New Turbine Designs for Low-Wind Regimes

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Outline

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5. Advanced Gearless Technology
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   - Winding Specification and Manufacturing
6. Efficiency Comparison in Relation to Geared Systems
7. Conclusions

Dr.-Ing. Stephan JÖCKEL – Short Resume

Education:

1987 – 1995 **Study of Mechanical Engineering at Technische Universität Darmstadt / Germany**

1995 – 2000 **PhD study of Electrical Engineering at Technische Universität Darmstadt / Germany**

Working Experience:

1995 – 2000 **Research and teaching assistant with Technische Universität Darmstadt**
Direct-drive generators for wind turbines, EU funded research project with Lagerwey etc.
Teaching renewable energies, rational use of energy and electrical machines

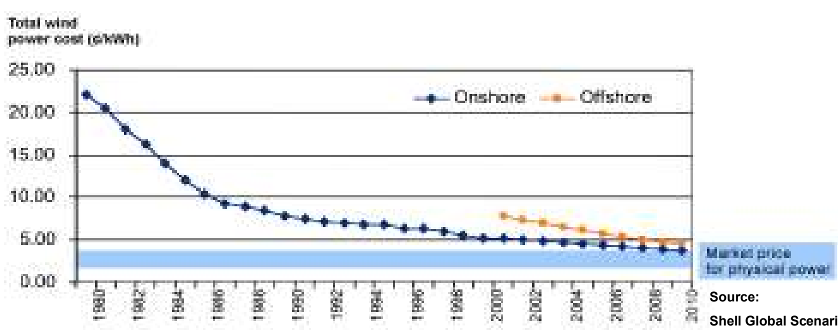
2001 – 2003 **Head of "System Simulation and Loads" group with GE Energy, Salzbergen**
Simulation and load calculation of wind turbines and wind farms

2003 – 2008 **Head of "Electrical Department" with VENSYS Energy AG, Saarbrücken**
Responsible for electric system of VENSYS 1.5 MW and 2.5 MW wind turbine

Since 09/2008 **Managing Director of wind turbine consulting company wind-direct GmbH at Mannheim/Germany**

Wind Becoming Cost Competitive

Cost trend of wind-generated electricity at sites > 8.5 m/s av. wind speed:



Source:
Shell Global Scenarios

How about low-wind regimes with < 8.5 m/s???

wind-direct approach: → **Maximising the energy production**
→ **Reducing the total cost with focus on O&M**

Low Wind Speed Turbines – Basic Requirements

How to capture low-wind sites for wind energy?

Low-wind regimes need low wind speed turbines for achieving competitive cost of energy (COE)!

Special features of low wind speed turbines:

1. **Reduced capital investment through mass and load minimisation:**
   - Minimised extreme loads in load case “50-year storm”.
   - Reduced extreme loads in operating gust load cases.
   - Minimum fatigue loads by intelligent controller design.
2. **Reduced O&M cost through design simplicity and redundancy:**
   - No gearbox through direct drive generators.
   - Minimum number of proven components.
   - Redundant design of auxiliary systems and sensors.
3. **Increased energy capture, especially at partial load:**
   - Highly efficient components (blades, generator, converter).
   - Larger rotor on same turbine platform (low specific power W/m^2)
   - Taller towers, especially in very low-wind regimes.

Low Wind Speed Turbines – Load Mitigation

Load mitigation through specific features of direct-drive permanent-magnet generator systems with strong rectifiers:

- **Load case “50-year storm”:** Yawing the turbine into the wind by using idling energy from the PM generator in case of grid outage
- **Load case “pitch or safety system fault”:** Extreme load reduction through heavy electric braking into the grid
- **Load case “grid fault”:** Extreme load reduction through heavy electric braking into a large resistor
- **Load case “generator short circuit”:** Extreme load reduction through parallelisation of power paths
- **Tower fatigue loads reduction by acceleration feedback into pitch controller**

Low Wind Speed Turbines – Reduced O&M Cost

Reduced O&M cost through design simplicity and redundancy

- **No gearbox through direct drive generators:**
  - No gearbox failures.
  - No oil cooling / monitoring systems.
- **No generator excitation through permanent magnets:**
  - Very simple and reliable generator rotor.
  - No rotor pole winding issues.
- **No generator cooling system:**
  - Very simple passive generator air-cooling.
  - No rotor pole winding issues.
- **No separate generator bearings:**
  - Turbine bearings also perform as generator bearings.
- **No couplings, no mechanical brake:**
  - Generator rotor directly flanged to turbine rotor.
  - Pure aerodynamic braking by full-span blade pitch.

Source: VENSYS Energy AG

Low Wind Speed Turbines – Increased Energy Capture

Increased energy capture, especially at partial load

- **Taller towers, especially in low-wind regimes:**
  - Up to 0.5% more energy yield per meter hub height: 100 m vs. 65 m means up to 18% higher output!
- **Low specific turbine power < 400 W/m^2:**
  - Large and efficient rotor blades for given turbine platform.
  - Identical load level through lower wind regime.
- **Wide-range variable-speed plus low cut-in rotor speed:**
  - Highest rotor efficiency under partial load.
  - Moderate fatigue loads under full load.
- **Highly efficient generator, especially under partial load:**
  - No excitation losses through permanent magnets.
  - No gearbox losses through direct drive.
  - Simple and efficient frequency converter using latest technology of low-loss IGBTs.

160 m lattice tower in Germany
Source: Dipl.-Ing. Joachim Dehm

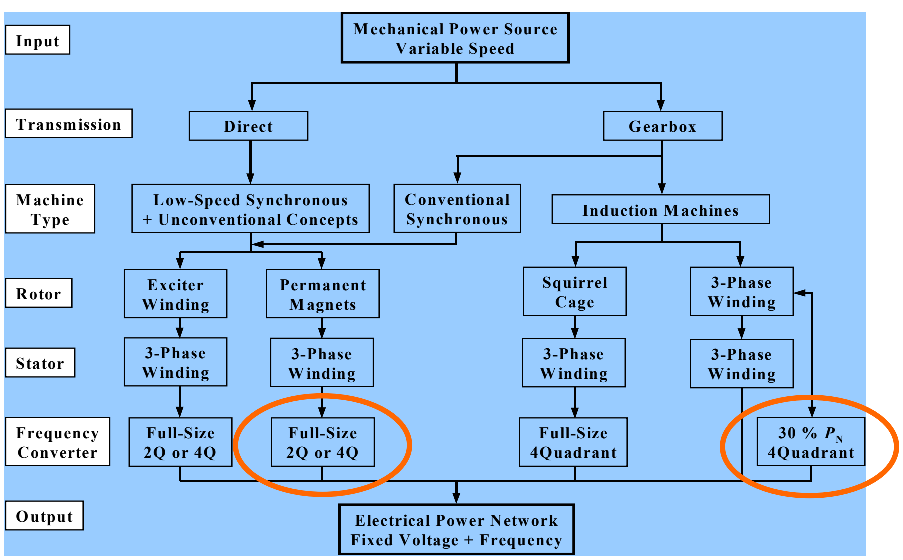
Special Requirements for Wind Generators

Low-wind speed turbines – focus on generator systems

Source: VENSYS Energy AG

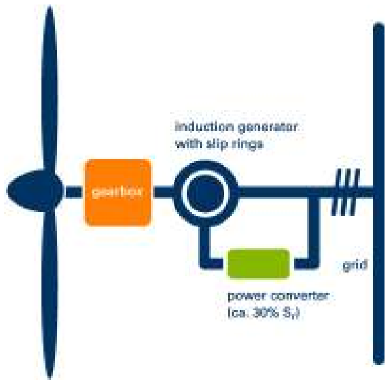
- **Speed elasticity absolutely required**
  → Reduction of torque fluctuations and flickers
- **Variable speed desirable**
  → Increased aerodynamic efficiency, reduced rotor noise and mechanical loads
- **Superior partial-load efficiency necessary**
  → Rated efficiency not relevant, „only“ losses need to be dissipated
- **Low maintenance effort – high reliability**
  → especially important for offshore applications
- **Low noise emissions**
  → No resonances in the whole speed range
- **Protection according to IP 54 desirable**
  → especially important for offshore / nearshore applications

Power Conversion of Variable-Speed Systems



Variable-Speed – The 2 Competing Systems

Geared drive with doubly-fed induction generator

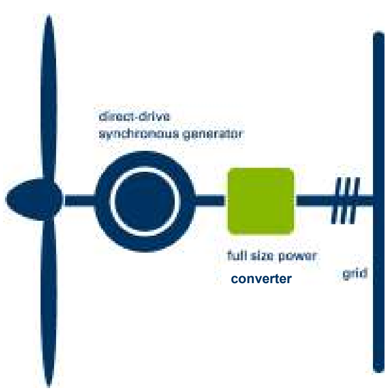


Advantages compared to gearless systems:

- Component sourcing from different suppliers
- Small dimensions and masses (easier manufacturing an transport)
- Smaller power converter rating (but almost identical converter cost)

Variable-Speed – The 2 Competing Systems

Direct-drive synchronous generator – Advantages:



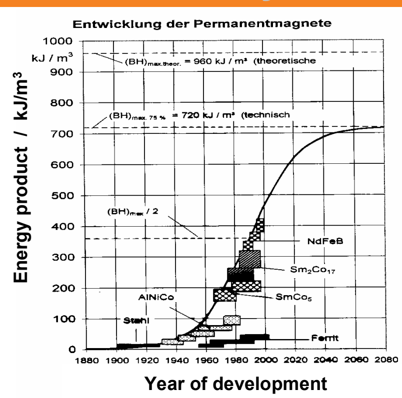
- Fewer components, higher reliability
- No gearbox (less losses, failures, maintenance, noise)
- Higher partial load efficiency (3 – 5% higher energy production for permanent-magnet excitation)
- No generator slip rings and brushes (lower maintenance cost)
- Low voltage, low speed, reliable generator rotor (especially true for permanent-magnet excitation)
- Grid-code requirements easily achieved by simple power converters

Pros & Cons of Variable-Speed Systems

	Doubly-fed induction generator with gearbox	Direct-drive generator with direct-current excitation	Direct-drive generator with permanent-magnet excitation
Main current suppliers	Vestas, GE, Gamesa, Nordex, REpower, etc.	Enercon, MTorres, Lagerwey, etc.	VENSYS, RegenPowertech, Goldwind, etc.
Average drive train efficiency	89 %	90 %	93 %
Tower top mass	100 %	130 %	100 %
Manufacturing cost	100 %	~ 110 %	~ 100 %
Reliability	– –	+	++
Power quality	–	++	++
Component sourcing	+	–	–

- **Direct drive with permanent magnets offers the highest potentials**
- **General industry trend: automation, railways, marine propulsion, etc.**

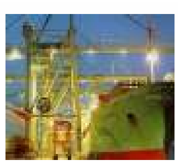
General Drive System Trends – Permanent Magnets

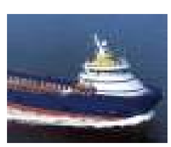


General Drive System Trends:

- Increasing number of variable-speed vs. fixed speed applications (system advantages)
- Rising energy cost → efficiency becoming more important
- Low noise requirements
- Increasing number of high-torque drives with permanent magnets (omission of gearbox)

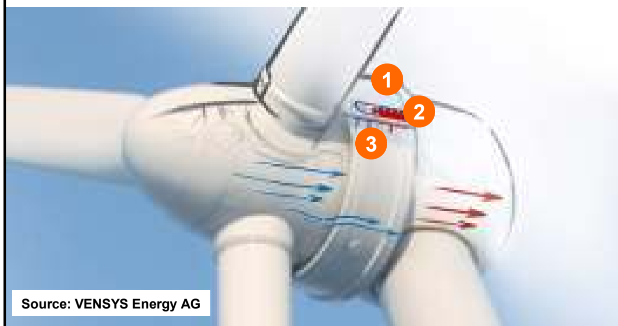

Paper production


Cranes / Logistics


Ship propulsion


Railway applications

Gearless Technology – Passive Generator Cooling



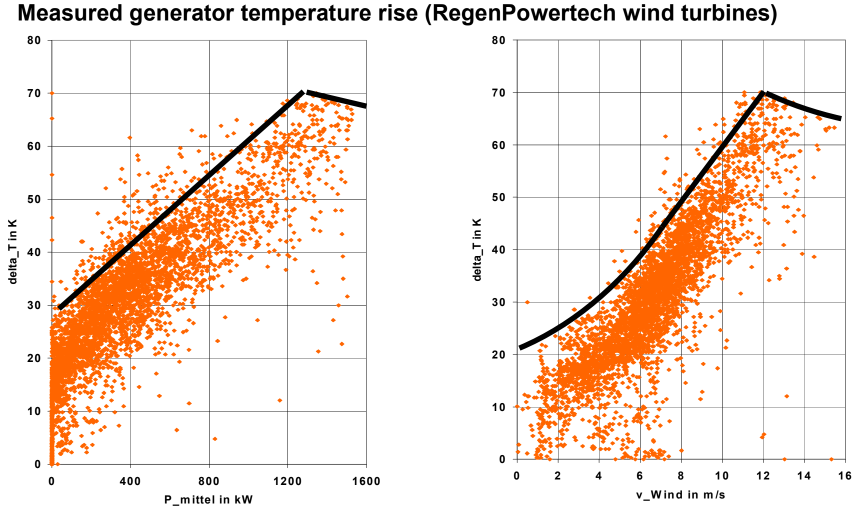
1. External rotor with permanent magnets
2. Internal stator
3. Cooling duct

Passive cooling system

- Totally enclosed generator, stack cooling with backside cooling fins
- No ambient air gets contact with winding
- Perfectly cooled magnets, high flux, no demagnetisation
- Outstanding cooling performance: max. temperature rise 70 °K !!!

Gearless Technology – Generator Cooling Performance

Measured generator temperature rise (RegenPowertech wind turbines)



40°C + 70°C = 110°C: → Temperature stress less than Class B (130°C)

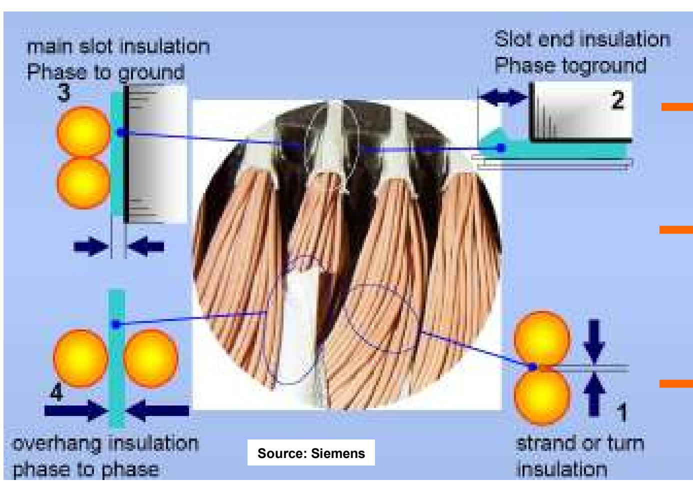
Gearless Technology – The Generator

The VENSYS 70 / 77 Generator:

- Rated output: 1.5 MW
- Stator voltage: 690 V
- Rated speed: 19.0 or 17.3 rpm
- Internal stator
- External rotor
- Insulation class: Class F
- Dimensions: D < 5 m, L < 1.5 m
- Generator mass: < 40 tons

Gearless Technology – Generator Winding

Standard Technology – Normal low-voltage winding design
Random-wound windings with round wires

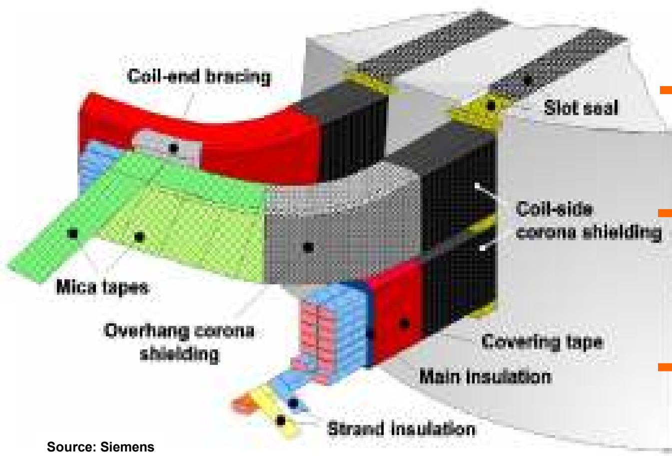


- **Low copper filling of the slots → higher losses**
- **High dielectric stress between single conductors!**
- **Need for high-tech impregnation process**

Gearless Technology – Generator Winding

Advanced winding design

Form-wound windings with rectangular conductors

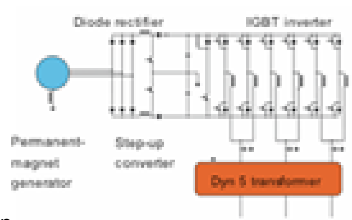


Source: Siemens

- **High copper filling of the slots → lower losses**
- **Low dielectric stress between single conductors!**
- **Low-tech impregnation process sufficient**

Gearless Technology – Frequency Converter

Suitable Variable-speed Technology:



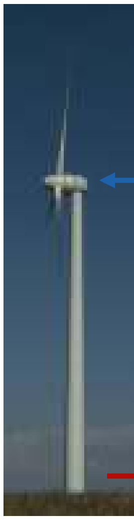
- Passive diode rectifier: high efficiency, low EMI.
- Very low harmonics to the grid.
- Automatic adjustment to 50 Hz or 60 Hz.
- Measured and certified low-voltage ride through operation
- Full reactive power control.
- High reliability: air cooling with only 1 fan, robust converter control.
- Good serviceability: modular design with fast IGBT exchange.

→ **"Simple converter" of highly integrated IGBT modules**

- **Integrated current sensor**
- **Integrated temperature sensor**
- **Integrated heat sink**
- **Integrated driving circuit & protection**

Source: VENSYS Energy AG

Gearless Technology – Optimised Tower Base Cooling

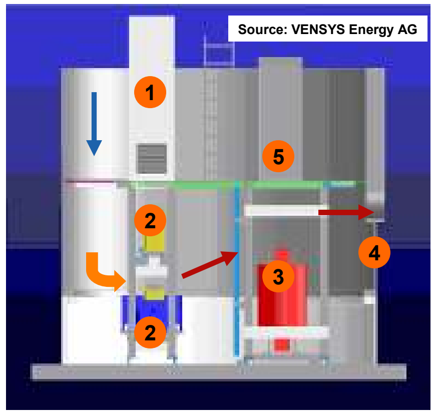


Air intake

Cool & clean

Cooling air exhaust

Source: VENSYS Energy AG

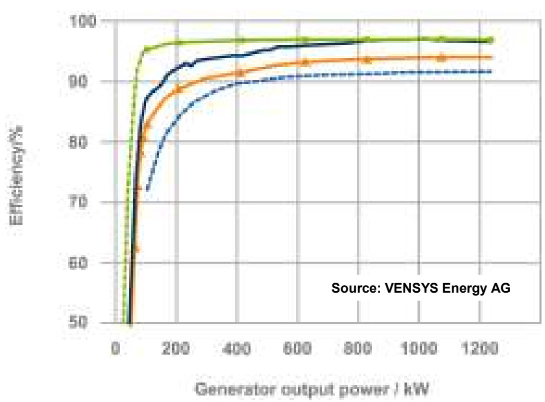


1. Frequency converter (IGBT heat sinks)
2. Filter chokes
3. Transformer
4. Air exhaust
5. Tower internal air

Effective tower base cooling:
Tower internal air < 10°K above ambient

PM Direct-Drive Efficiency – Load Test of 1.2 MW System

Efficiency measured directly: $\eta = 1 - P_{out} / P_{in}$



Generator only

Total drive

Frequency converter

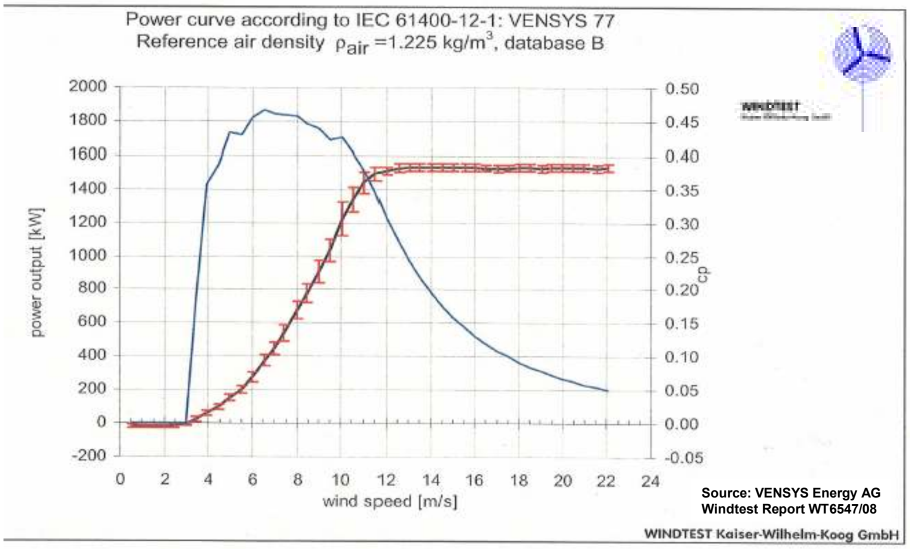
Typical generator + gearbox (calc.)

Rated total efficiency over 94%

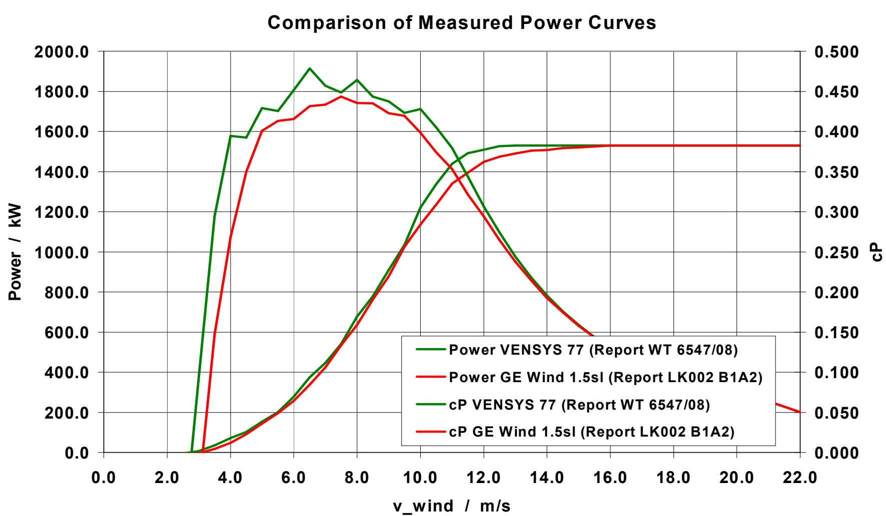
Up to 5% higher efficiency than conventional drive train!

3 – 5% higher energy production!

PM Direct-Drive Efficiency – Measured Power Curve

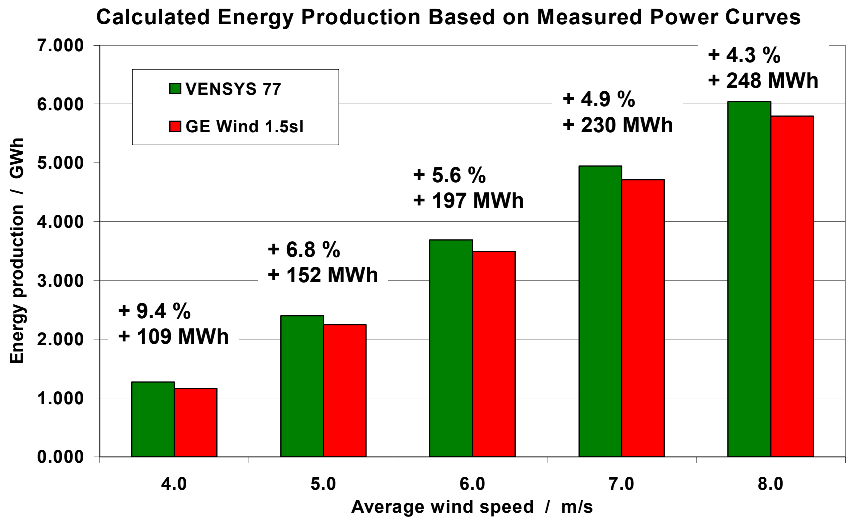


PM Direct-Drive Efficiency – Measured Power Curves



➡ **Considerably better cP curve, especially at low output**

PM Direct-Drive Efficiency – Energy Production



→ **Considerably better energy production, especially at low wind sites!!**

Conclusions

Turbine Requirements for Low-wind Regimes:

- Highly efficient transmission system (gearbox, generator and converter), partial load efficiency of special importance for low-wind regimes
- Highly efficient rotor blades, variable-speed plus low cut-in rotor speed
- Low specific power < 400 W/m^2: larger rotor for given turbine platform

Wind Generator Systems:

- Direct-drive systems with permanent magnets offer distinct advantages and will become increasingly competitive (general industry trend)
- Direct-drive systems with permanent magnets offer energy yield advantages between 3% and 10%: the lower the wind speed, the larger the benefit

Future Perspectives:

- Optimised permanent-magnet generators for gearless wind turbines will appear on the market offering further cost advantages over geared turbines
- Optimised turbines for low-wind regimes will open up new markets worldwide