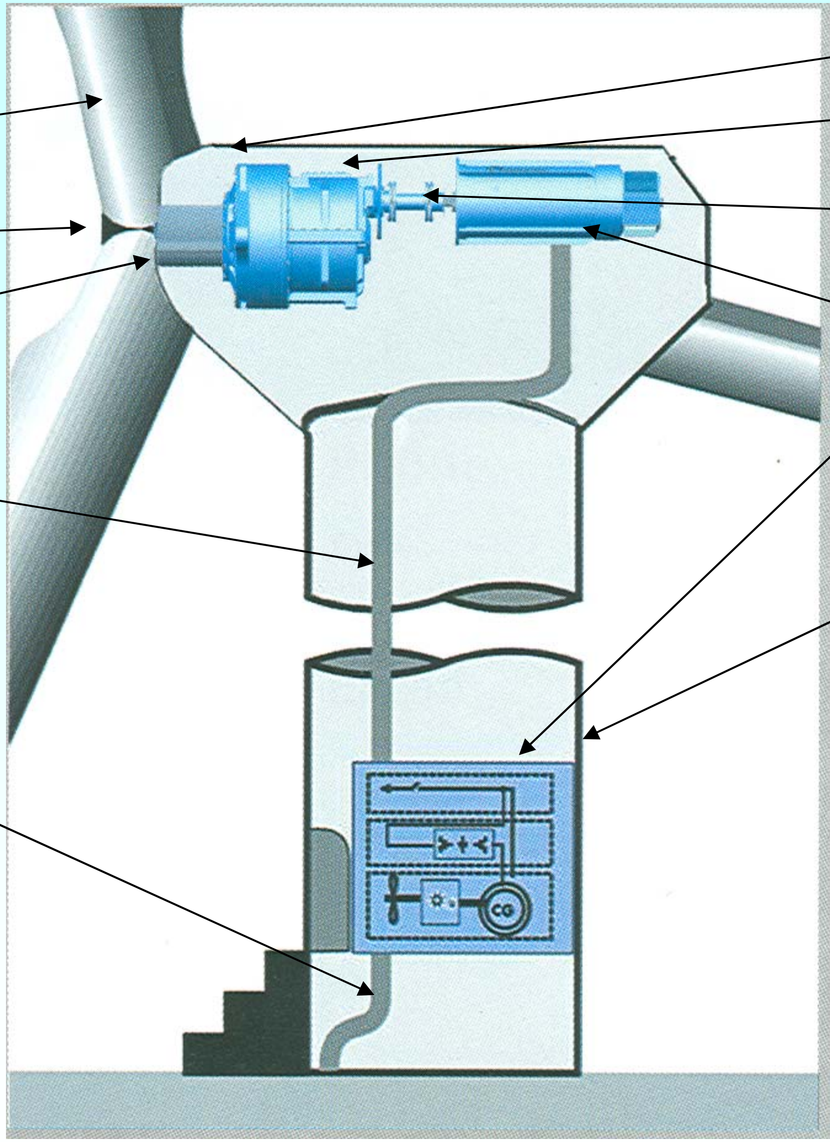
Blade

Spider

Turbine shaft

Generator three-phase cable

Transformer low-voltage three phase cable



Nacelle:

Three-stage gear

Generator shaft + coupling

Induction generator

Rotor side inverter

Centre pole

Components of variable speed wind converter systems

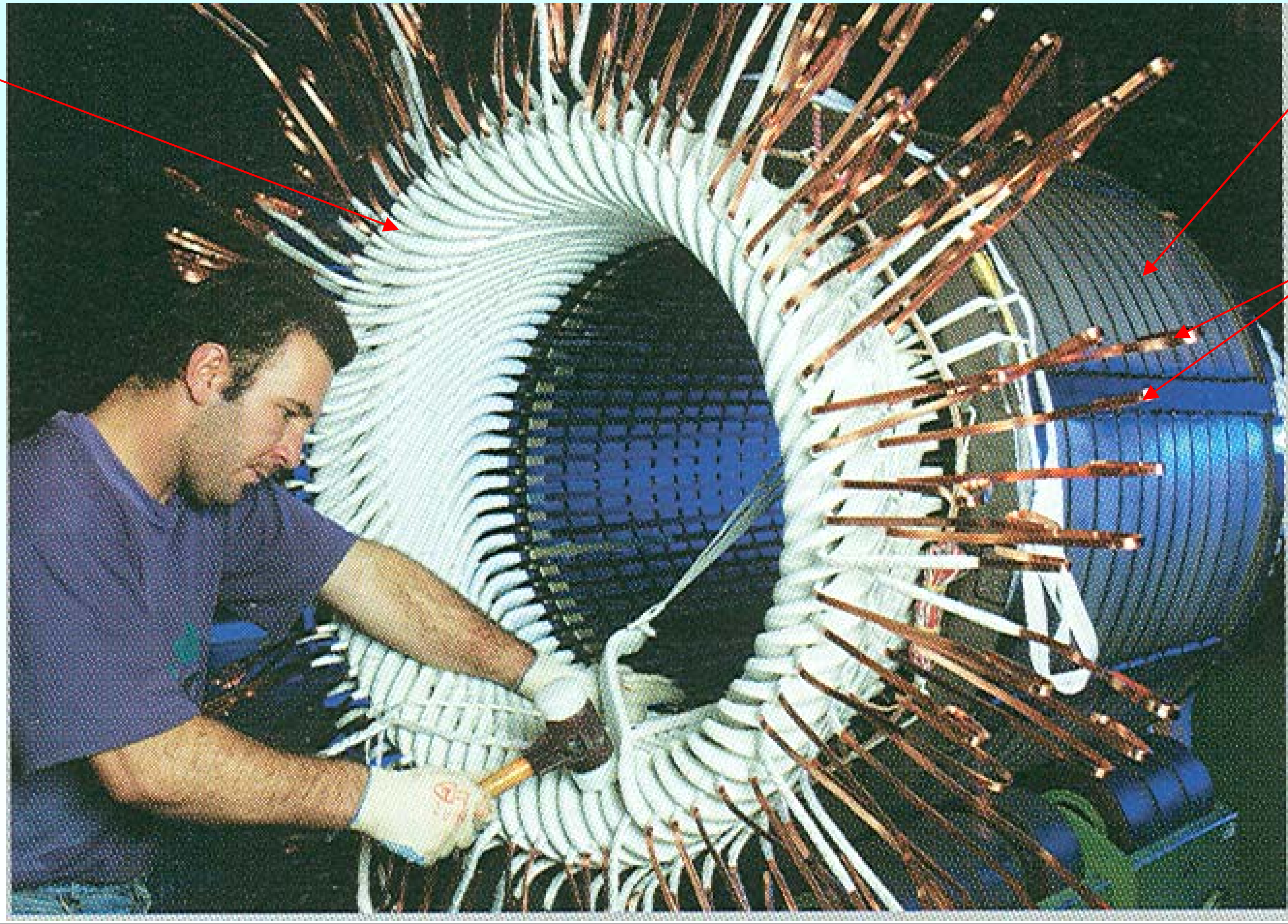
Source:

Winergy, Germany

Wind generators

Inserting form-wound two-layer winding in induction generator stator

Winding overhang



Stator iron stack

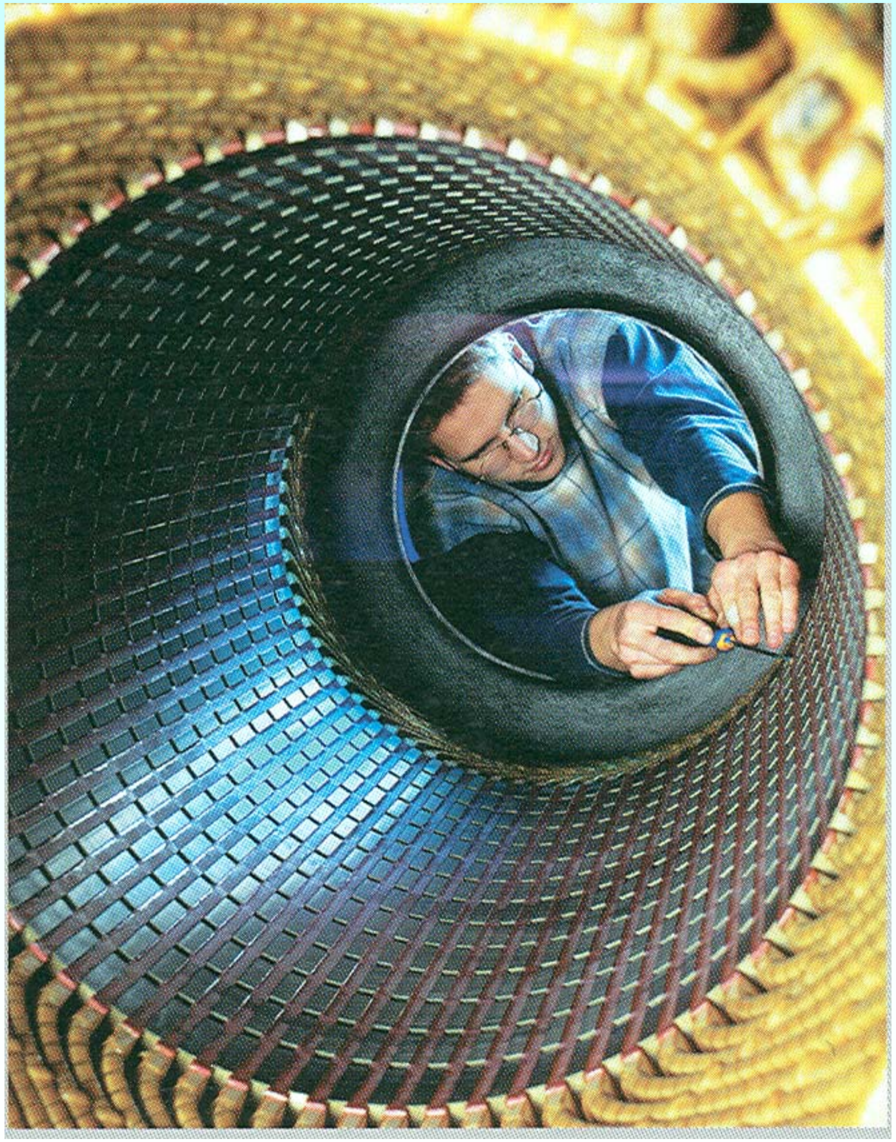
coil ends

Source:

Winergy

Germany

Wind generators



Stator three phase two-layer winding of induction generator

Source:

Winergy

Germany

Wind generators

Rotor three phase two-layer winding of slip ring induction generator

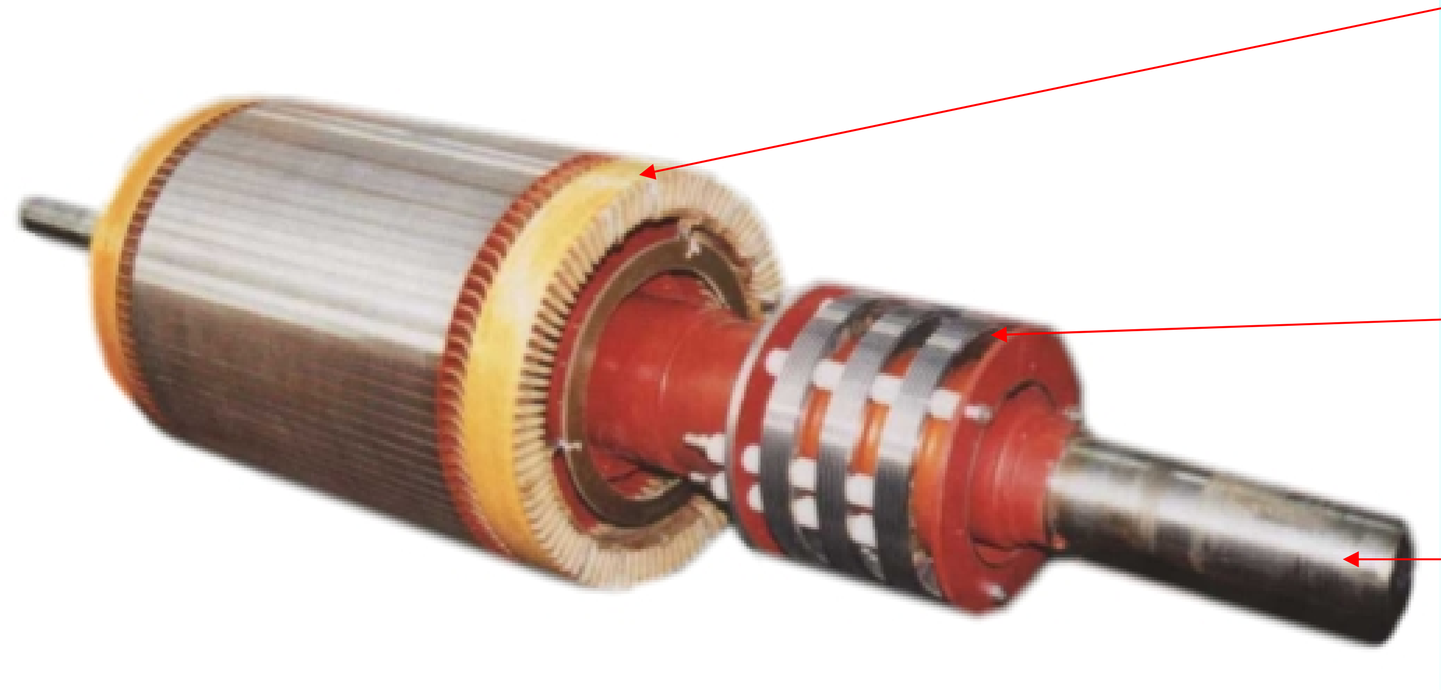
Source:

Winergy

Germany

Wind generators

Wound rotor of slip ring induction machine



Two-layer three-phase rotor winding

Y connected

3 slip rings of the three phases

shaft end

Source:

GE Wind, Germany

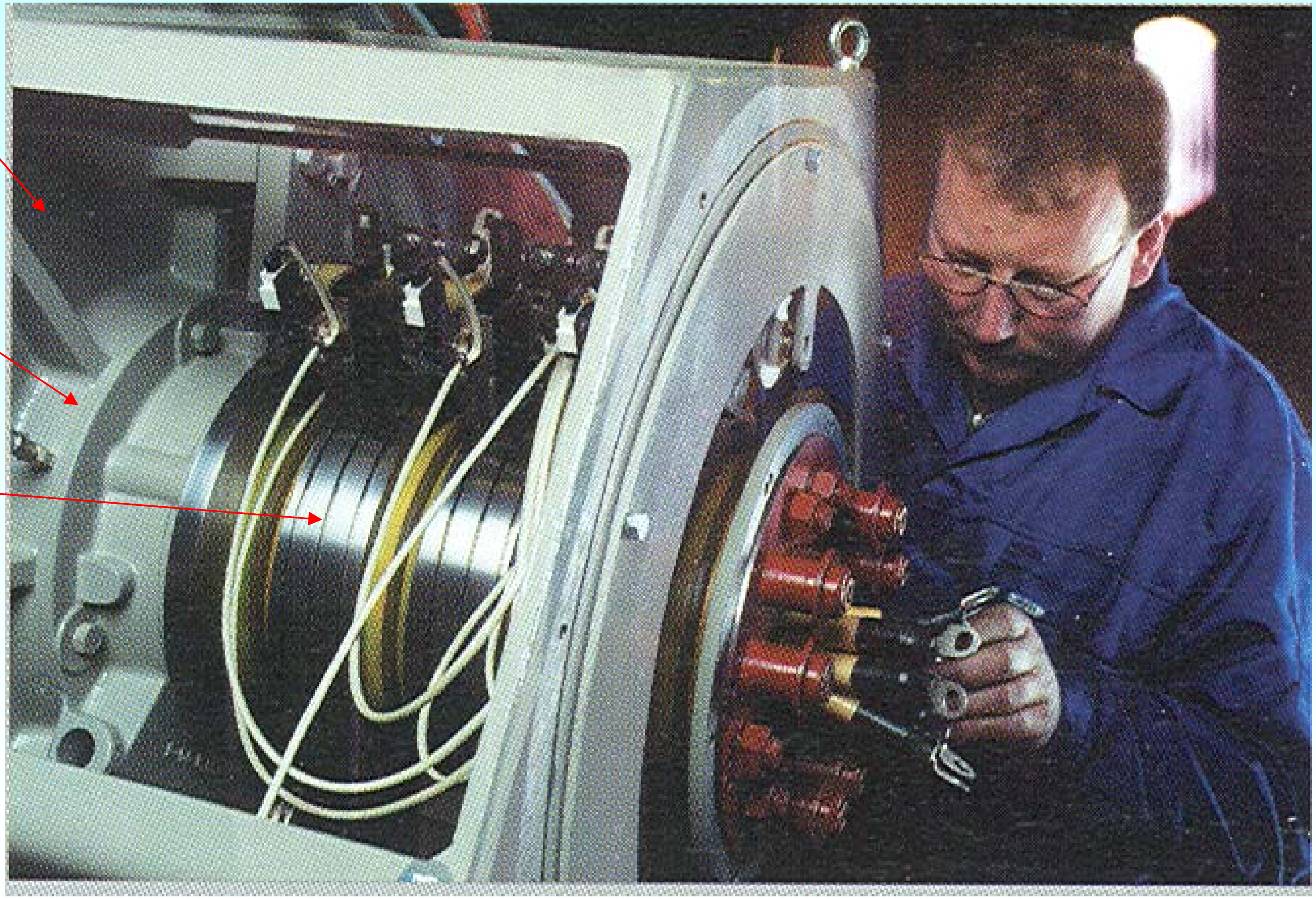
Wind generators

Connecting rotor winding to slip rings

Non-drive end shield

bearing seat

slip rings with spiral slot to avoid aerodynamic levitation of brushes



Source: Winergy Germany

Wind generators

Carbon slip rings instead of steel slip rings shall enhance brush life

Source: Winergy, Germany

Wind generators

Doubly-fed induction generator with heat exchanger

Air-inlet fan Feet Power terminal box Slip ring terminal box

Air-air heat exchanger above

Doubly-fed induction generator

4 poles

2000 kW at 1800/min, 50 Hz and slip -20%

Rotor frequency 10 Hz

Source:

Winergy

Germany

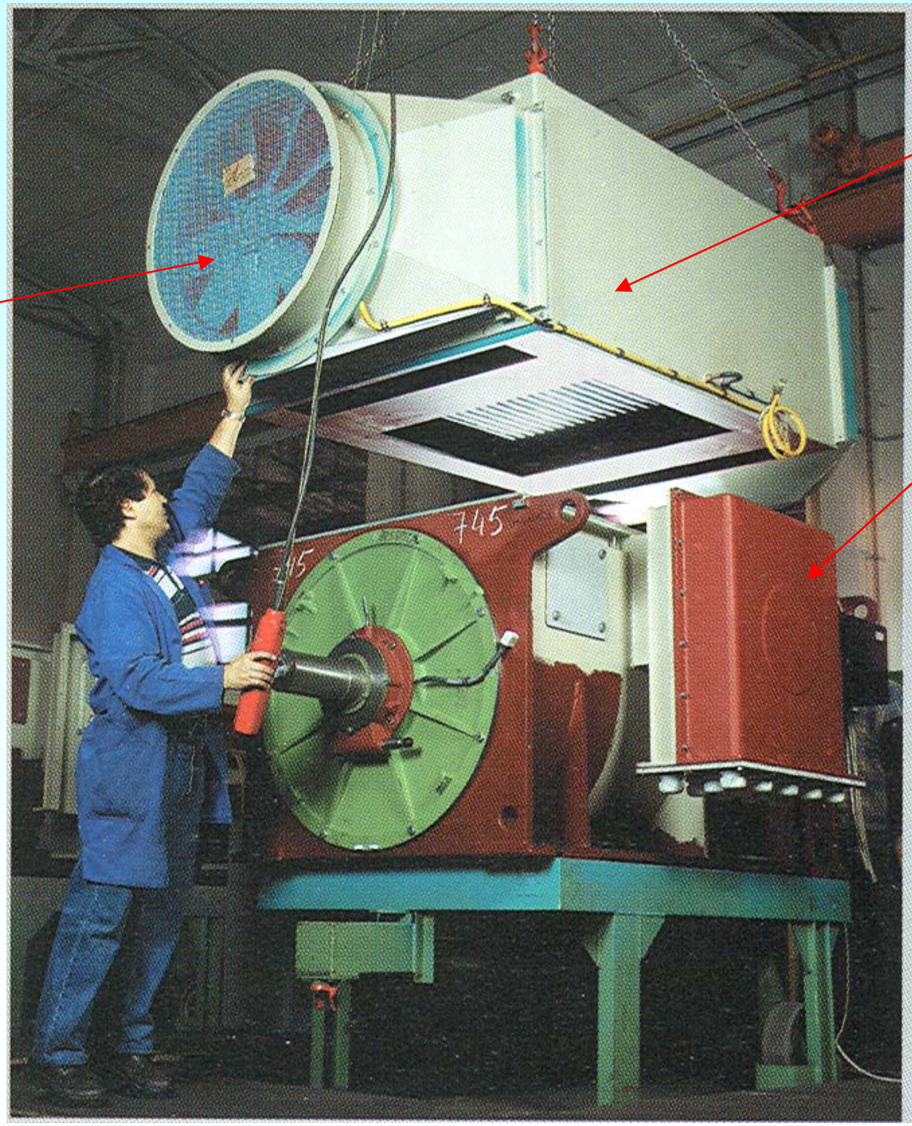
Wind generators

Doubly-fed induction generator

1500 kW at 1800/min

Air inlet fan

Mounting of air-air heat exchanger on slip ring induction generator



Air-air heat exchanger

Generator terminal box

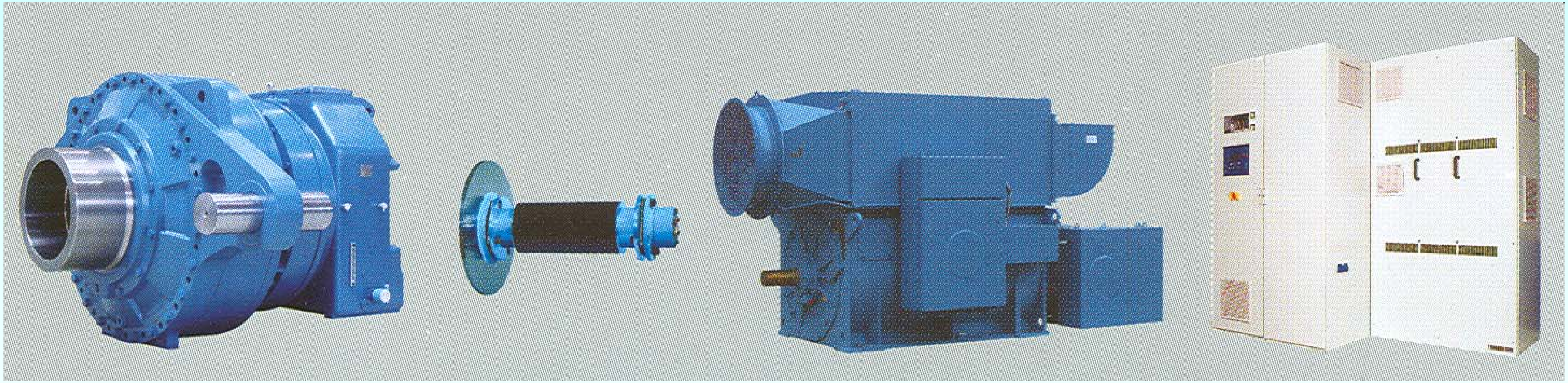
Source:

Winergy

Germany

Wind generators

Components of doubly-fed induction generator system 2 MW



Three-stage planetary gear | generator coupling | slip-ring induction generator | rotor side inverter

Source: Winergy, Germany

Wind generators

Electric drive system assembly with doubly fed induction generator 1.5 MW variable speed

Air-air heat exchanger spider

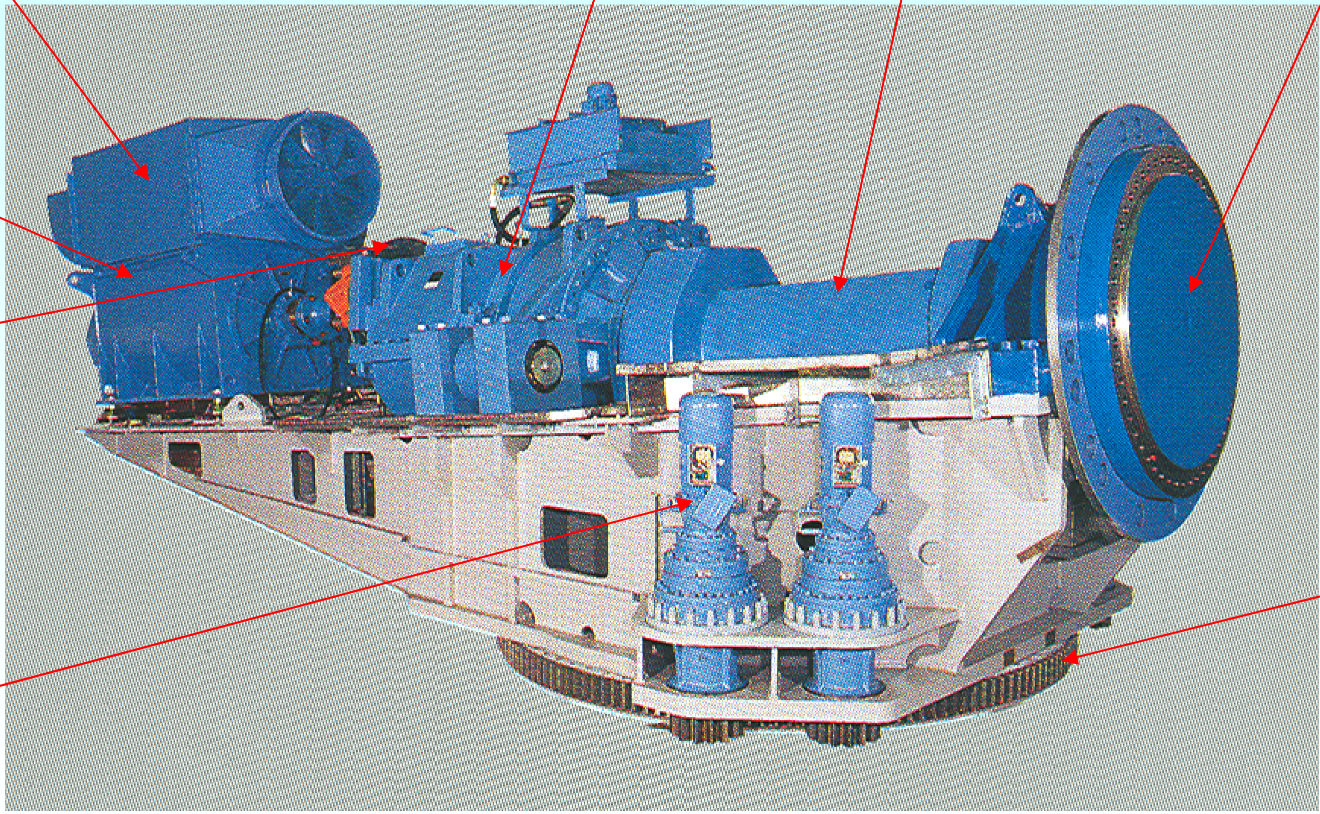
Three-stage gear unit

turbine shaft

turbine flange for wind rotor

Induction generator

Brake system



Inverter-fed induction motors for yaw positioning

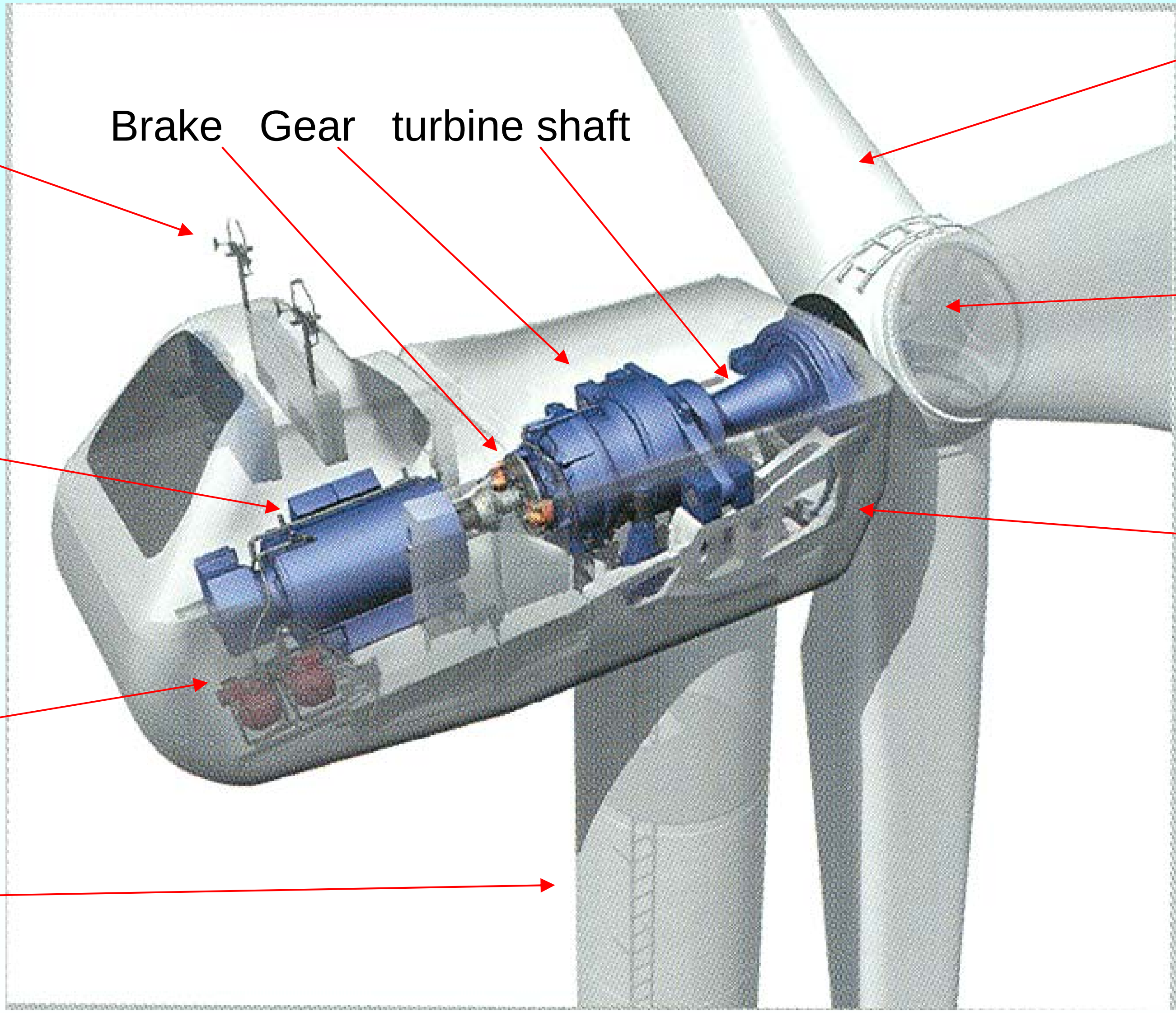
Cog wheel for yaw positioning

Source:

Winergy, Germany

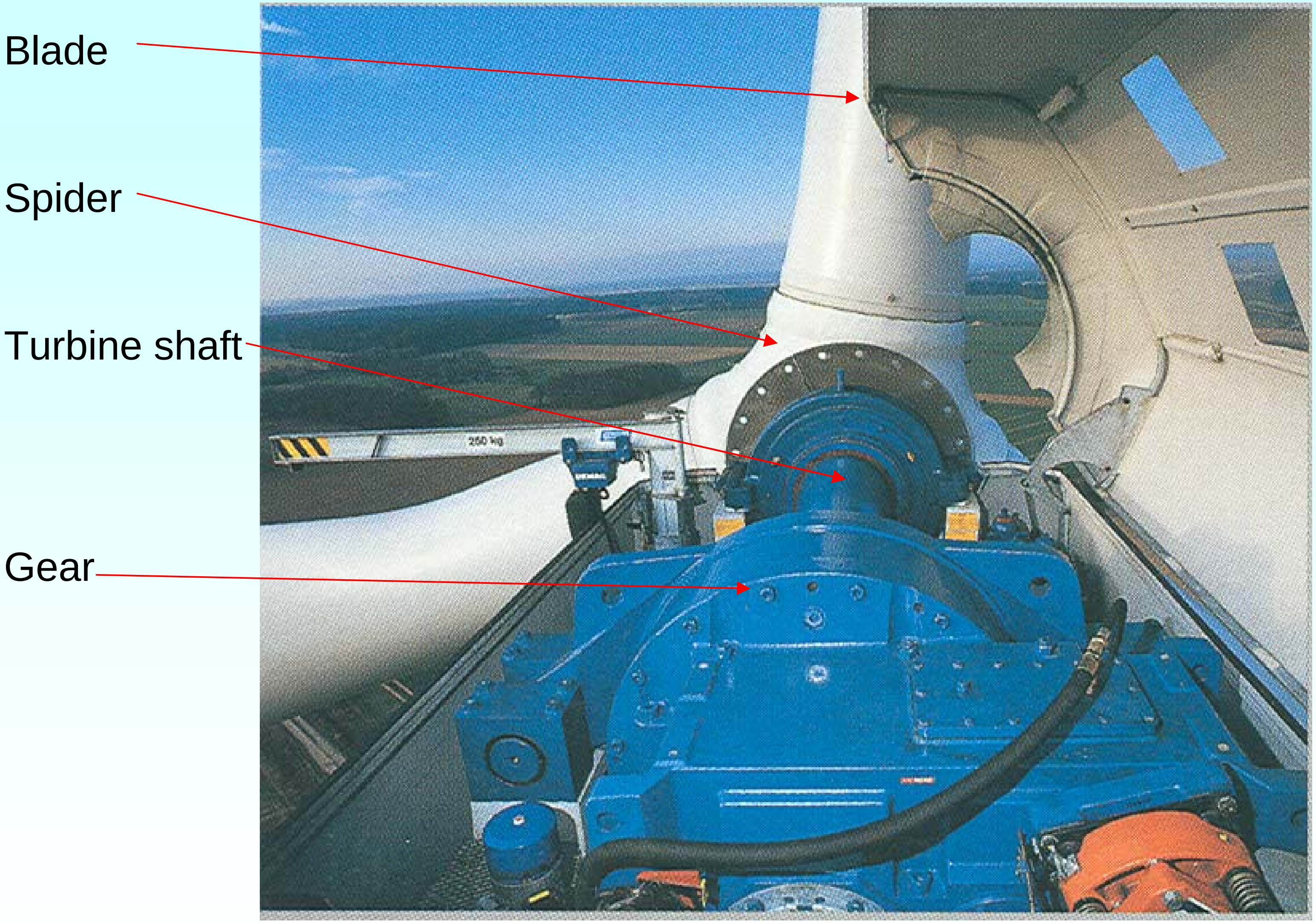
Wind generators

Wind converter assembly



Source: Winergy Germany

Wind generators



Mounting of drive assembly in nacelle

Source:

Winergy

Germany

Wind generators

Totally enclosed induction generator with shaft mounted fan

Generator coupling

Gear

Installation of monitoring system for generator unit

Source:

Winergy

Germany

Wind generators

Typical variable speed wind turbine data for off-shore

Rated power	3 MW	5 MW
Wind turbine rotor diameter	104 m	125 m
Speed range 1/min	8.5 ... 13 (Rated) ... 15.3	7 ... 11 (Rated) ... 13
Wind velocity m/s	3.5 ... 25	3 ... 25

Cut-in wind speed: typically 3 m/s

Cut-off wind speed: typically 25 m/s

Dominating electrical system: Geared doubly-fed induction generator

System components:

- Induction generator with wound rotor and slip rings, voltage < 1000 V (e.g. 690 V/ 50 Hz)
- Rotor side IGBT inverter (Insulated gate bipolar transistor)
- Inverter PWM control on rotor and grid side (Pulse width modulation)
- Three stage gear unit (transfer ratio per stage < 8): i = 70 ... 100 from low turbine speed to high generator speed
- Transformer (e.g. 690 V / 20 kV) for grid connection

Masses of doubly-fed variable speed wind energy converters

Rated power	3-blade wind rotor	Generator system: Doubly fed induction gen.	Nacelle	Wind rotor + Nacelle
1.5 MW *Südwind*	D_R = 77 m, 5.6 t per blade, in total with spider: 34 t	Gear: i = 104 14 t (300 l Oil) Generator: 7 t	Total nacelle mass: 61 t	Total mass: 84 t
5 MW *Repower*	D_R = 125 m, 19 t per blade, in total with spider: 110 t	Gear: i = 98.3 65 t Shaft + Bearing: 35 t	Total nacelle mass: 240 t *Length* x *Height*: 23 m x 6 m	Total mass: 350 t

Wind generators

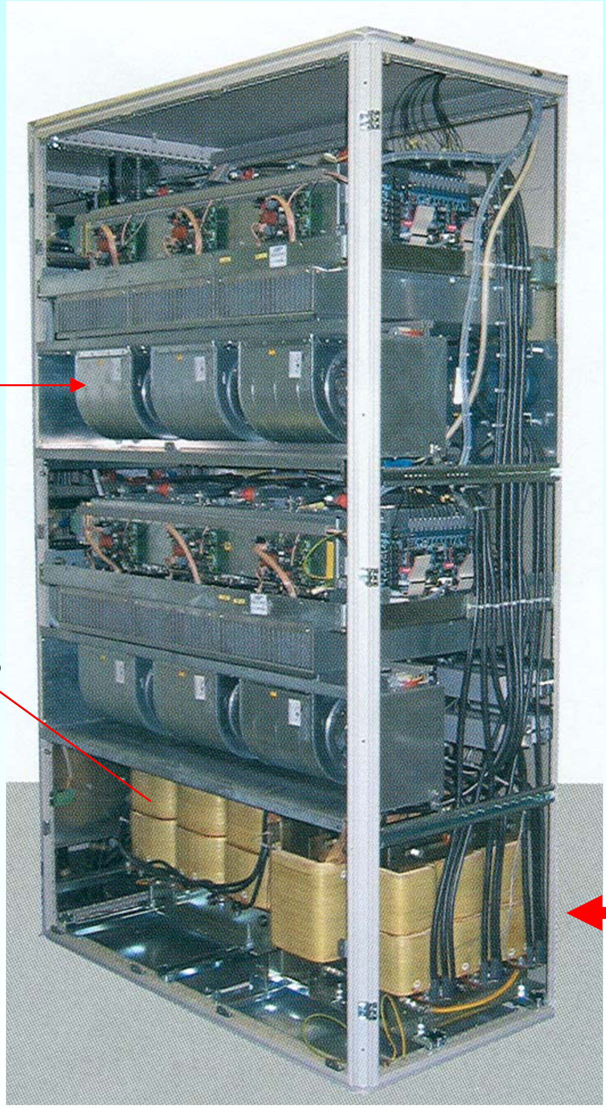
Example: Rating for doubly-fed generators

Wind power rating	3 MW
Generator cooling / Thermal class	Air-Air heat exchanger / Class F
Generator rating	3.3 kV / 616 A / 50 Hz
Apparent power / power factor	3.5 MVA / 0.88 inductive load
Real power / Generator mass	3.1 MW / 14.6 t
Slip range / Rotor voltage at stand still	+ / - 30 % / 2443 V at 50 Hz
Rotor: rated current / apparent power	748 A / 950 kVA
Generator frame size / dimensions *LxBxH*	630 mm / 3.8x2.6x1.7 m^3
Full load efficiency	97.1 %
Turbine speed/ Gear transmission ratio	11.9 / min / 990/11.9 = 83.2

Wind generators

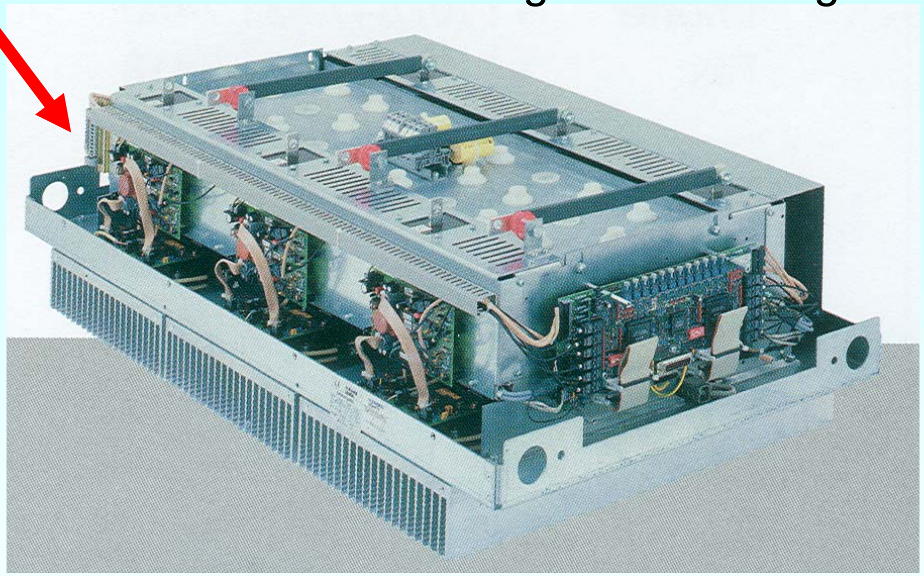
Fan units

Filter chokes



Rotor side PWM voltage source inverters

Air cooled IGBT-inverter bridge with cooling fins



Air-cooled power electronic circuit for a 1.5 MW-wind converter has a rating of about 450 kVA

Grid side: 690 V

Rotor side: Rated rotor current

Source:

Winergy

Germany

Wind generators

Inverter rating for doubly-fed generators

Rated power of wind converter	3 MW
Rated voltage / Current / Frequency	732 V / 748 A / <15 Hz; 50 Hz
Rated apparent power	950 kVA
Inverter unit / full-load efficiency	800 kW / 820 A / 97 %
Dimensions *LxBxH* / Mass	0.9x0.6x2.45 = 1.3 m^3 / 1045 kg
Crowbar:	ca. 1.3 m^3, ca. 1 t
Control unit for grid voltage break down 15 %	ca. 1.3 m^3, ca. 1 t

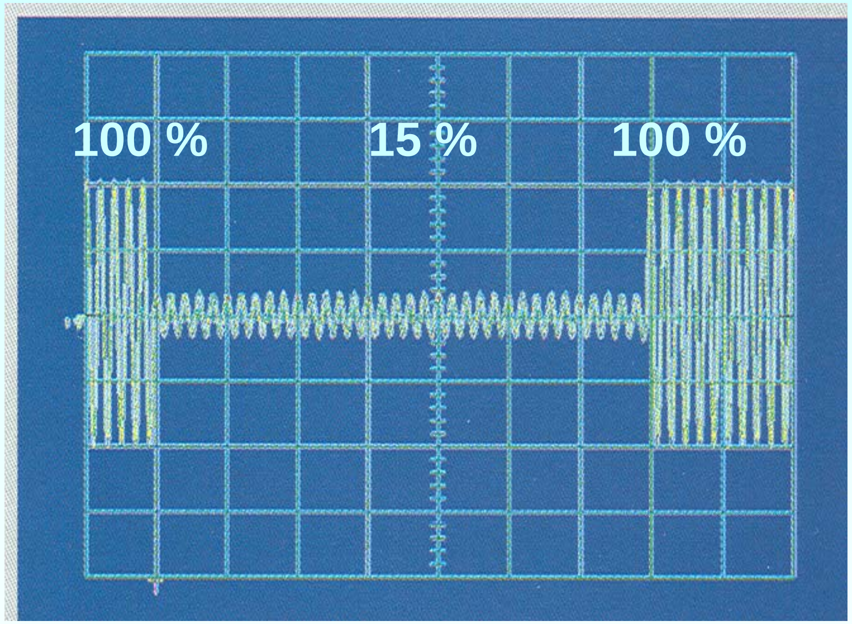
Crow bar: Thyristor switch short-circuits rotor side inverter in case of stator side winding fault. Otherwise transient rotor over-voltage and big rotor short circuit current would destroy rotor side power electronics.

Control unit for voltage break down: Is necessary to fulfil demand of TSO (transmission system operators), that wind converters have to stay at the grid even in case of voltage break down 15% of rated voltage.

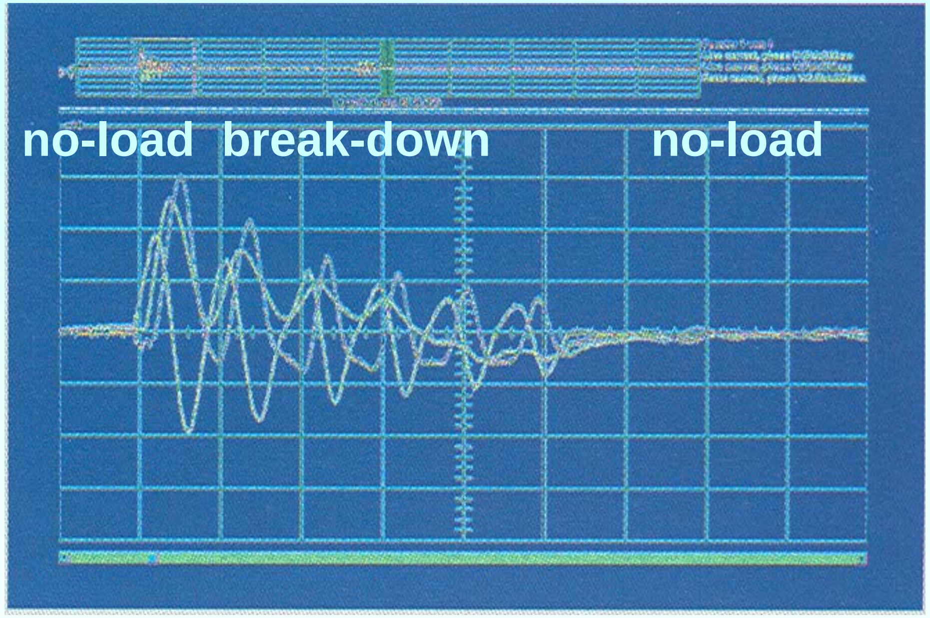
Wind generators

15% voltage break-down during 0.7 s

Generator terminal voltage



Generator transient currents



0.1 s/div. Measured voltage break-down response in test lab

TSO-demand (transmission system operators) ("E.ON"-demand):
Wind converters have to stay at the grid even in case of voltage break down 15% of rated voltage, in order to help stabilizing the grid.

Source: Winergy Germany

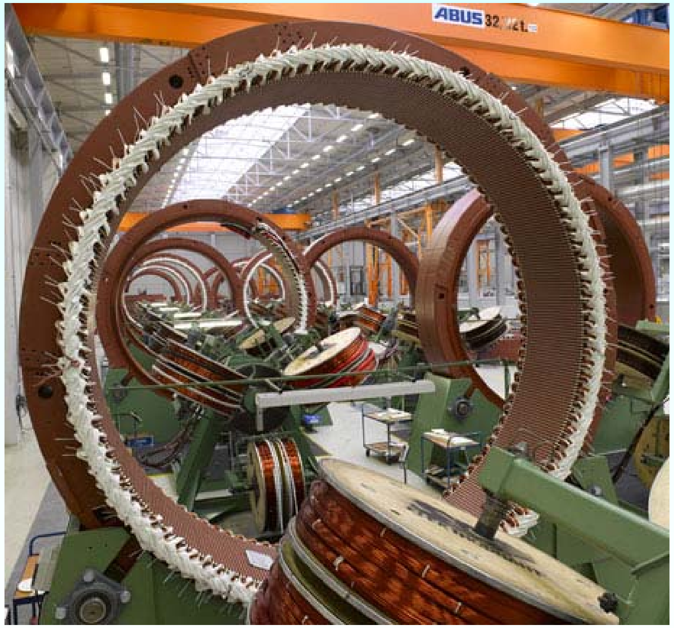
Wind generators

3. Gearless wind turbines

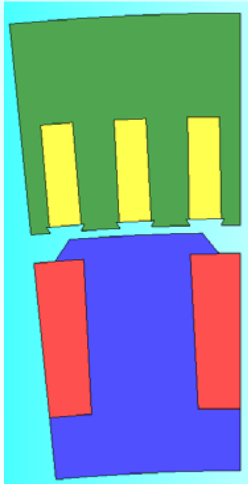
- Gearless: Turbine speed = generator speed: High pole count and low frequency are needed !

- An induction generator with small pole pitch and relatively big air gap needs a big magnetizing current. So power factor is poor (below 0.6), leading to lower efficiency !

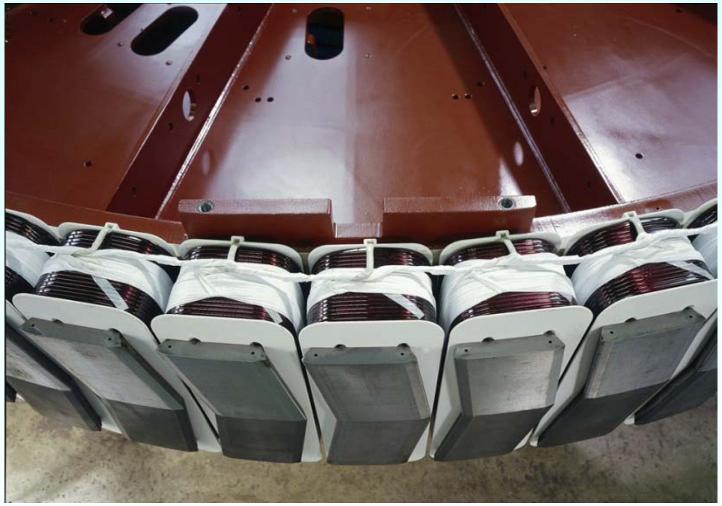
- Synchronous generators with electrical or permanent magnet excitation are used !



Integer-slot q = 1 round wire low voltage single layer stator 3-phase winding manufacturing



Integer-slot q = 1 stator winding, rotor electrical excitation



Rotor: Electrical excitation, rotor pole shoes skewed to reduce cogging. Double-skew avoids axial force

Source: Enercon, Aurich, Germany

Wind generators

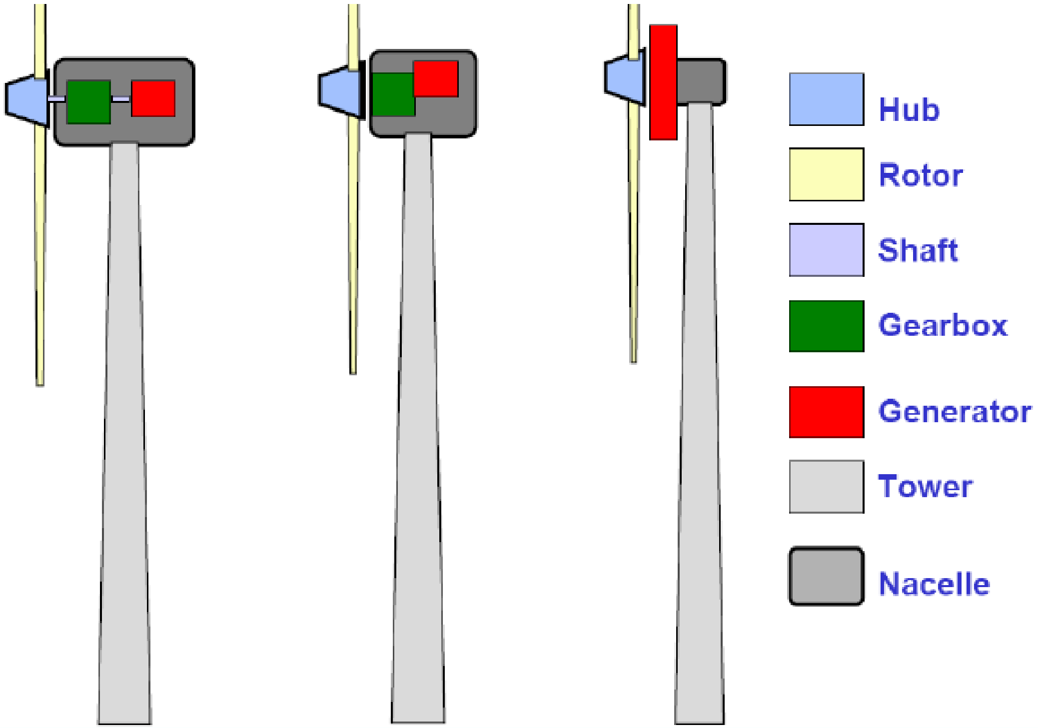
Masses of variable speed wind energy converters without gear or with only two-stage gear

Rated power	3-Blatt-Windrotor	Generator system: synchronous gen.	Nacelle	Wind rotor + Nacelle
4.5 MW *Enercon*	D_R = 104 m Rotor diameter	gearless, high pole count, electrically excited synchronous generator + inverter	No data	Total mass: 500 t
5 MW *Multibrid*	In total with spider: 100 t	Gear: i = ca.14 PM-Synchronous generator	Total nacelle mass: 130 t	Total mass: 230 t

Wind generators

Overview on different variable speed wind generator concepts

- Conventional : 15 RPM → 1:100 gearbox → 1500 RPM gen.
- Hybrid: 15 RPM → 1:6 gearbox → 90 RPM gen.
- Multi-pole: 15 RPM direct drive



Source:
DTU, Denmark

Wind generators

Gearless wind turbines with PM synchronous generators

- Synchronous generators with permanent magnet excitation do not need rotor exciter slip-rings and don not need any rotor excitation power!

Source: Siemens AG, Germany

Permanent magnet synchronous wind generator: 3 MW, 606 V, 3360 A, f = 13.6 Hz (via inverter feeding)

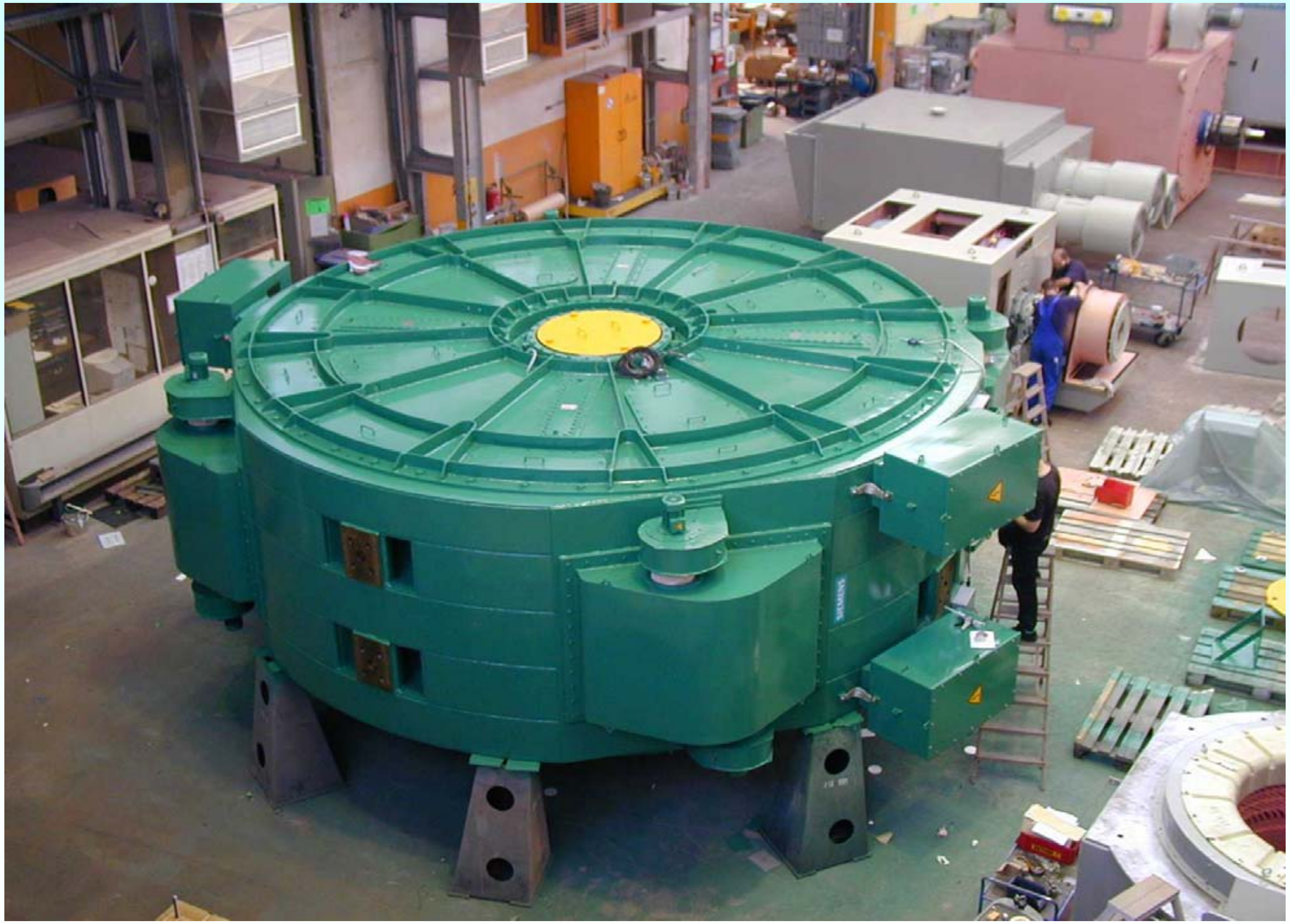
cos phi = 0.85 under-excited, speed 17 / min, efficiency 95.5%, rated torque: 1685 k Nm (!)

Outer diameter of generators: ca. 5.8 m, axial length: ca. 2.3 m

Mass ca. 85 t, high pole count: typically 90 ... 100 poles

Wind generators

Gearless permanent magnet wind generator *Scanwind / Norway* 3 MW, 17/min



Wind rotor diameter 90 m

Three-blade rotor

Pitch control

Variable speed operation

10 ... 20/min

Gearless drive

IGBT inverter 690 V

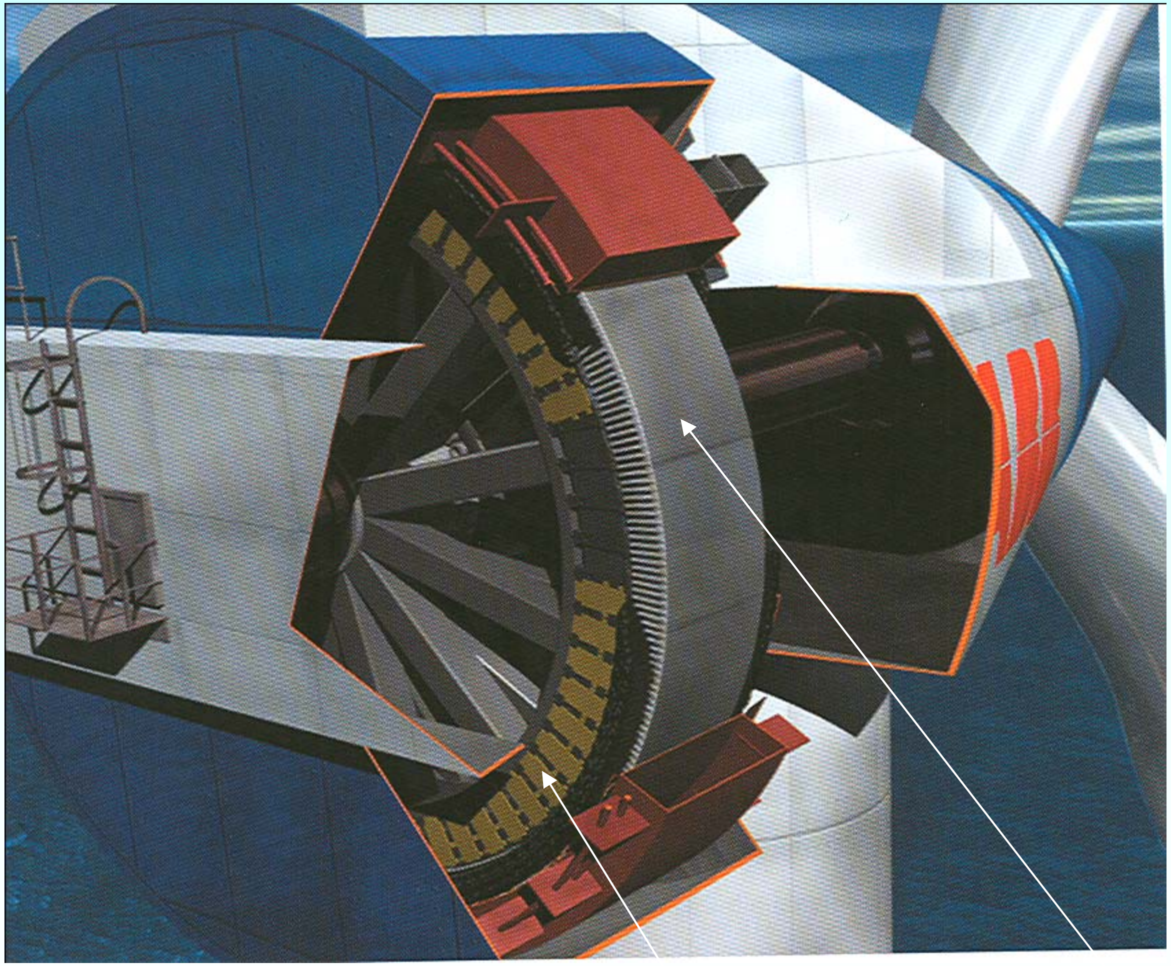
Source:

Siemens AG

Germany

Wind generators

Gearless permanent magnet wind generator



- High pole count synchronous generators have a small flux per pole.

- So height of magnetic iron back in stator and rotor may be small = thin ring shape of generator.

- Good possibility to integrate generator with turbine

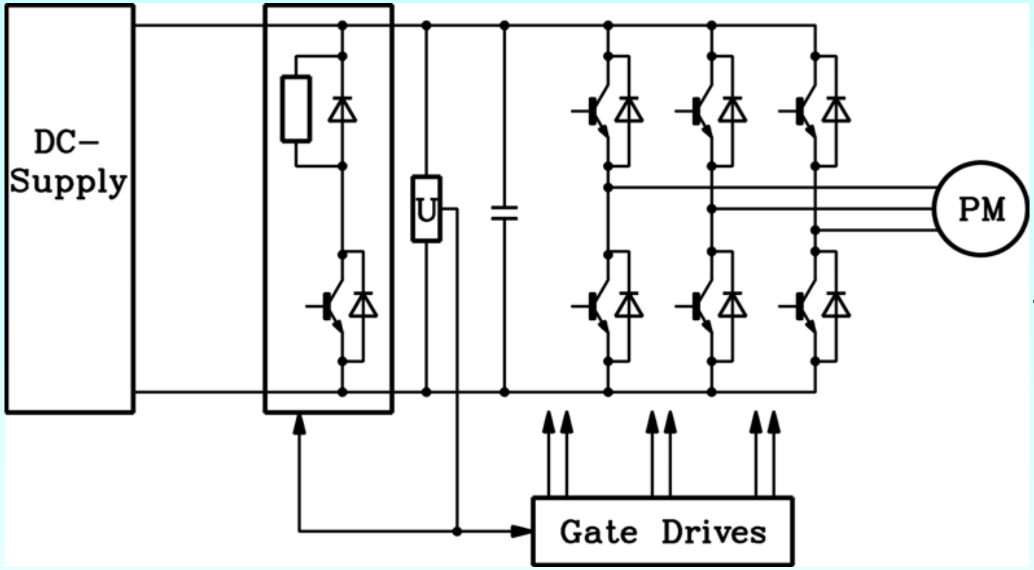
- HV stator winding to save transformer

Source: ABB, Sweden

Magnet rotor

high voltage stator with winding

Wind generators

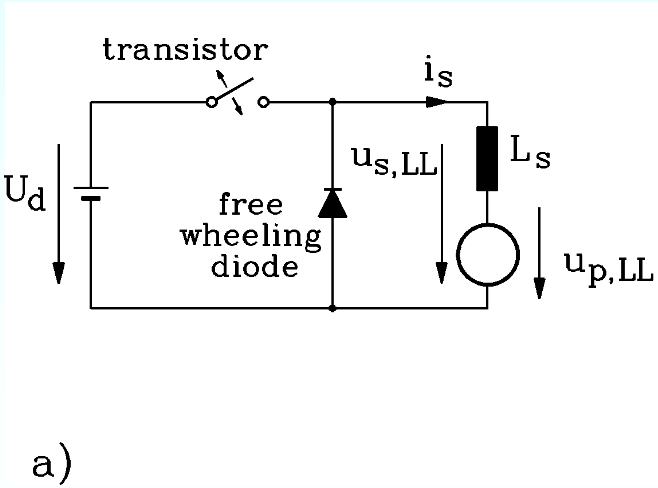


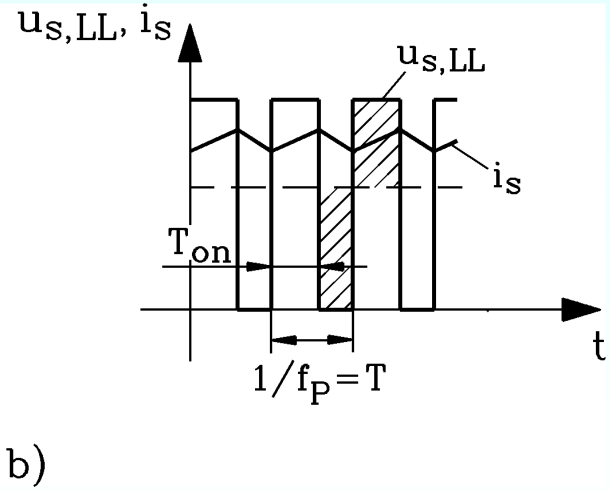
Stator feeding via IGBT inverter

DC link voltage source inverter with switching transistors and free-wheeling diodes

R_s neglected:

$$\boxed{U_d - U_{p,LL} \approx L_s \cdot di_s / dt}$$

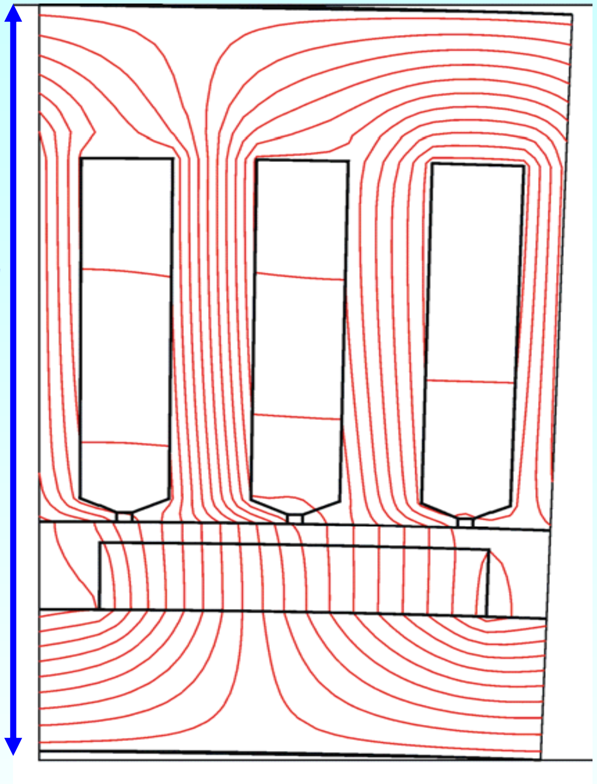




a) Equivalent switching scheme of DC link voltage source inverter, connected to the two phases with switching transistor and free-wheeling diode,

b) Current ripple and chopped inverter voltage

Wind generators



Small !

1.5 MW-wind generator:

Numerically evaluated total magnetic field per pole pitch at rated data: 1320 A, 690 V, cosphi = 0.85

Gearless high pole count wind generator

Comparison to electrically excited synchronous generator with high pole count:

-Permanent magnets avoid excitation losses: efficiency increases, temperature level decreases, exciter feeding converter not needed, so in spite of expensive permanent magnets (ca. 40 Euro / kg) still an interesting alternative.

• BUT: Danger of de-magnetization due to stator magnetic field at overload. This must be avoided by deliberate generator design (e.g. at sudden short circuit).

Wind generators

Permanent magnet wind generator: inner stator

Design for direct coupling to wind turbine without gear

21 / min rated speed

1.2 MW

690 V rated voltage

Grid side IGBT-Inverter

Generator side: Diode rectifier and step-up converter

Source:

Innowind, Germany

Goldwind, Urumqi, Xinjiang, China

Wind generators

Transportation of 1.2 MW permanent magnet wind generator to plant site

Outer PM rotor to increase torque by increased bore diameter

Inner stator with 3-phase winding, operated by inverter

Source:

Innowind, Germany

Goldwind, Urumqi

Xinjiang, China

Wind generators

Mounting of permanent magnet wind generator onto nacelle

Centre pole height 69 m

Steel pole mass 96 t

Wind rotor diameter 62 m

Speed 21 /min

Source:

Innowind, Germany

Goldwind, Urumqi

Xinjiang, China

Wind generators

Permanent magnet wind generator: Mounting of 3 blade wind rotor

1.2 MW turbine

wind rotor diameter 62 m

pole height 69 m

speed 21/min

pitch control

electrical pitch drives

Nacelle and rotor mass: 81 t

Source:

Innowind, Germany

Goldwind, Urumqi

Xinjiang, China

Wind generators

1.2 MW gearless permanent magnet wind generator in operation

1.2 MW turbine

wind rotor diameter 62 m

pole height 69 m

speed 21/min

pitch control

electrical pitch drives

Nacelle and rotor mass: 81 t

Centre pole mass: 96 t

PM generator

Source:

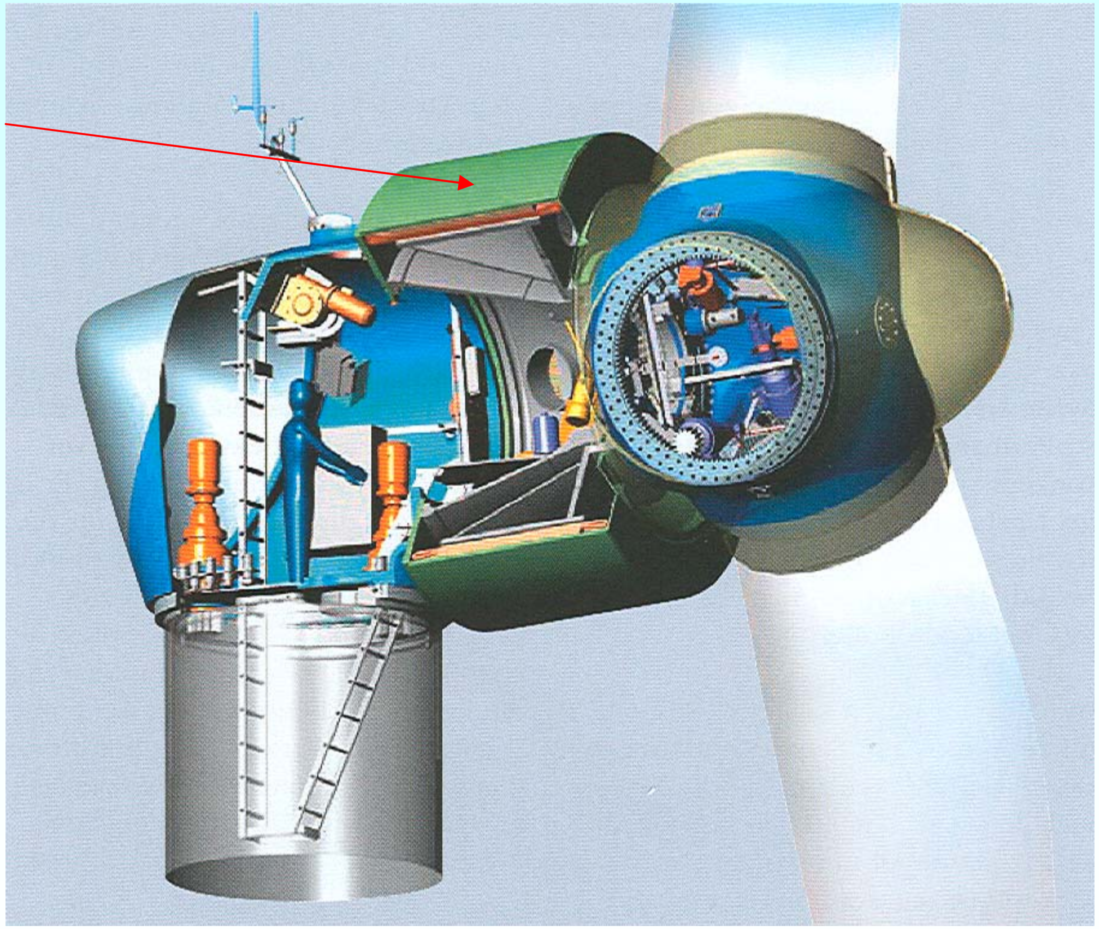
Innowind, Germany

Goldwind, Urumqi, Xinjiang, China

Wind generators

Gearless wind turbine *Zephyros Z72* with inner rotor permanent magnet wind generator (ABB)

PM generator

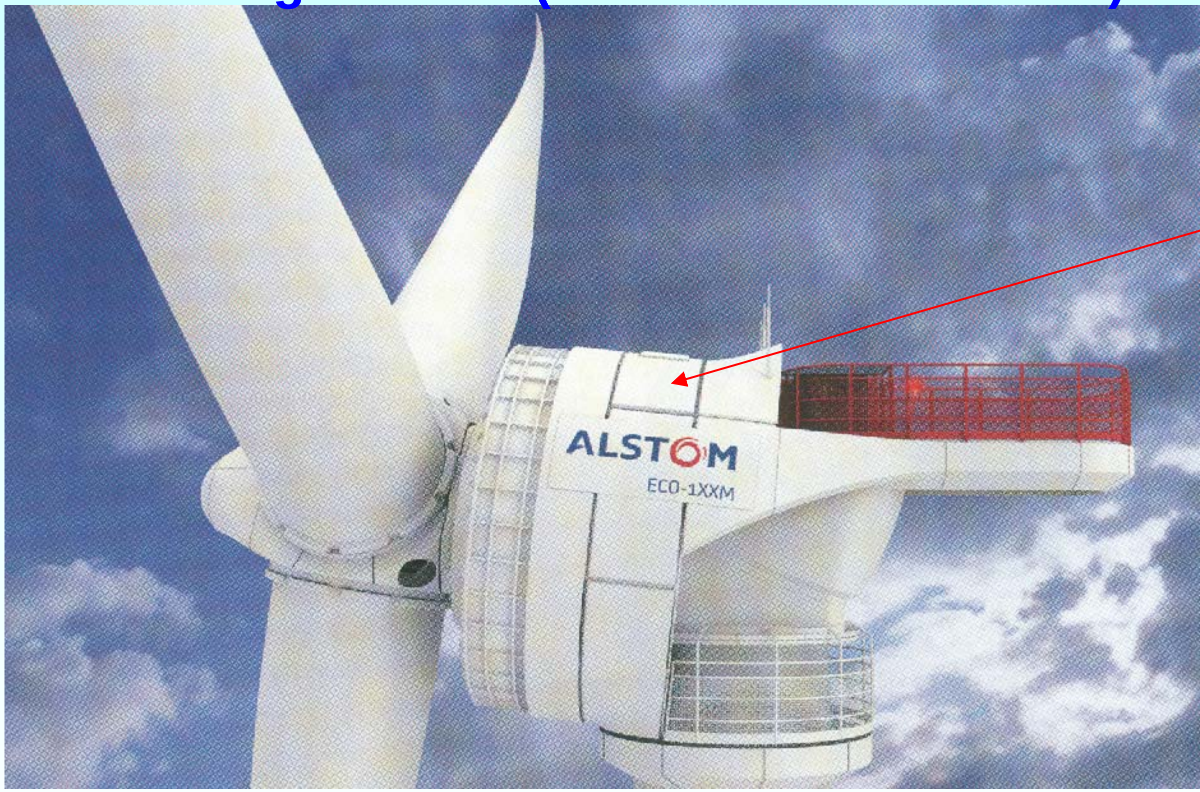


Source:

J. Salo, ABB Technik 2/2009

Wind generators

6 MW Gearless wind turbine *“Advanced High Density”* permanent magnet wind generator (*Converteam & Alstom*)

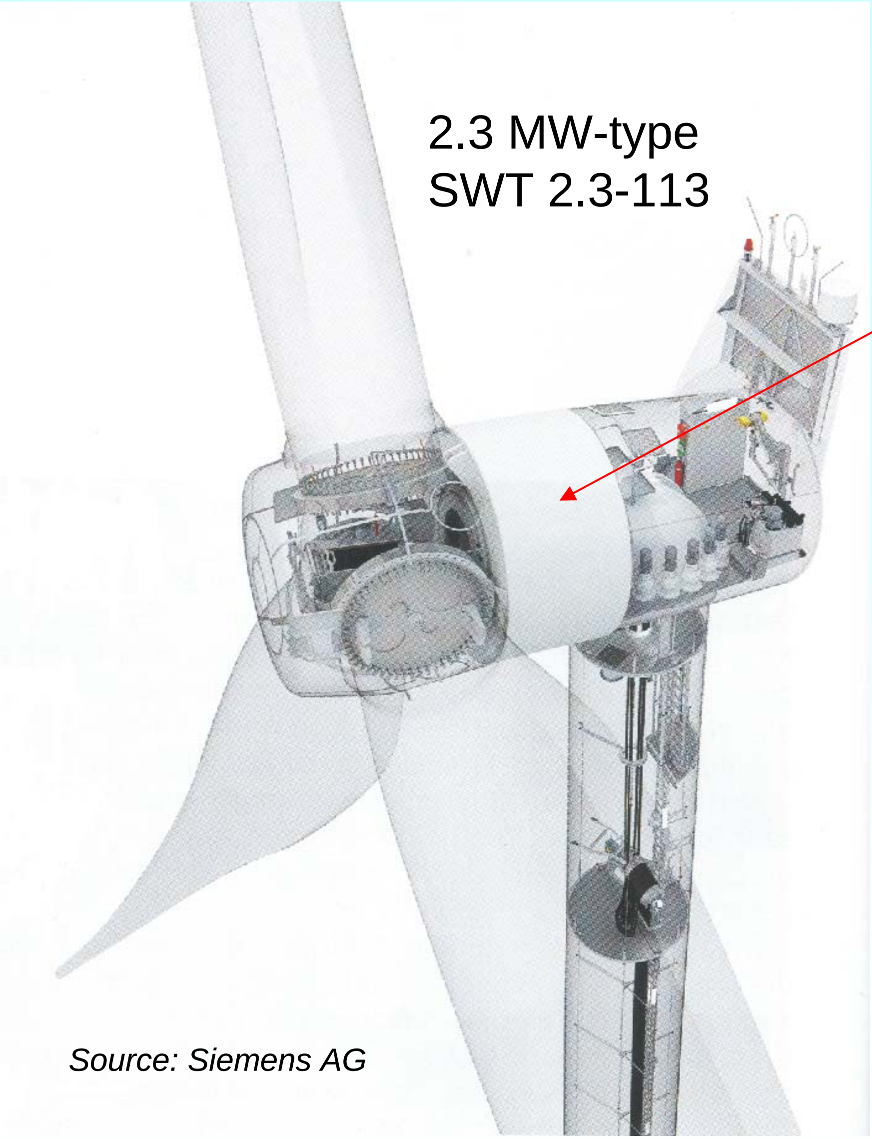


PM generator

Source: Alstom Power

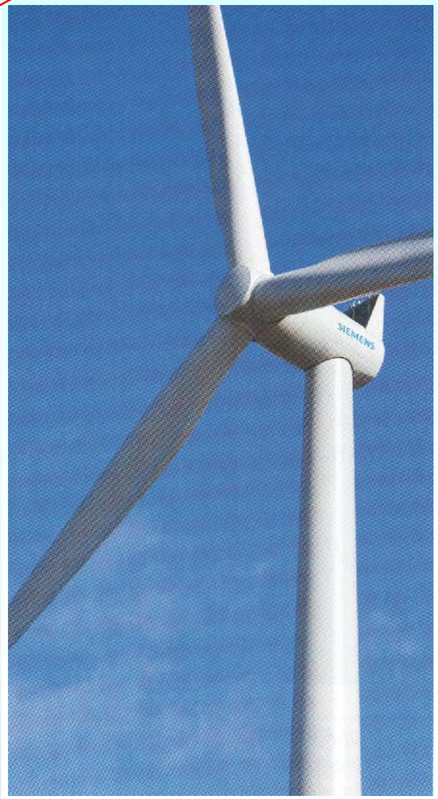
- World´s largest wind turbines 6 MW (2012): here: gearless PM high-pole count synchronous generators with grid-side inverter, planned for off-shore near *Zeebrugge (Belgium)*

Wind generators



Gearless wind turbine *"Siemens Wind Turbine SWT" with* permanent magnet synchronous generator (*Siemens*)

PM generator



Ratings:

PM generator	Turbine Rotor diameter
2.3 MW	113 m
3.0 MW	101 m
6.0 MW	120 m

3.0 MW-type
SWT 3.0-101

Wind generators

Source: Siemens AG

Gearless *"Siemens Wind Turbine SWT" with* permanent magnet synchronous generator

Mounting of the PM generator SWT-6.0-120

Ratings:

PM generator 6.0 MW

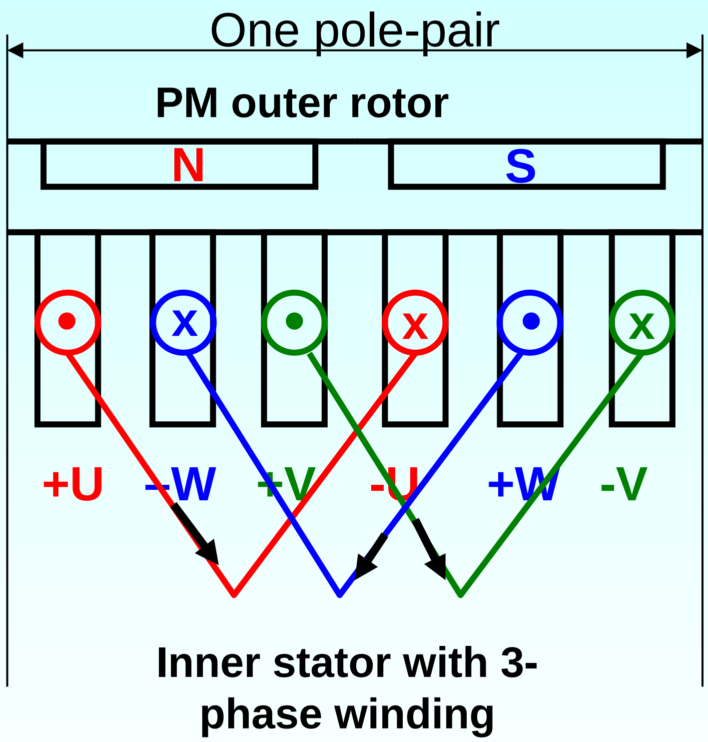
Mass of nacelle and rotor: 350 t

Turbine rotor diameter: 120 m

Single casted rotor blades

Wind generators

Gearless modular outer rotor PM synchronous generator with distributed 3-phase winding q = 1

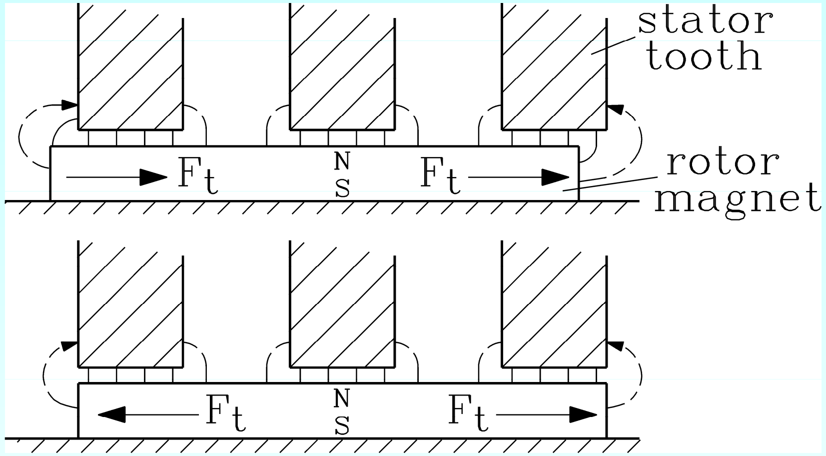


- Single layer integer-slot winding
- Asymmetric arrangement of winding overhang of 3rd phase W
- One pole-pair can be wound as a modular pre-fabricated segment
- Large generator diameters can be realized, which are necessary for huge rated torque in gearless applications, as the generator is assembled from modular segments on-site
- No transportation problems due to generator outer diameters or more than 3.5 m!
- Outer rotor design increases the air gap diameter and for a given *Lorentz* force the electromagnetic torque!
- Centrifugal forces press magnets to rotor construction!

Source: Siemens AG, registered patent

Wind generators

Reduction of cogging torque in PM synchronous generators



- The unbalanced tangential rotor magnet force shifts the rotor into a balanced position.

- Hence a “cogging” occurs, which deviates from the aimed smooth torque production.

- It may excited disturbing torsion vibrations in the shaft.

- An integer-slot winding (e. g. q = 1) causes a considerable cogging torque, which with fractional slot windings can be considerably reduced.

- But fractional slot windings cause additional harmonic field waves, which generate additional eddy-current losses in the rotor magnets and the rotor iron back

- The cogging can be reduced by

a) skewing the rotor magnets or the stator slots

b) by staggering the magnet rows in axial direction. By that a skewing is approximated.

c) by shifting the rotor magnet poles e. g. per pole pair the N- and S-pole are shifted each towards each other by a quarter of a stator slot pitch

Literature: Richter, R.: Ankerwicklungen für Gleich- und Wechselstrommaschinen, Springer, Berlin, 1922

Wind generators

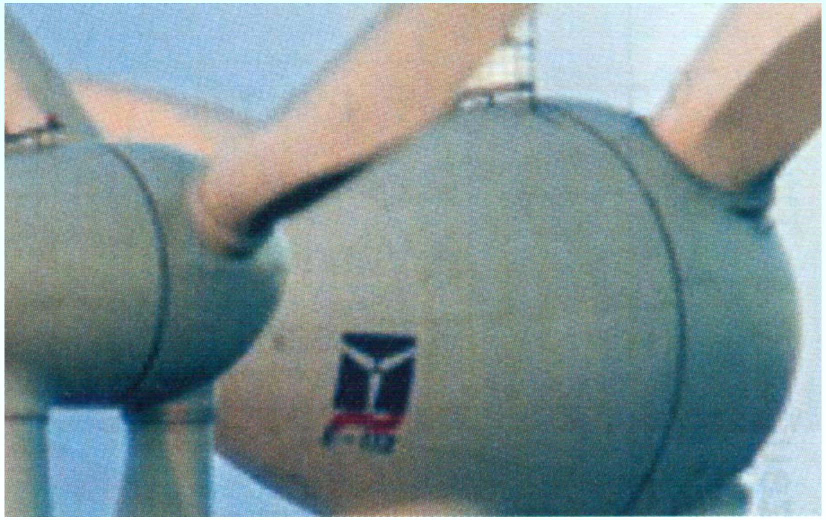
4. Wind turbines with two-stage gear

"Multibrid" - permanent magnet wind generator – dual stage gear

- **Only dual stage gear:** Medium generator speed ca. 150/min reduces generator size in comparison to gearless generator systems

- Special planetary gear with second stage reduces gear size and avoids high speed stage

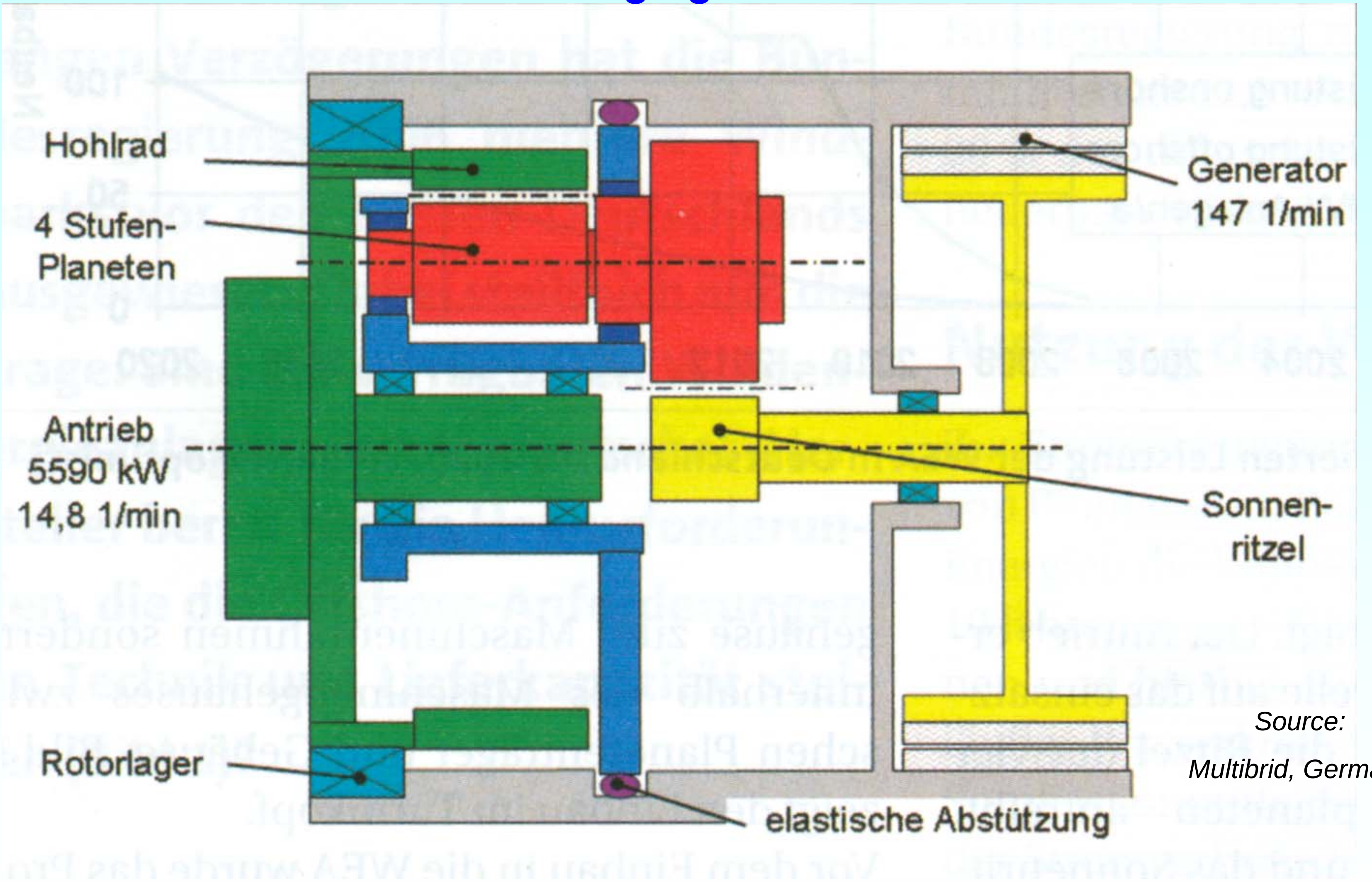
- **Overall mass reduction** in comparison to the gearless system due to smaller generator, which outweighs the increased mass due to the gear



Source: Multibrid, Germany

Wind generators

"Multibrid" - Dual stage gear 5.5 MW   Transfer ratio 1:10

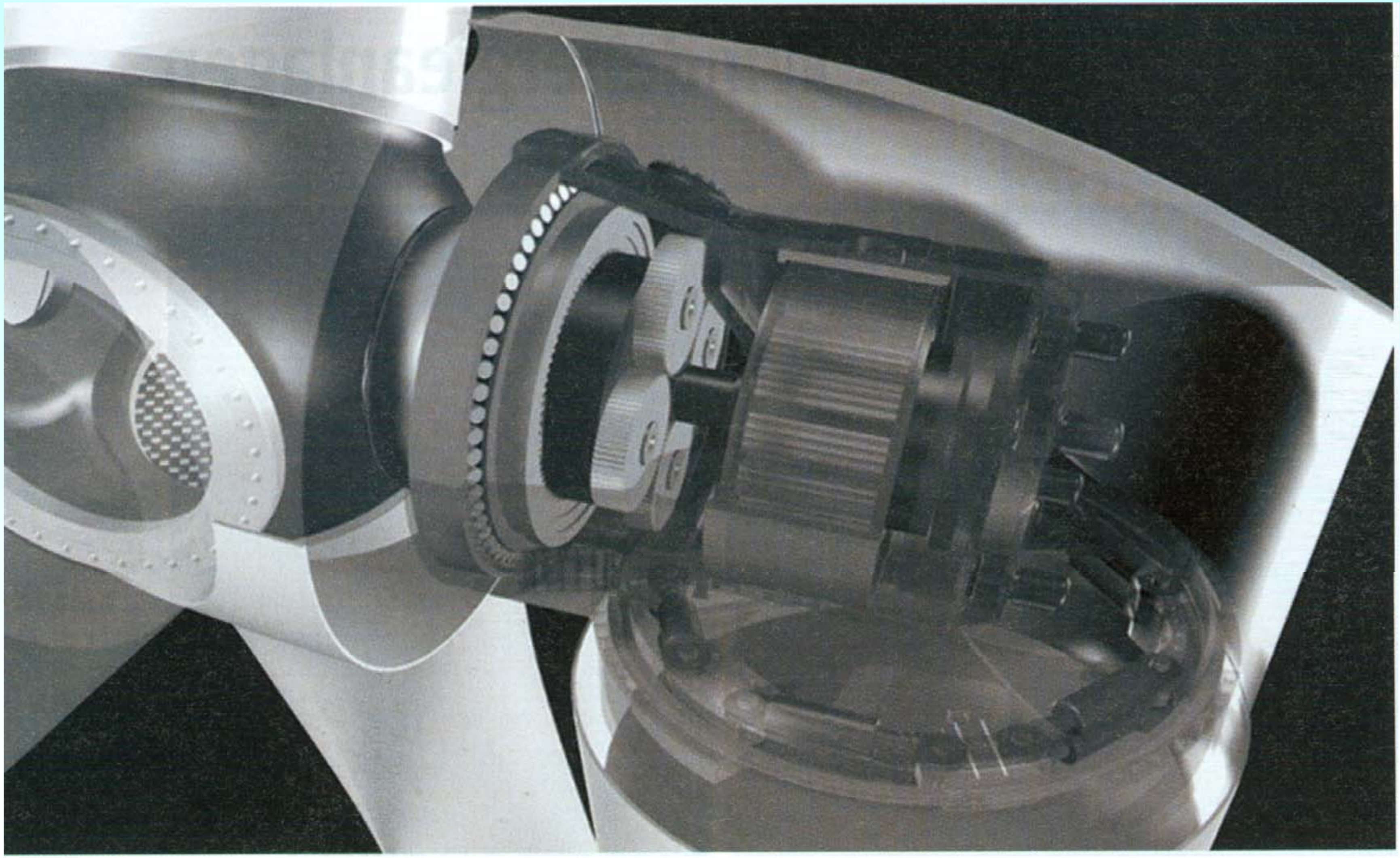


Source:

Multibrid, Germany

Wind generators

"Multibrid" - permanent magnet wind generator – dual stage gear



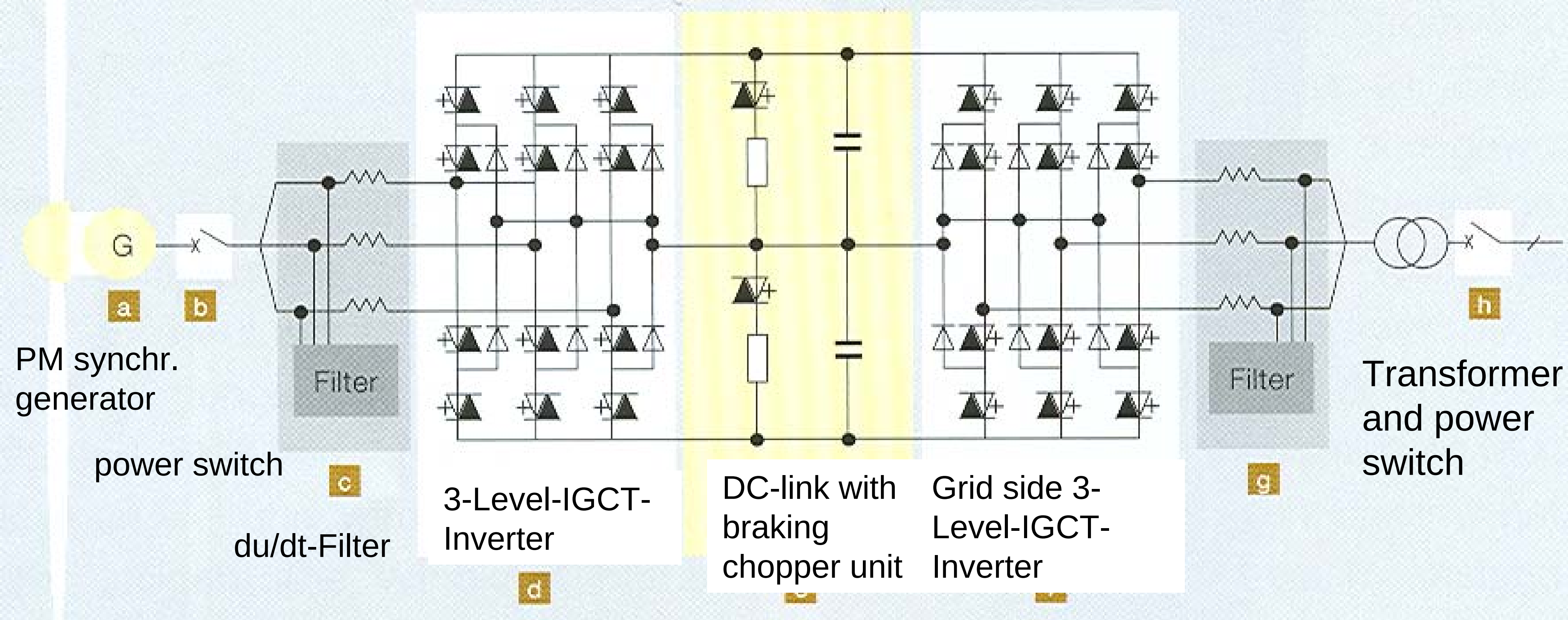
Source:

Multibrid, Germany

Wind generators

Inverter topology for the 5 MW “Multibrid” - permanent magnet wind generator system

ABB 6000 Inverter: Four-quadrant inverter, 100% real or reactive power on grid side possible

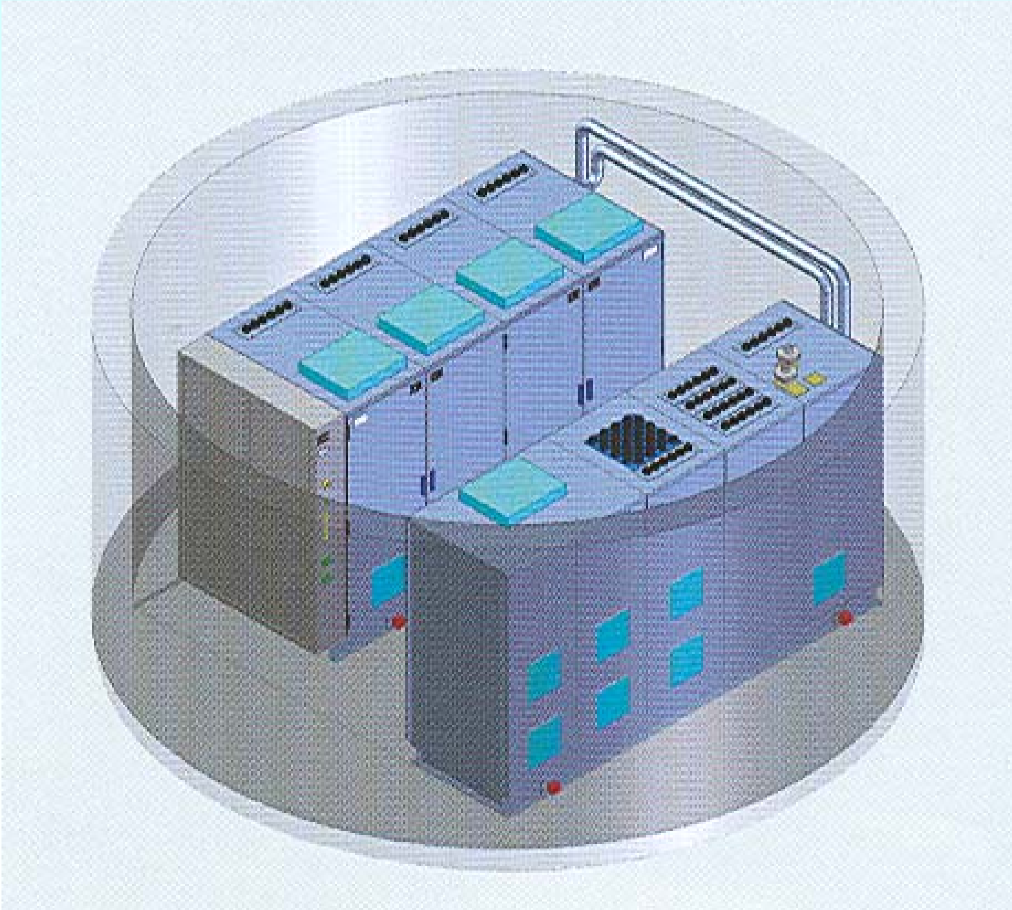


IGCT: Integrated Gate-Commutated Thyristor

Source:
M. Nyfeler, A. Moglestue,
ABB Technik 3/2010

Wind generators

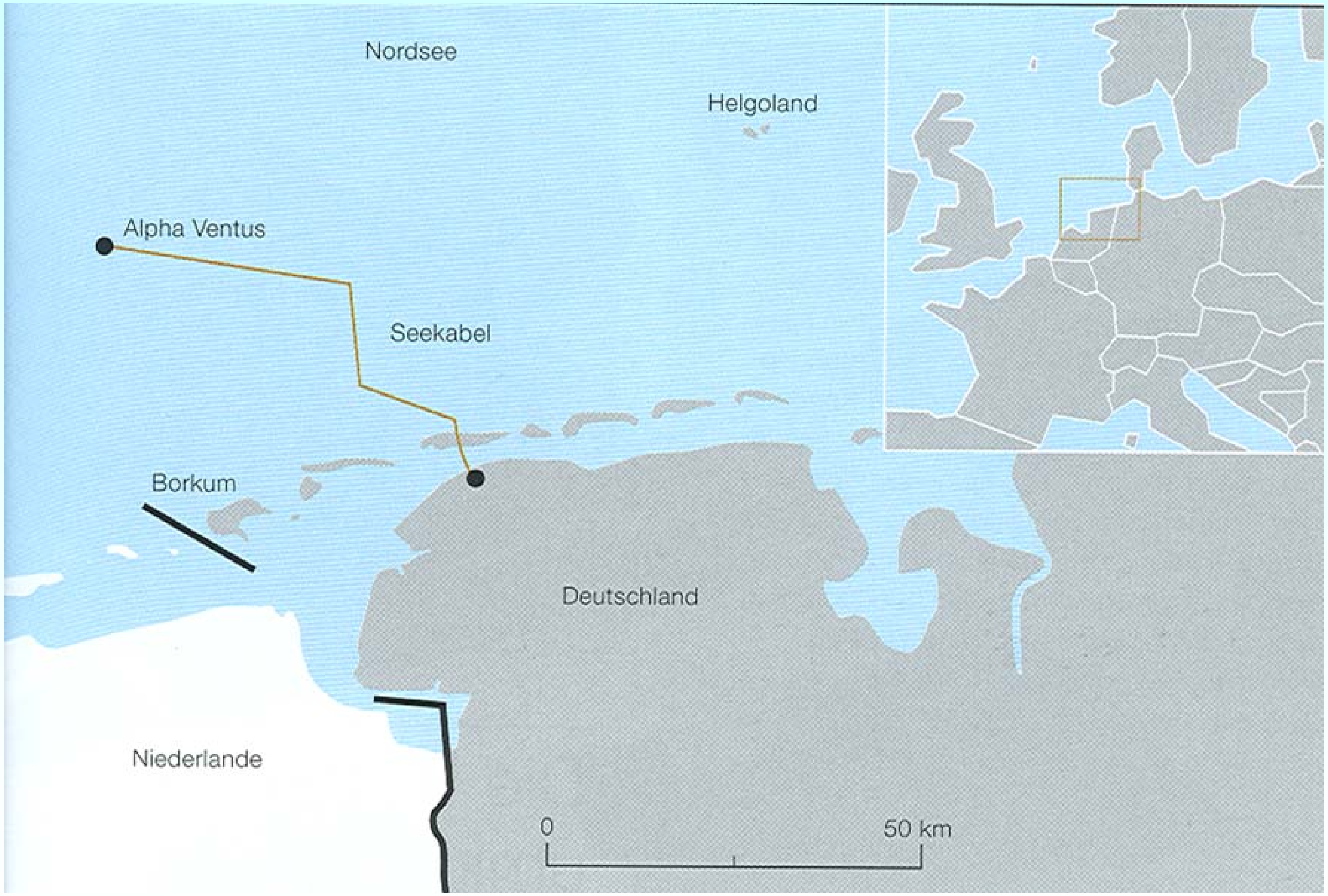
Arrangement of the inverter for the 5 MW “Multibrid” - permanent magnet wind generator system inside the mast on a single platform



Source:
M. Nyfeler, A. Moglestue,
ABB Technik 3/2010

5. First *German* off-shore wind park

"First" *German* off-shore wind park *ALPHA VENTUS*, 45 km north of *Borkum* island in the *North Sea*



Joint project of *E.on, EWE, Vattenfall*

12 wind turbines with 5 MW each

- Six Multi-brid PM synchr. Generators
- Six doubly fed induction generators of *Repower*

- 800 m distance between turbines

Source:
M. Nyfeler, A. Moglestue, ABB Technik 3/2010

Wind generators

- Off-shore wind power plant 5 MW of *ALPHA VENTUS* with doubly-fed induction generator

- Nacelle elevation 90 m above sea level

- Sea depth 30 m

- Rotor max. height 148 m

- 1000 t per complete turbine plant

- Rotor diameter 116 m, blade tip speed 324 km/h, rotational speed 14.8 /min

Source: M. Nyfeler, A. Moglestue, ABB Technik 3/2010