SmartMotor
Smarter Energy Conversion

Novel PM generators for large wind turbines

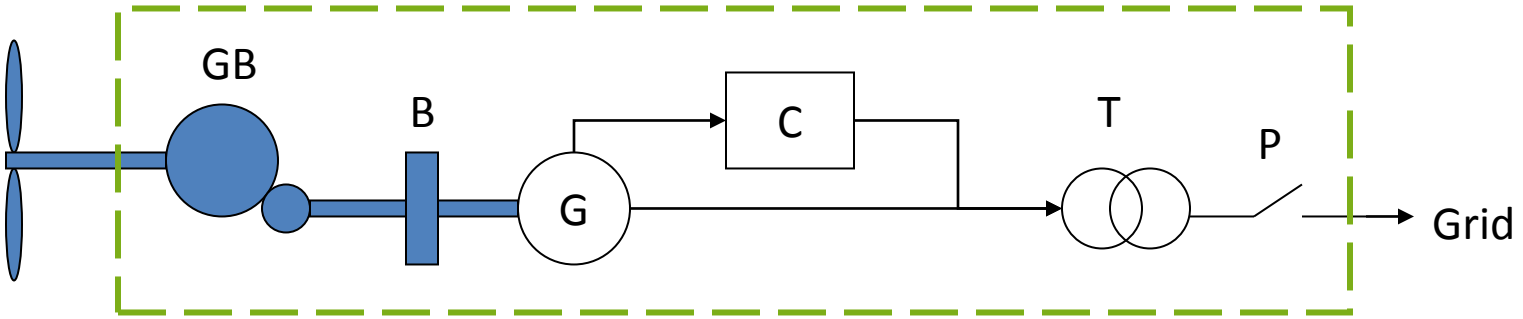
by Alexey Matveev

Wind Power R&D seminar - Deep sea offshore wind power, 20-21 January 2011, Trondheim, Norway

Contents

- Drive train configurations
- State-of-the-art PMG-based solutions
- Integration: the path to win for direct drive
- SmartMotor in wind

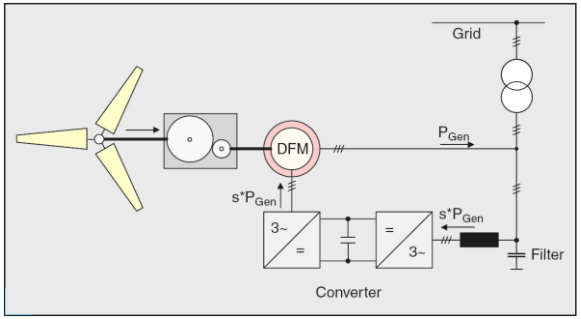
The general drive train scheme



GB – gearbox
B – brake
G – generator
C – converter
T – transformer
P - protection

Basic drive train solutions

Configuration 1: gear + double-fed IG

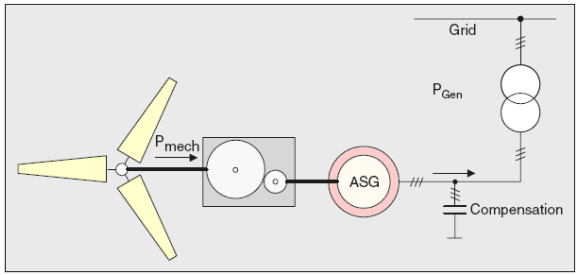


Vestas

NORDEX

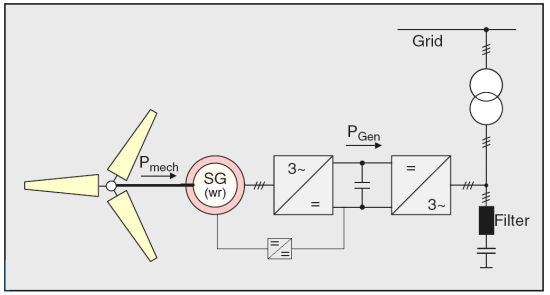
REpower Systems

Configuration 2: gear + IG



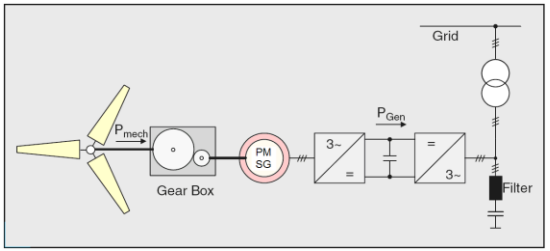
SIEMENS

Configuration 3: direct SG with wound rotor



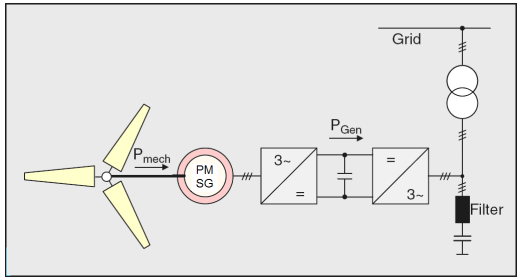
ENERCON

Configuration 4: gear + PMSG



Multibrid

Configuration 5: DD PMSG



SIEMENS

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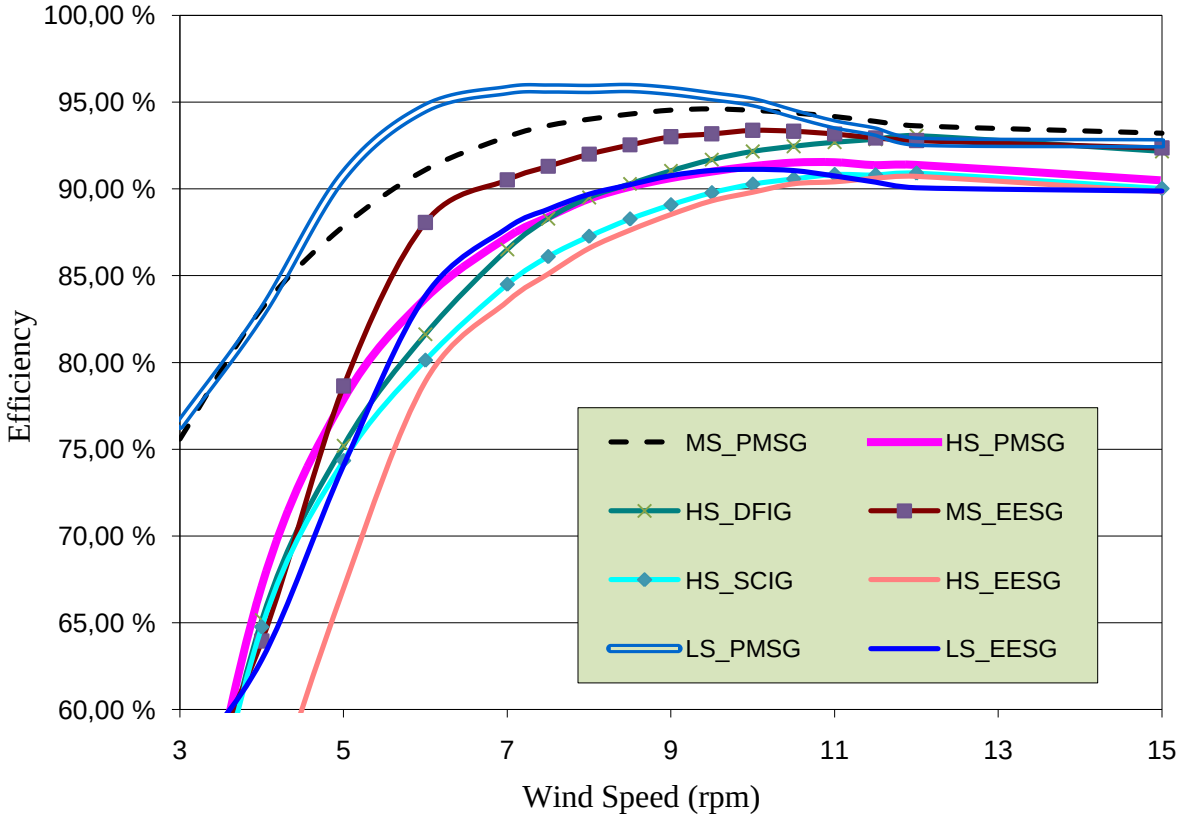
Efficiency of different drive trains

- Components included: gearbox, generator, converter, transformer
  - Direct driven PM generator solution gives the best efficiency at speeds below rated



LS – low speed
MS – medium speed
HS – high speed

PMSG – permanent magnet synchronous generator
DFIG – doubly-fed induction generator
EESG – electrically excited synchronous generator
SCIG – squirel-cage induction generator

Analysis performed in cooperation with Zhaoqiang Zhang, NTNU (supervisor Prof. Robert Nilssen)

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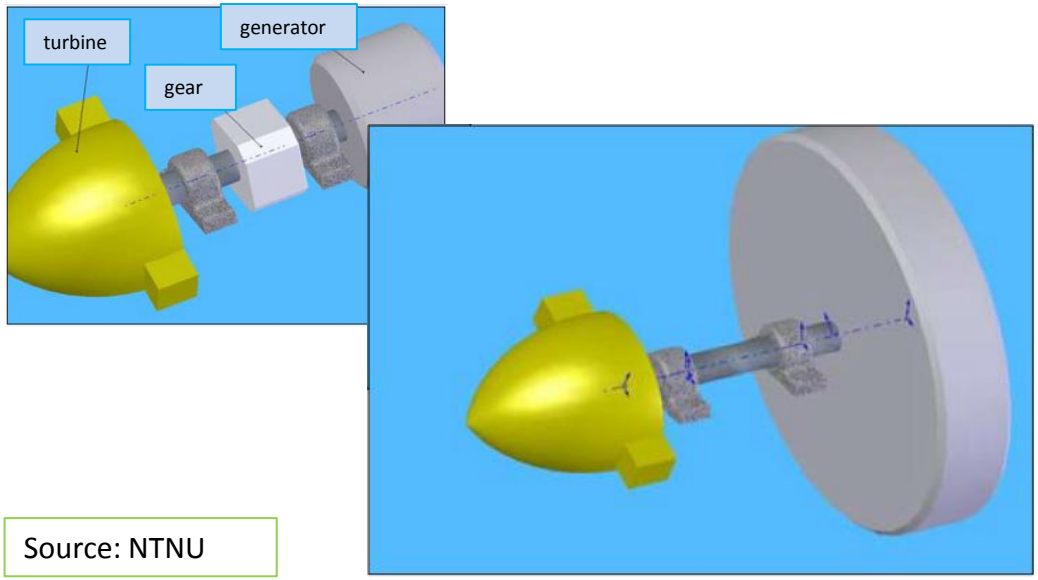
Direct drive vs geared solution

- Direct drive is larger and heavier, but
- it doesn't suffer gearbox-related problems



Source: NTNU

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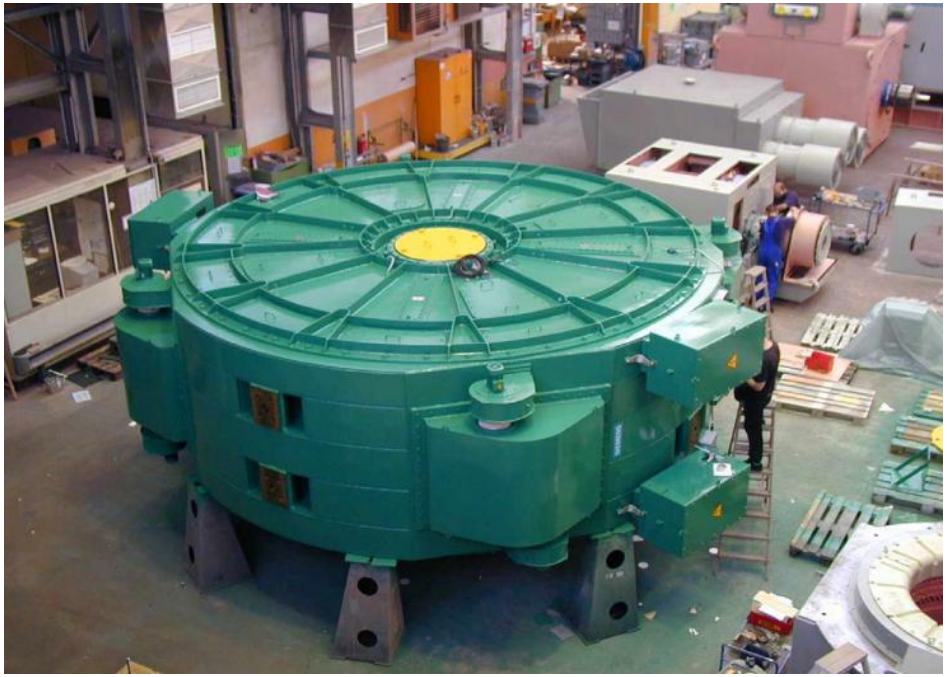
High-torque generator for direct drive

- High-torque generator for direct drive is large. This is basically the only drawback of direct drive solution

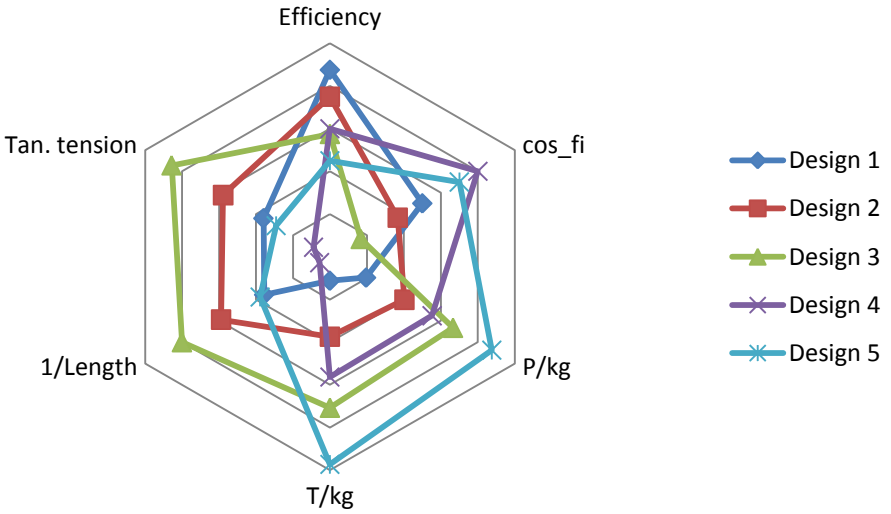


PM generator from Siemens. 3 MW, 17 rpm

Some conclusions

- Drive trains with PM generators have the best efficiency
  - Especially without gear (direct drive) and 1-stage gear

- However, there are other characteristics to take into account:
  - Weight
  - Cost
  - Power factor
  - Lifetime
  - Reliability
  - Manufacturability
  - ...

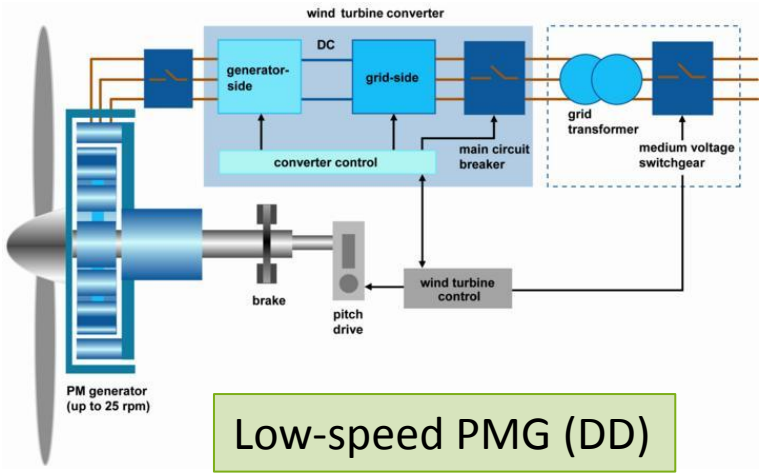


- Design means finding a trade-off between various criteria

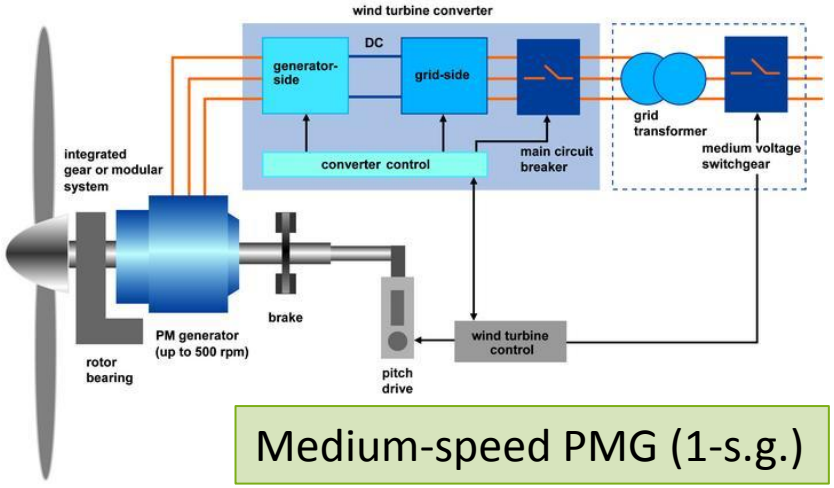
...next part

- Drive train configurations
- State-of-the-art PMG-based solutions
- Integration: the path to win for direct drive
- SmartMotor in wind

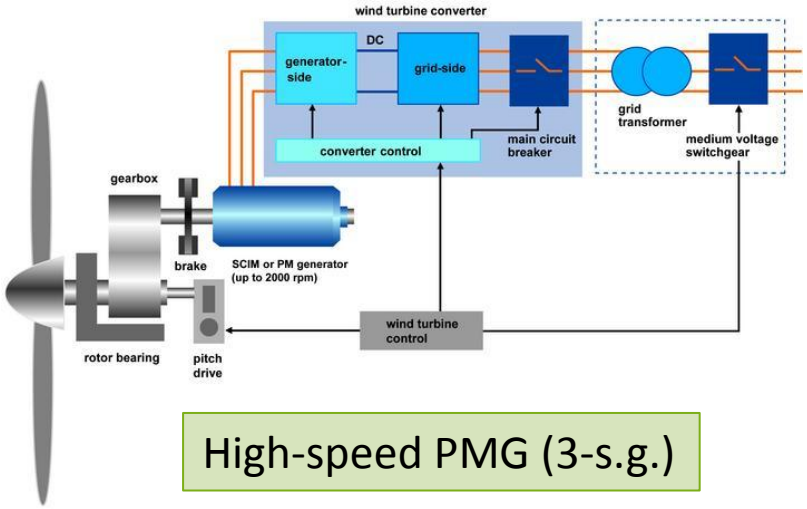
Available solutions with PMG



Low-speed PMG (DD)



Medium-speed PMG (1-s.g.)



High-speed PMG (3-s.g.)

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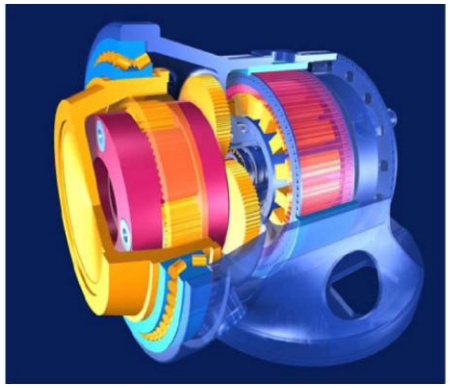
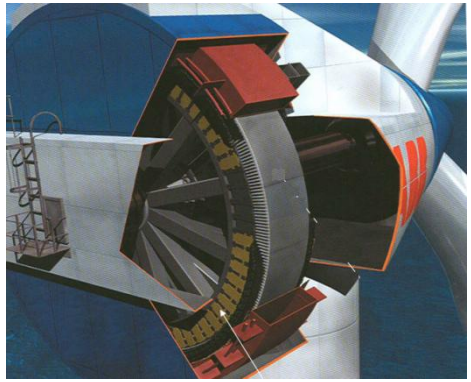
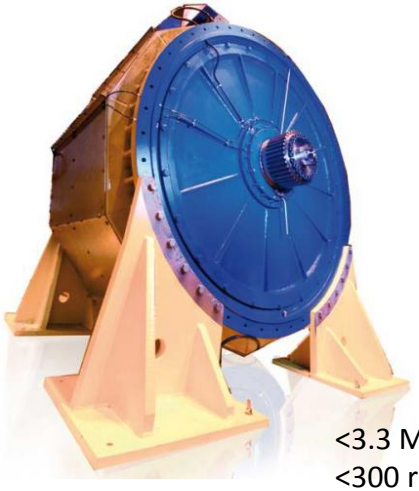
Products of ABB and TheSwitch

- Low-speed, medium-speed and high-speed generators





<1 MW
<2000 rpm



<3.3 MW
<300 rpm

<4.25 MW
<20 rpm

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Commercial power electronics

- Examples of medium-voltage (ABB) and low-voltage (TheSwitch) converters

ABB

TheSwitch

Is it end of the story?

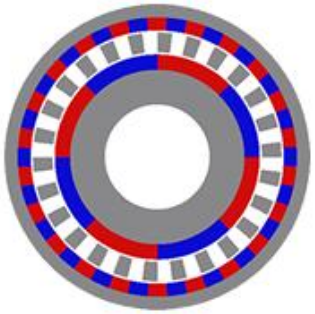
- Big companies have products and even complete packages up to approximately 5-7 MW. Is it end of the development?

NO!!!

- New concepts under investigation, for example:
  - Magnetic gears and Pseudo-direct drive
  - Superconducting machines
- There are problems when going to powers higher then 5-7 MW. These are to be solved!

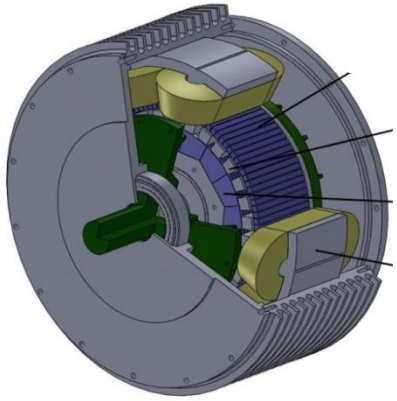
Examples of new concepts

- Magnetic gears, pseudo-direct drive (PDD), superconducting machines
- The concepts have not been proven yet for high-power WEC

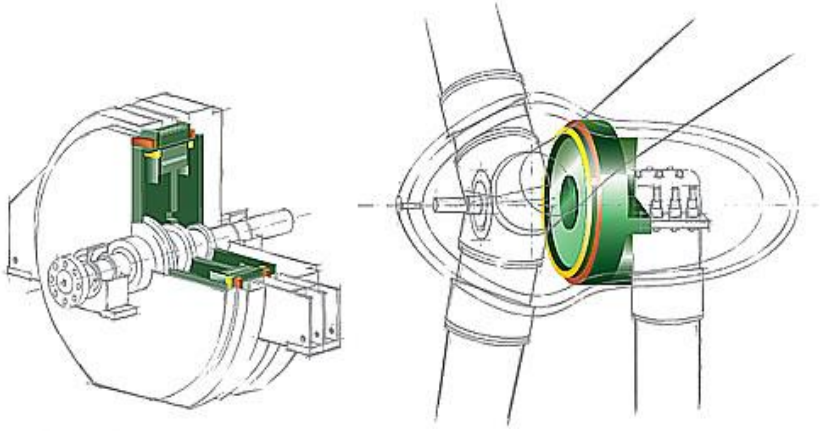


Magnetic gears

Magnomatics



PDD

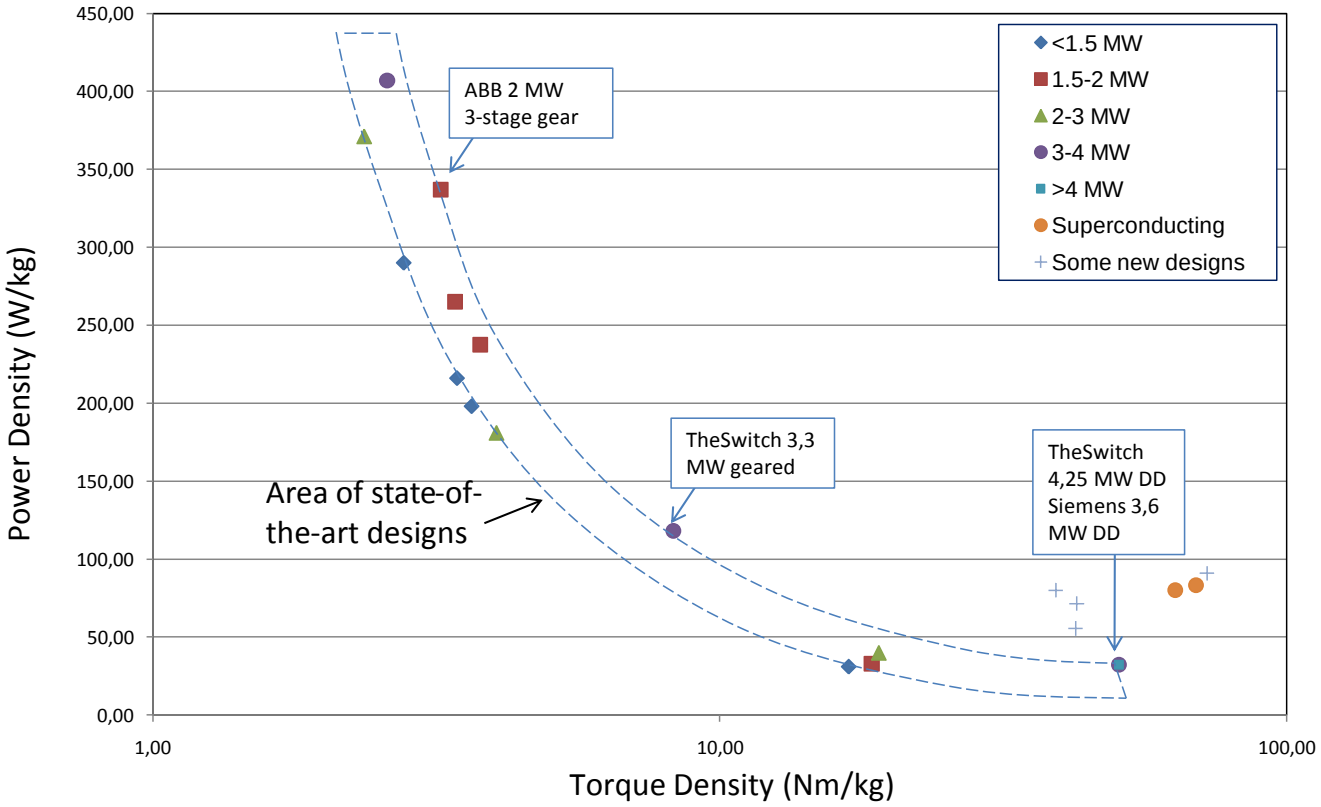


Direct drive using HTS superconductors

Converteam/Zenergy

Technology frontier for PM generators

- State-of-the-art in generator weight (expressed via power and torque densities, each point corresponds to one generator design)



Analysis performed in cooperation with Zhaoqiang Zhang, NTNU (supervisor Prof. Robert Nilssen)

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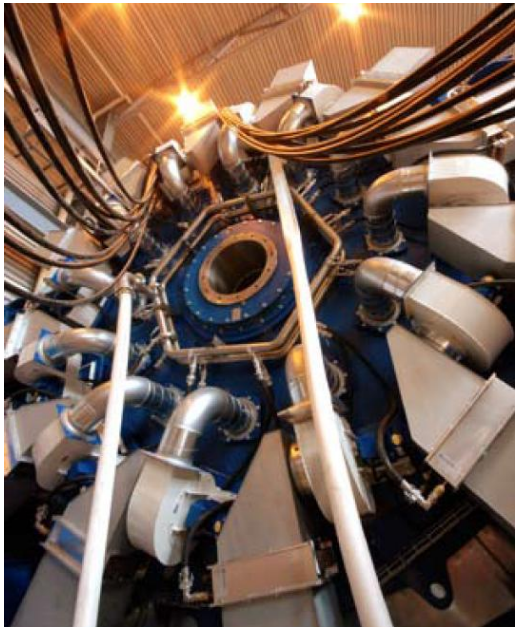
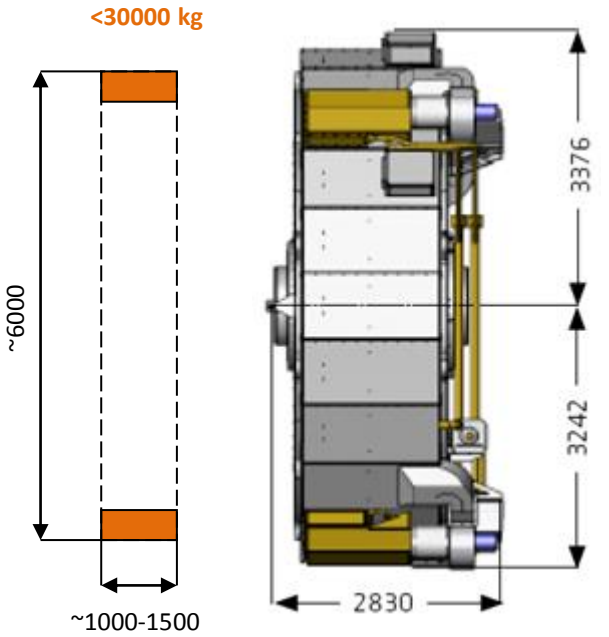
Active parts, cooling and carrying structure

- Active parts make 30-40% of total weight
- Cooling system defines size of active parts, it may take considerable space
- Carrying structure is usually massive

Rated power	3800 kW
Rated speed	17.5 rpm
Voltage	690 V
Weight	81000 kg
Cooling system	Air-to-air heat exchanger

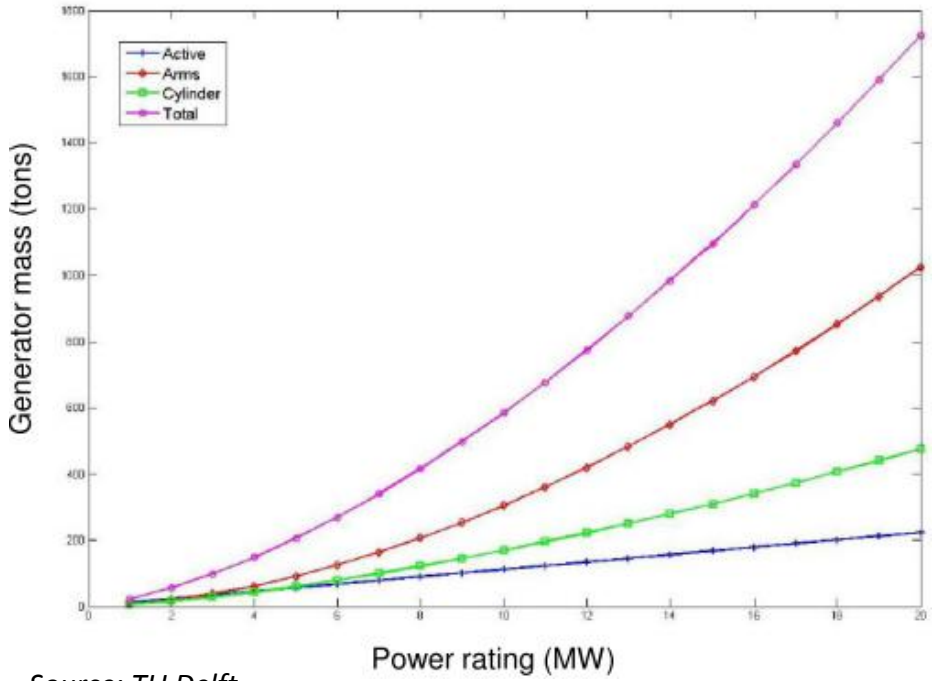


TheSwitch



When going for higher powers...

- Weight of carrying structure grows disproportionally!



Source: TU Delft

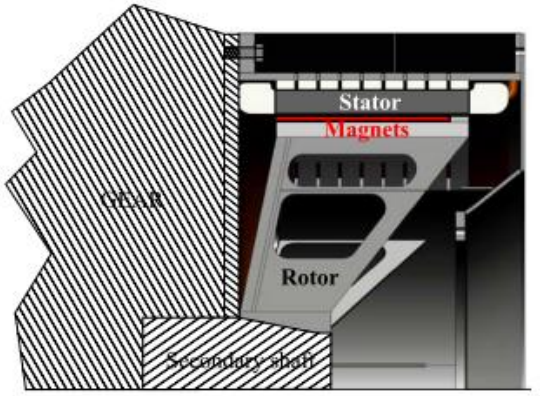
Enercon

...next part

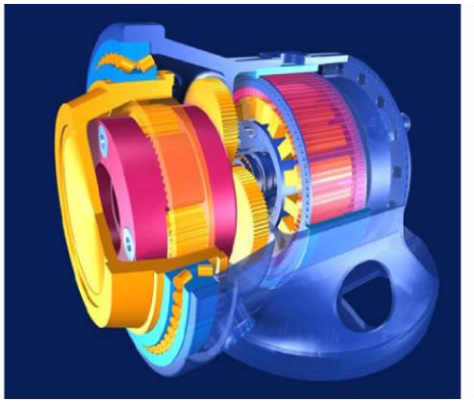
- Drive train configurations
- State of the art PMG-based solutions
- Integration: the path to win for direct drive
- SmartMotor in wind

Integration strategies

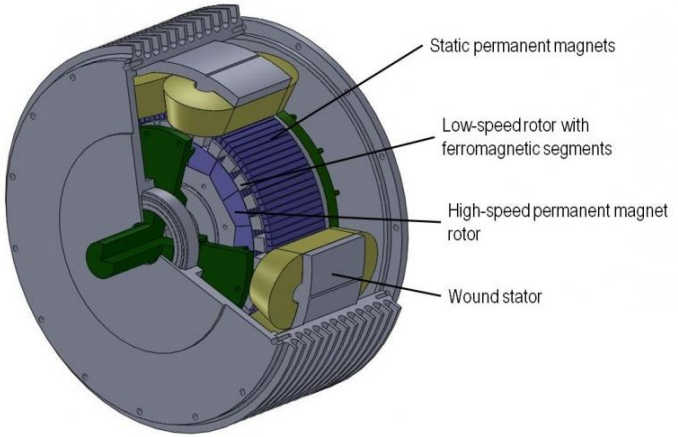
- For drive trains with gearboxes: integrate generator with gearbox (see examples below)
- For direct drive: integrate generator with the turbine! (examples will follow)



TheSwitch



ABB



Magnomatics

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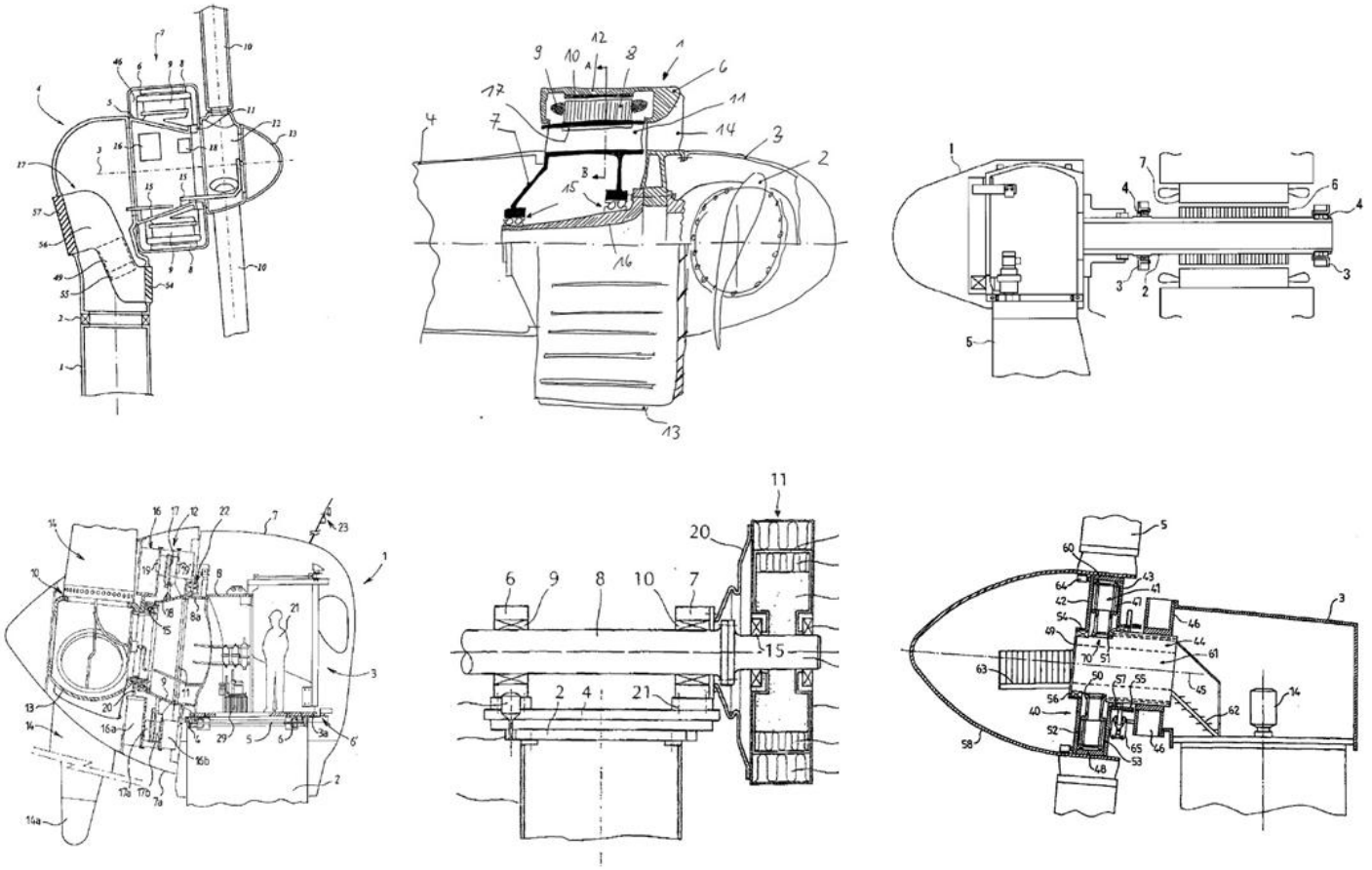
Direct-driven generator in the nacelle

- Just a few of numerous patented designs



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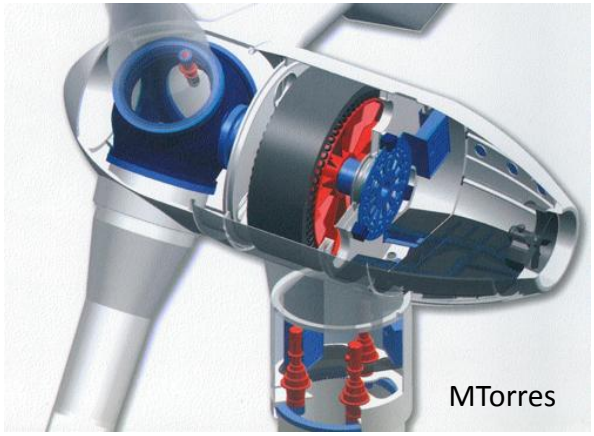
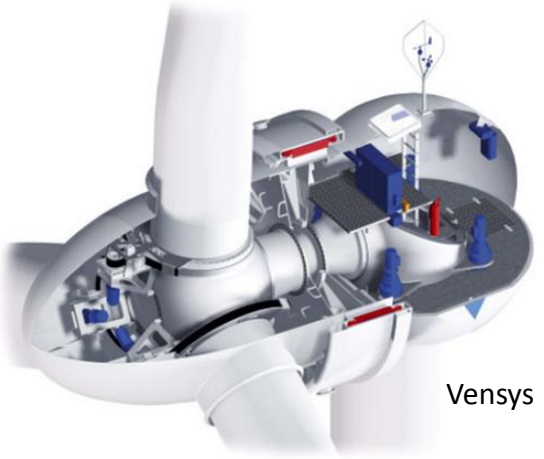
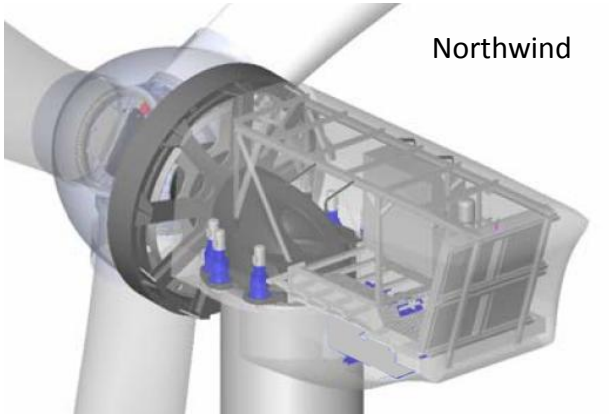
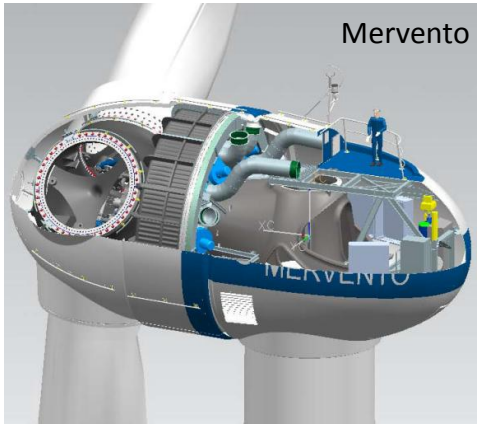
Direct-driven generator in the nacelle

- Popular concept: generator between blades and tower


MTorres

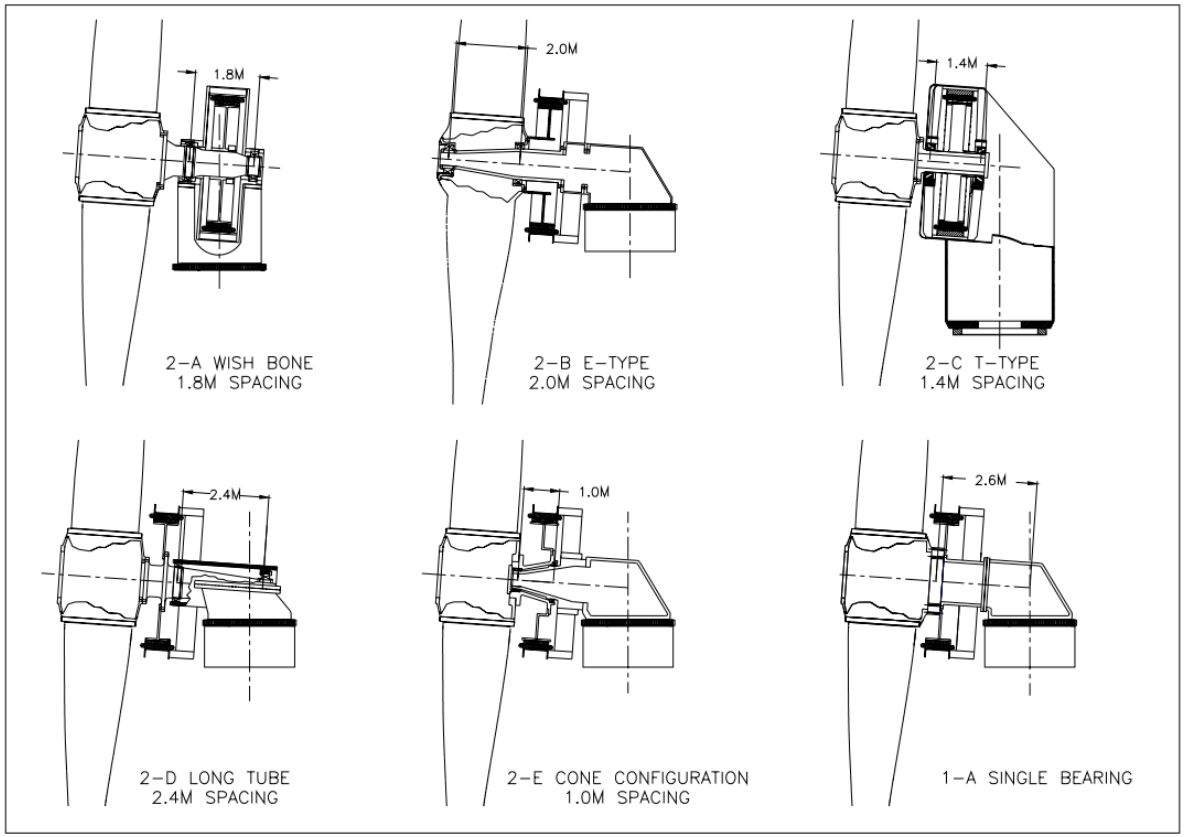

Vensys


Northwind


Mervento

Direct-driven generator in the nacelle

- Integration variants



Source: NREL

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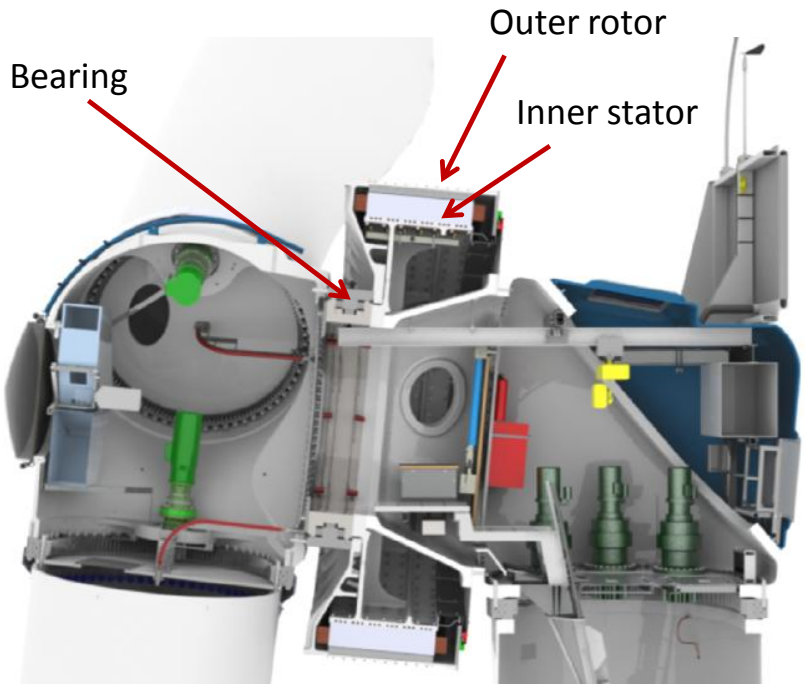
Direct-driven generator outside the nacelle

- No shaft
- Single bearing common for generator and blades



Emergia

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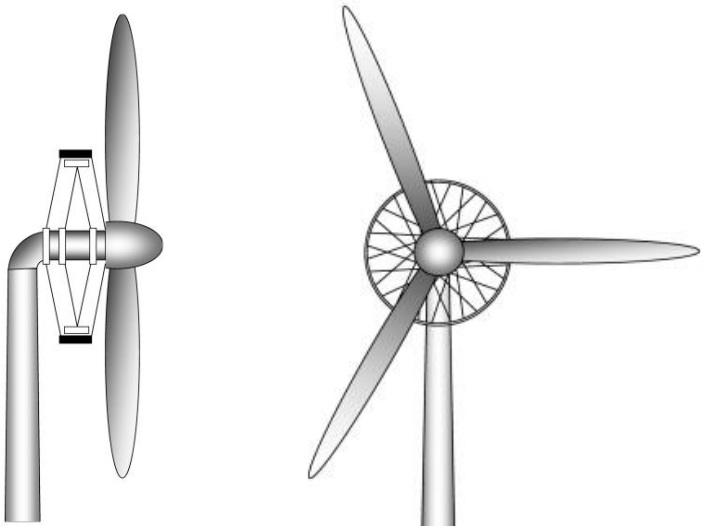
Direct-driven generator outside the nacelle

- Different approaches to weight reduction



Concept: light carrying structure of the generator

Concept: integration of generator with blades

Key to success for generator supplier

- Work in close contact with the turbine designers
- Provide best active parts
  - Lightest
  - Most compact
  - Giving high efficient energy conversion
  - Segmented
  - Easy to integrate
  - Cheap in production
  - With low cogging
  - Medium- and low-voltage

...next part

- Drive train configurations
- State of the art PMG-based solutions
- Integration: the path to win for direct drive
- SmartMotor in wind

What is SmartMotor

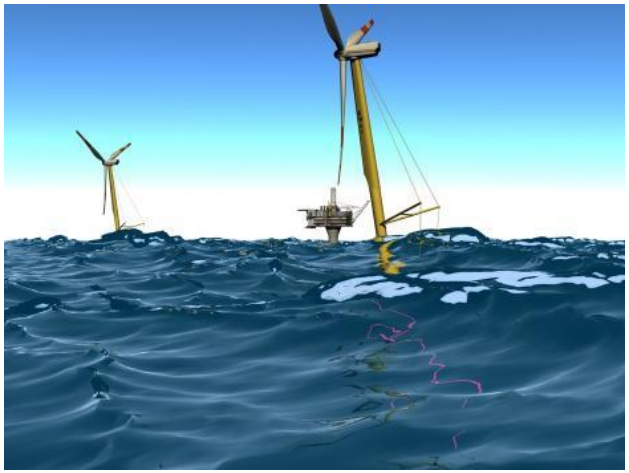
- Established in 1996 in Trondheim, Norway
- One of the largest R&D groups in the world with focus on PM technology

Reference projects offshore

- Low-voltage and medium-voltage machines of MW-class

1.1 MW tidal turbine of Atlantis Resource Corporation (delivered)

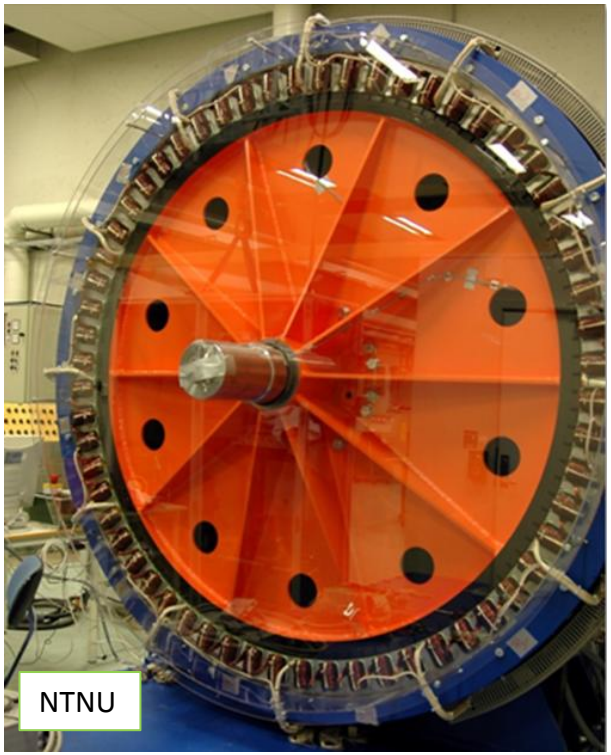
0.8 MW propulsion system for Rolls-Royce Marine (in operation)

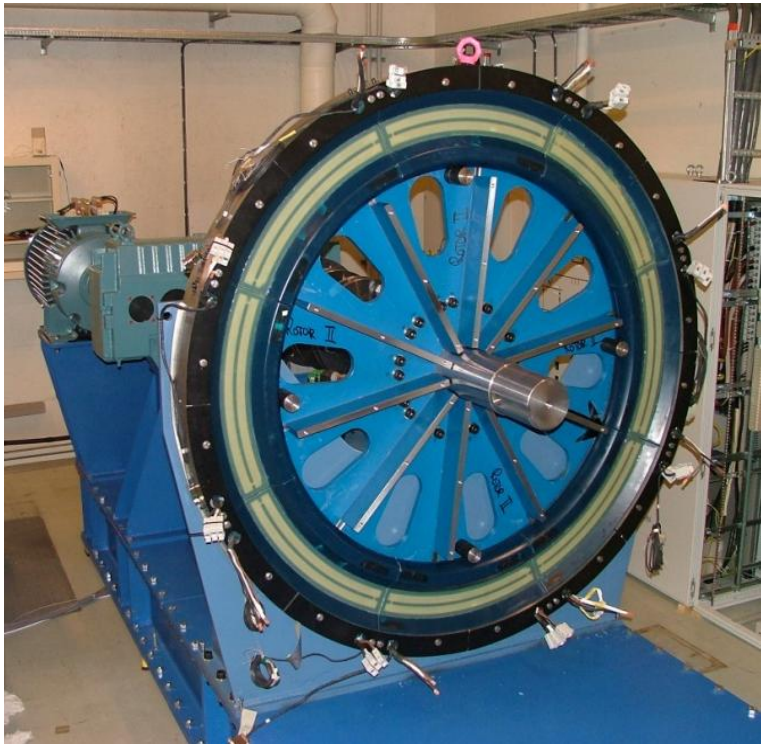


10 MW offshore wind turbine of SWAY (under construction)

The technologies we believe in

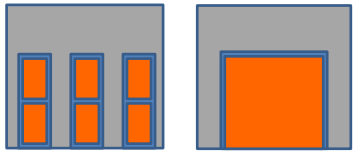
- PM machines with concentrated winding and ironless machines
- Ideal for high-torque applications like wind turbines with direct drive



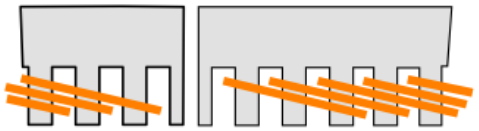


Our technologies

- Concentrated winding technology is advantageous compared to distributed winding in high-torque applications due to
  - higher slot fill factor and consequently better cooling of the copper
    - Pre-shaping of the coil
    - No insulation is needed between different phases



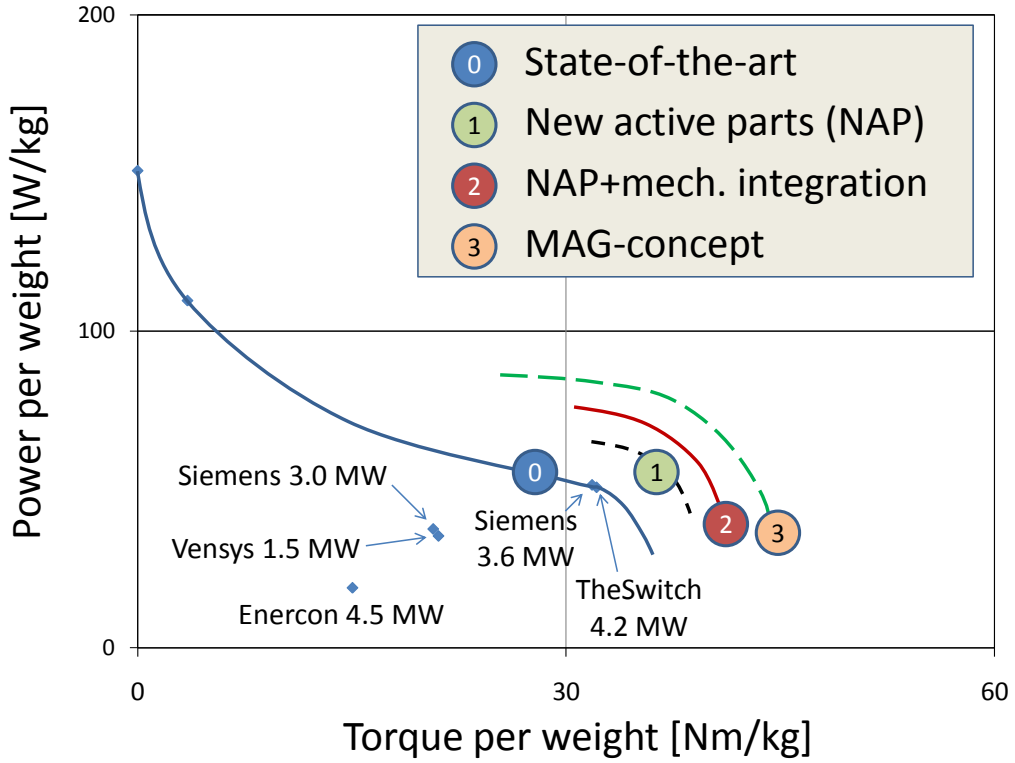
  - segmentation with distributed winding leads to half-empty slots (10% loss in total slot filling), while with concentrated winding all slots are filled
  - low cogging
    - Competitors achieve this by shaping magnets
    - SmartMotor apply patented slot/pole combinations



- Ironless technology is advantageous for machines with large diameter
  - There is no attracting force between rotors and stator
  - The structure is not sensitive to relative displacement of rotors and stator

Our R&D directions

- Shift PMG technology frontier by introducing new concepts
- Find new integration solutions together with wind turbine manufacturers



Our R&D directions

- Novel transformer-less concepts
- ABB have developed concepts with direct high-voltage DC outputs based on use of machines with high-voltage insulation
- **SmartMotor have developed similar concept where machine with low-voltage insulation can be used (which means considerably more compact and cheap machine)**

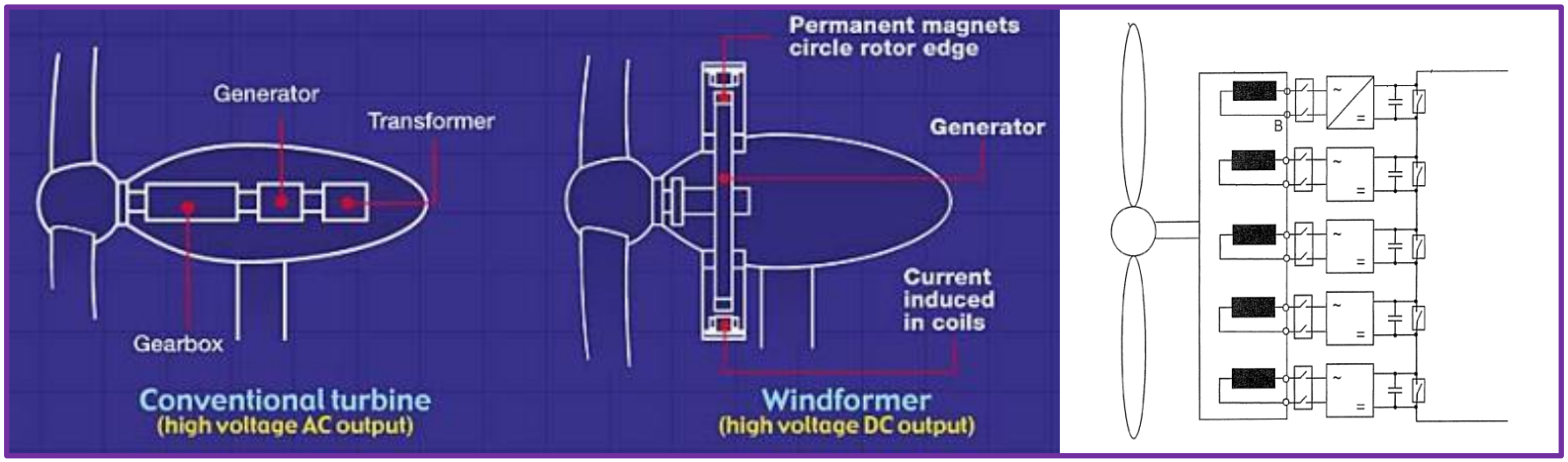


ABB concepts

...the end)

Thank you!

Contact information: alexey@smartmotor.no, www.smartmotor.no

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