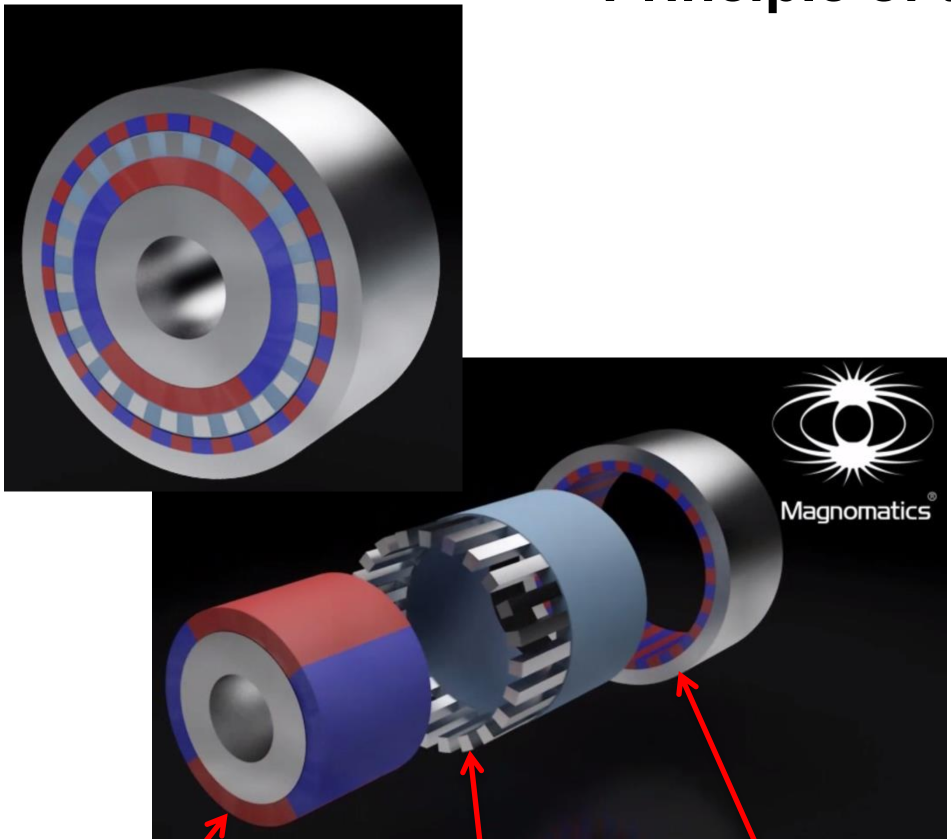
Scaling of Pseudo Direct-Drives for Wind Turbine Application

Andreas Penzkofer and Kais Atallah
Electronic and Electrical Engineering, The University of Sheffield

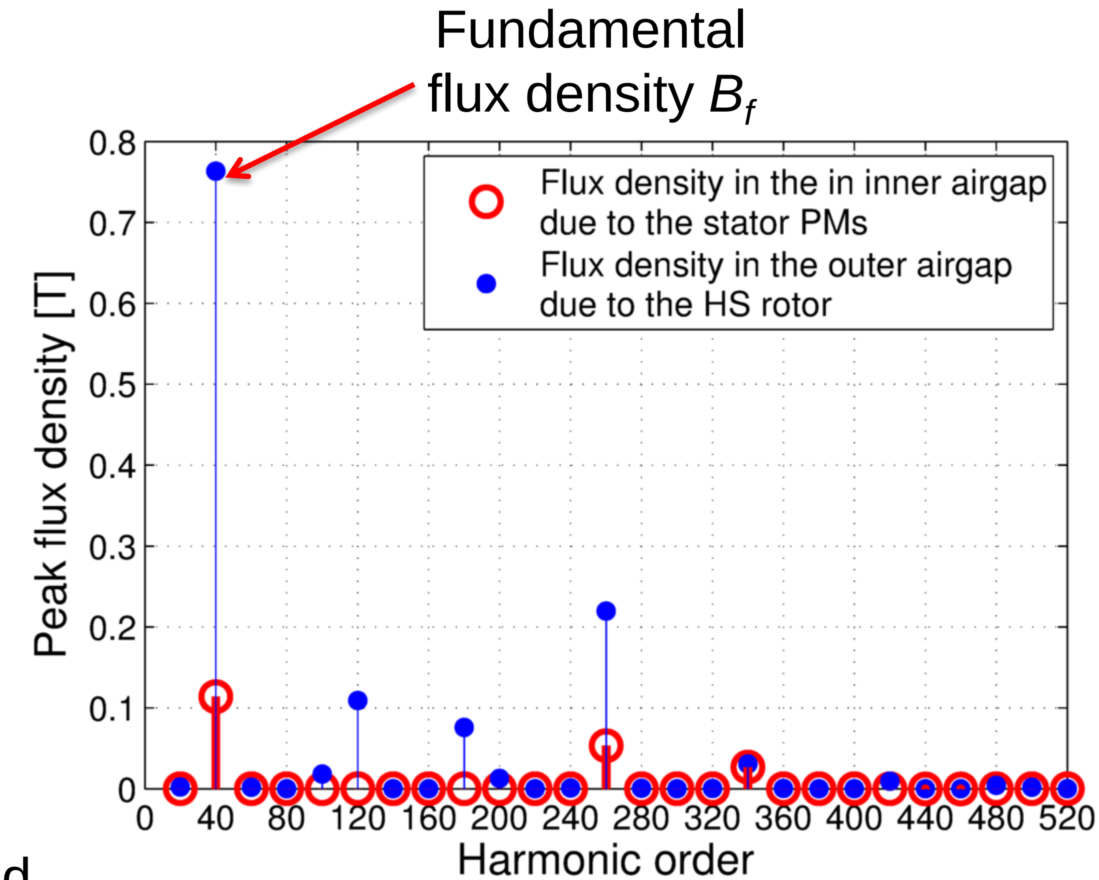
Principle of the magnetic gear



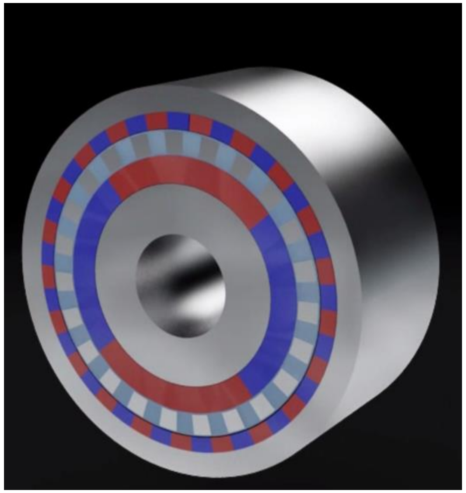
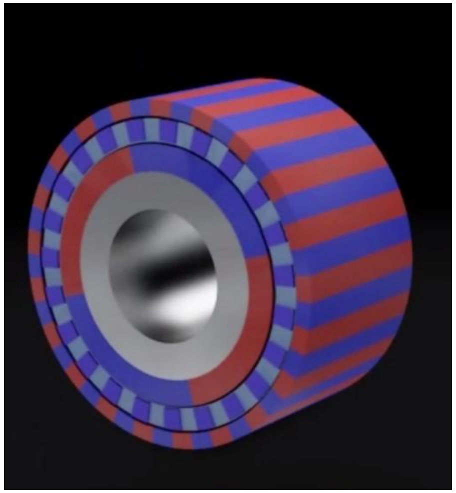
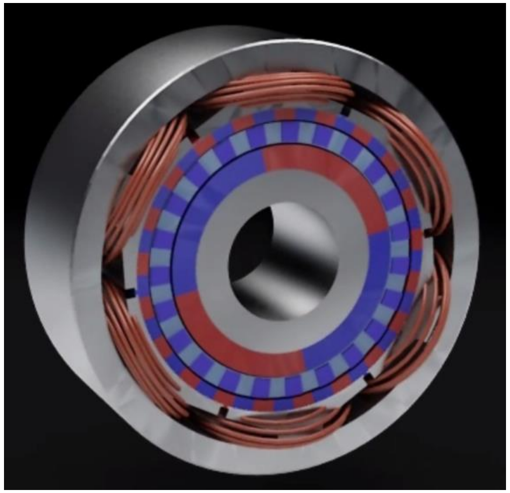
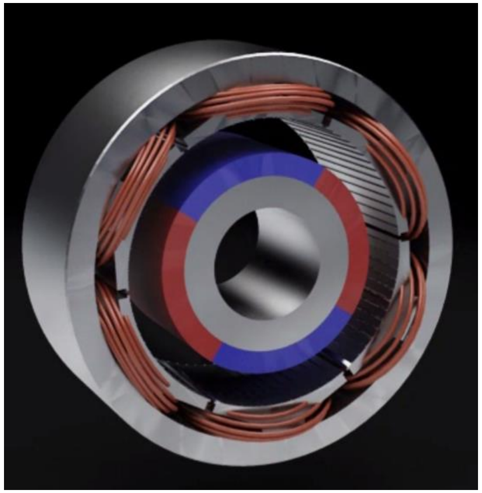
High-speed rotor

Pole-piece rotor

Low-speed rotor



Integration with a permanent magnet machine to form a Pseudo-Direct Drive

Magnetic gear component → Pseudo-Direct Drive ← Permanent magnet machine

- Contact less gearing effect ⇨ reduction of maintenance cost
- Inherent overload protection ⇨ only the maximum torque of the magnetic gear (Pullout torque) can be transmitted to the turbine.
- Torque density of PDDs may be several times higher than conventional PM machines.

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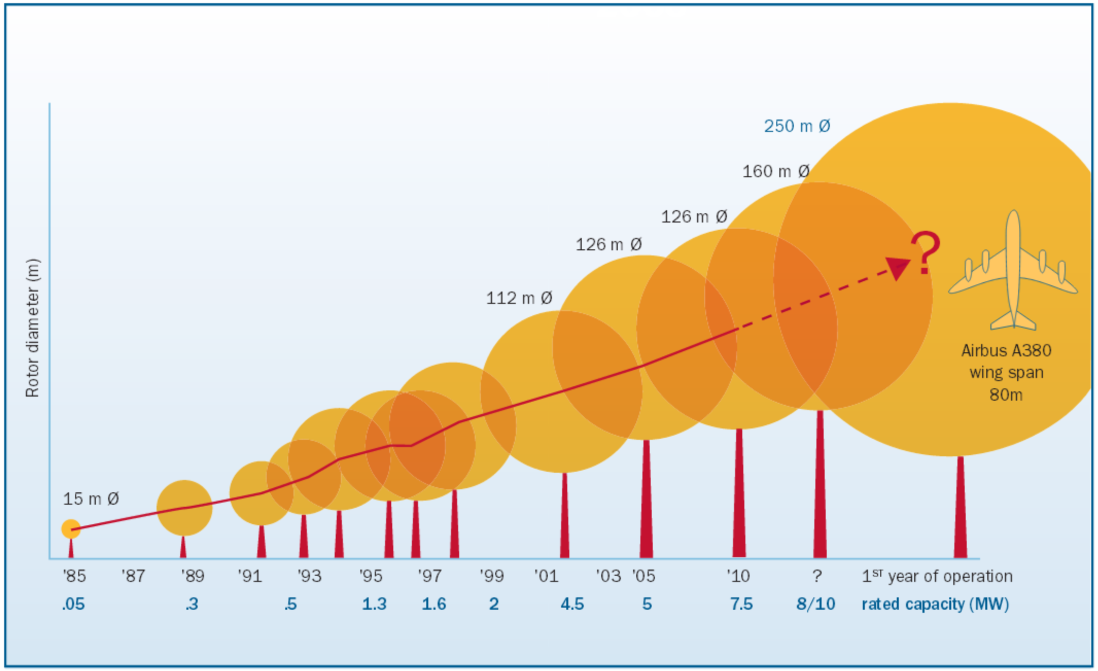
Upscaling of the wind turbine



Report: Upwind – Design of very large wind turbines, March 2011

Comparison of PMDD and PDD for the 10MW power class

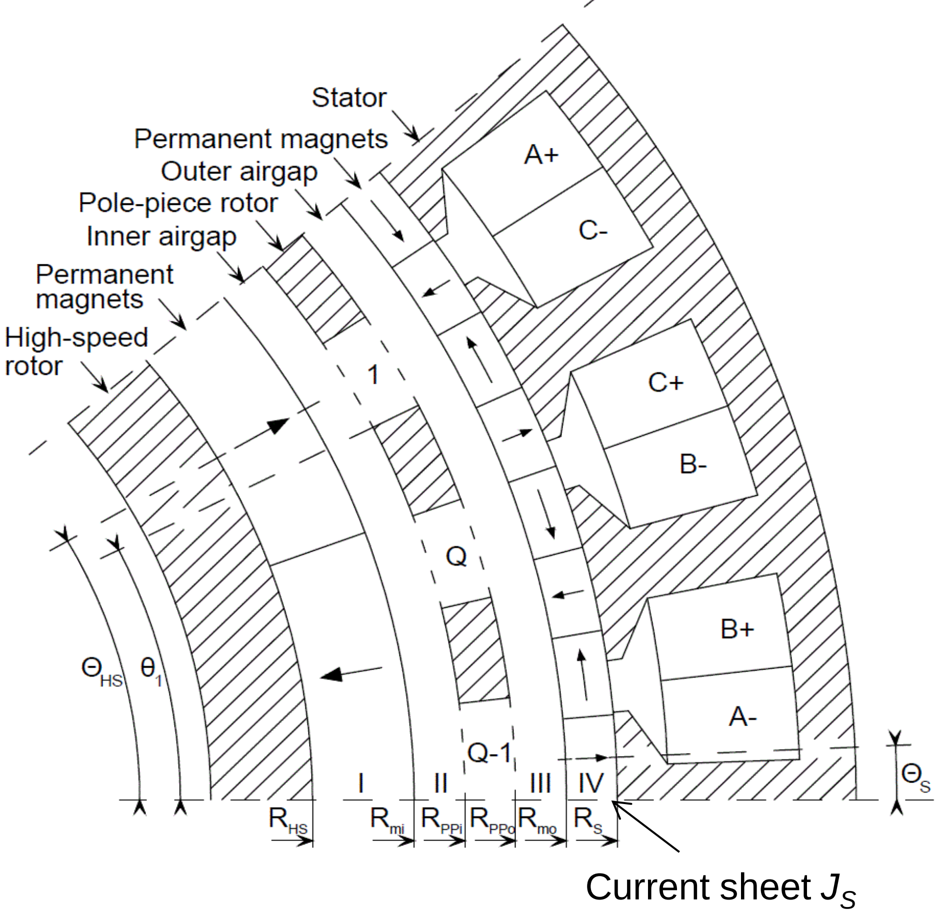
QUANTITY	PMDD [1]	PDD [2]
Rated efficiency [%]	97.0	98.7
Copper mass [tons]	12	7
PM mass [tons]	6	13.5
Laminated steel mass [tons]	47	19.5
Airgap diameter [m]	**10**	**6**
Axial length [m]	1.6	1.66

[1] H. Polinder, et. al., “10 MW wind turbine direct-drive generator design with pitch or active speed stall control,”
[2] INNWIND.EU, Deliverable report 3.21, Design and PI of PDD generator

- **Innwind**: Increase cost effectiveness through innovative designs
- For a 10MW Permanent-Magnet-Direct-Drive the structure material cost might be as high as 2/3 of the total material cost.

Description of the model

Geometry for
a Pseudo-Direct Drive segment



Flux density for a given region:

$$\vec{B} = \nabla \times \vec{A}$$

Assumptions:

- infinitely permeable steel
- 2D → only z-component A remains
- current sheet at bore radius

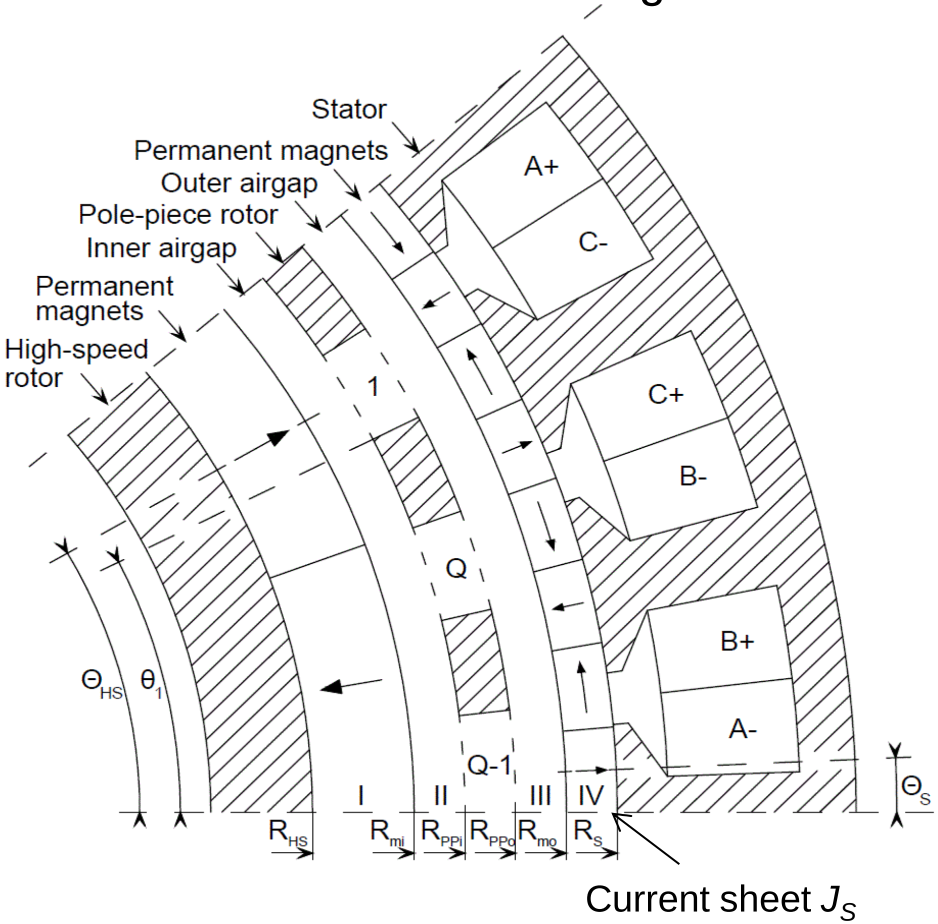
A can be expressed as a Fourier series:

$$A(r,\theta) = \sum_{n=1}^{\infty} \begin{pmatrix} f_{c,n}(r) \\ f_{s,n}(r) \end{pmatrix} \cdot \begin{pmatrix} cos(n\theta) \\ sin(n\theta) \end{pmatrix}$$

- Solutions are given for arbitrary magnetisations that depend on the circumferential coordinate.

Description of the model

Geometry for
a Pseudo-Direct Drive segment



Solving process

Apply the boundary conditions for the flux density at the interfaces between the regions.

↓

Connect the vector potential coefficients of the various regions.

↓

Solve matrix equation to calculate the coefficients:

$$\widehat{M}\vec{c} = \vec{v}$$

- $\vec{c}$ is a list of the coefficients
- Excitation vector $\vec{v}$ depends on the magnetisation and the current sheet.
- Correlation matrix $\widehat{M}$ is given by the relations between the coefficients

Scale invariance of the model

A scaling factor s is applied to all radial dimensions of the magnetic gear component.

Magnetic gear component
(i.e. current sheet set zero)

↓

correlation matrix $\widehat{M}$ and excitation vector $\vec{v}$ constant

→

Fundamental flux density B_f constant

→

Pseudo Direct Drive

↓

current loading constant

↓

correlation matrix $\widehat{M}$ and excitation vector $\vec{v}$ constant

↓

Constant quantities

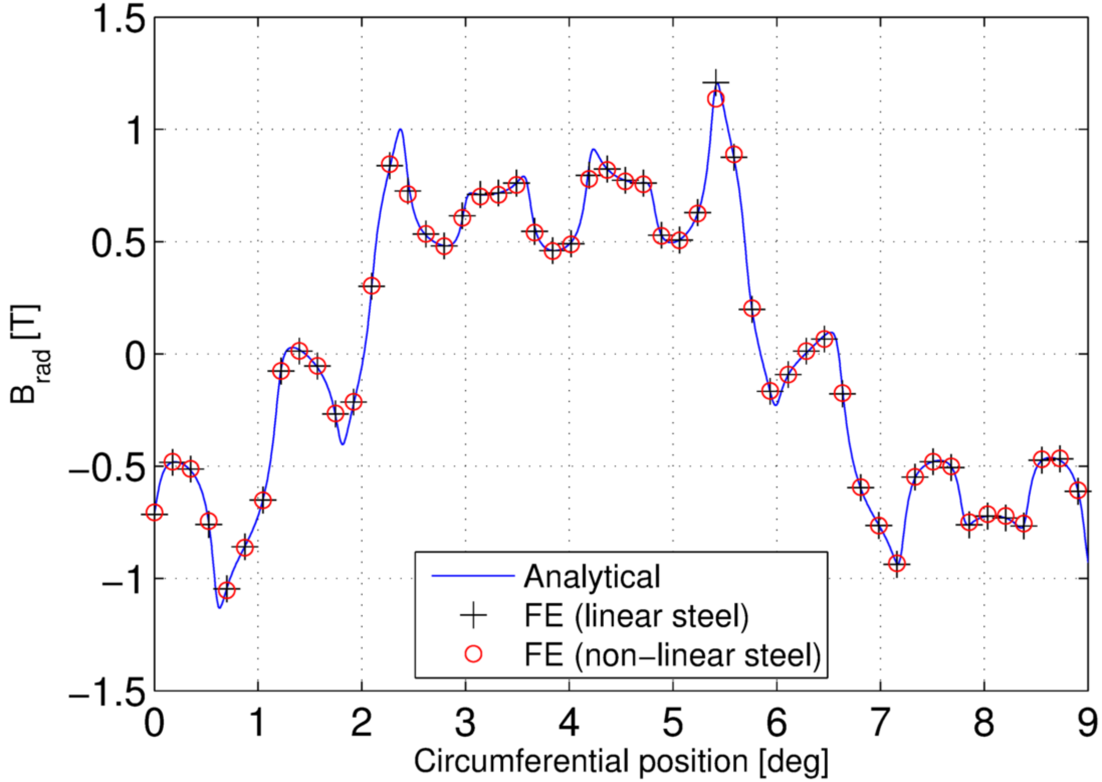
- Flux density $\vec{B}$ in the airgap and PM regions
- Airgap shear stress
- Permanent magnet mass per unit torque

Validation with finite element analysis

Parameters of a 10MW PDD

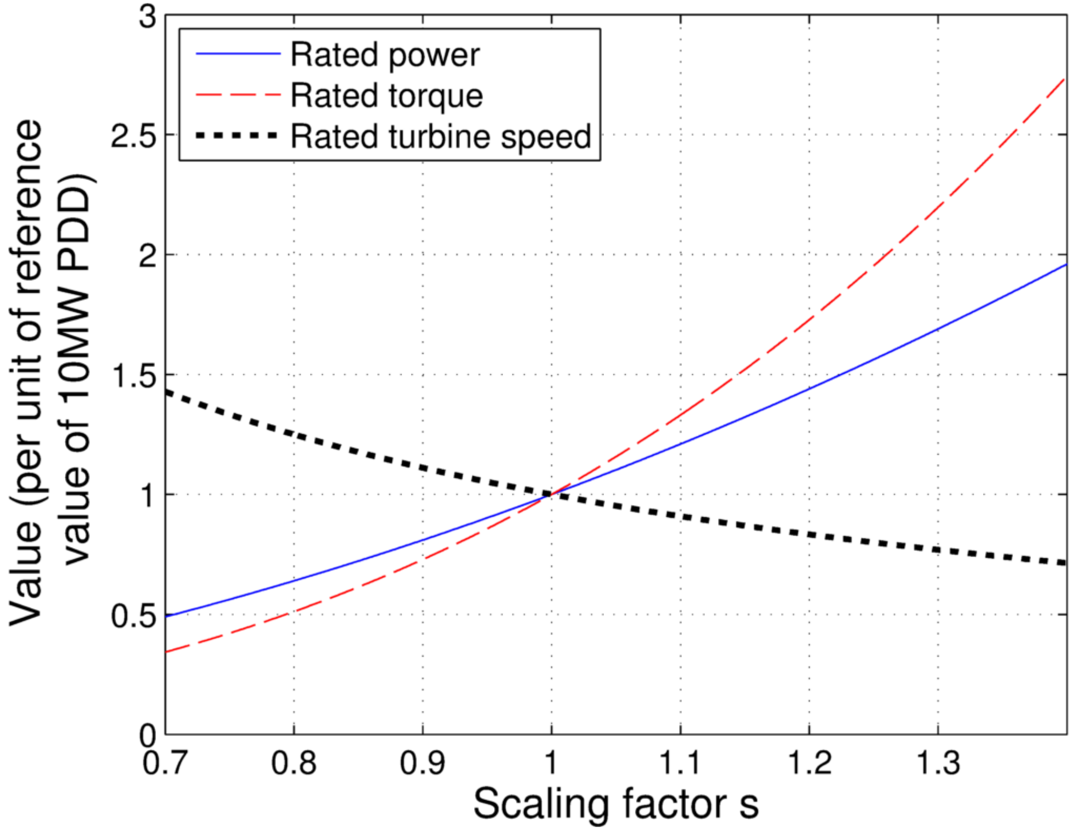
Quantity	Value
Rated power	10 MW
Analytical pullout torque	11.9 MNm
Gear ratio	7.5
Rated speed of PP rotor	9.65 rpm
Pole-pairs on HS rotor	40
Airgap diameter	6.0 m
Active axial length	1.66 m
Permanent magnets	NdFeB

Variation of radial flux density with the circumferential position in the inner airgap



Scaling of the wind turbine

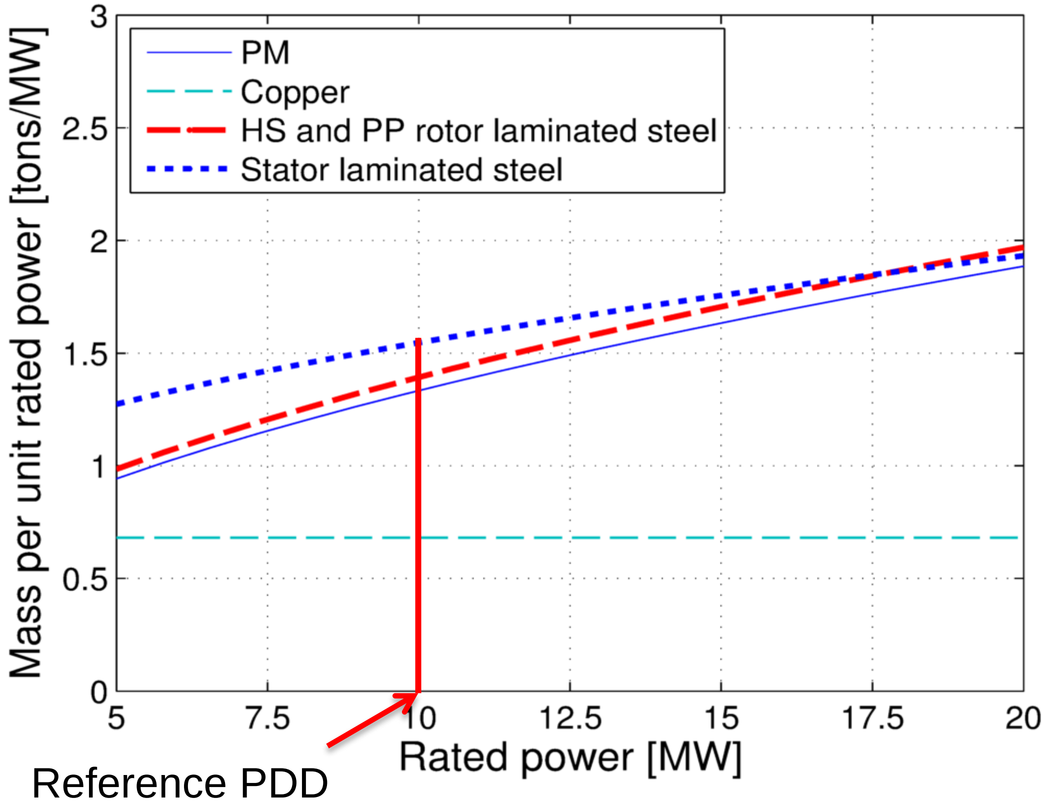
- The radial and axial dimensions of the turbine are scaled.
- The power coefficient is assumed constant
- The tip speed of the turbine is fixed.



Scaling of the Pseudo-Direct Drive

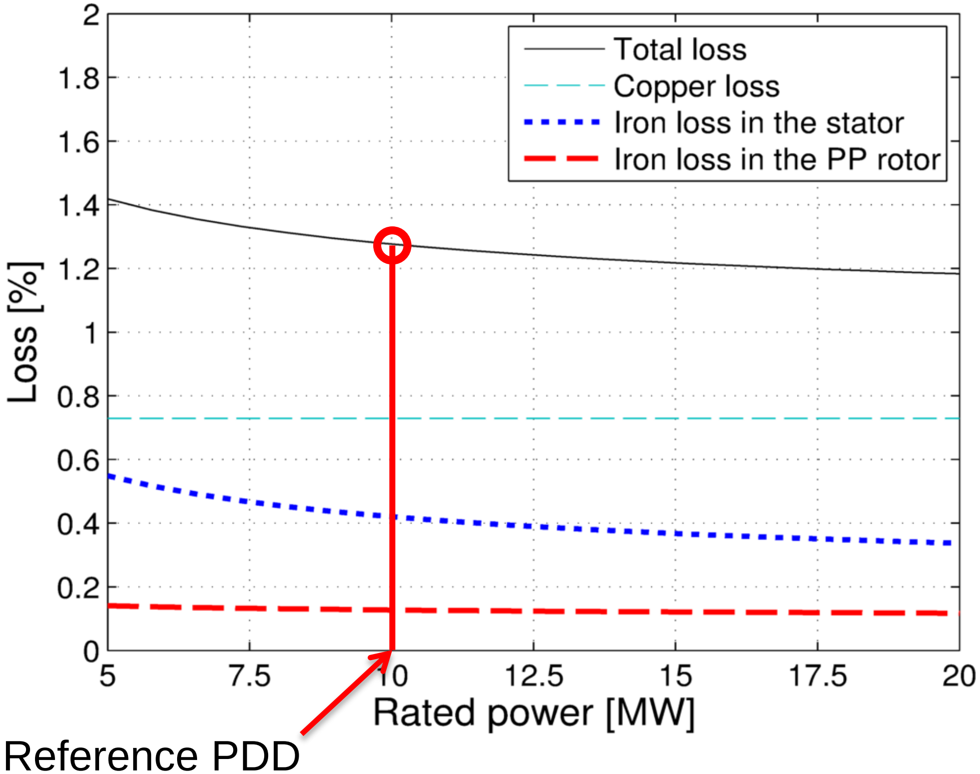
- The radial and axial dimensions of the magnetic gear component have been scaled.
- The rated current density has been fixed.

Variation of active masses with scaling

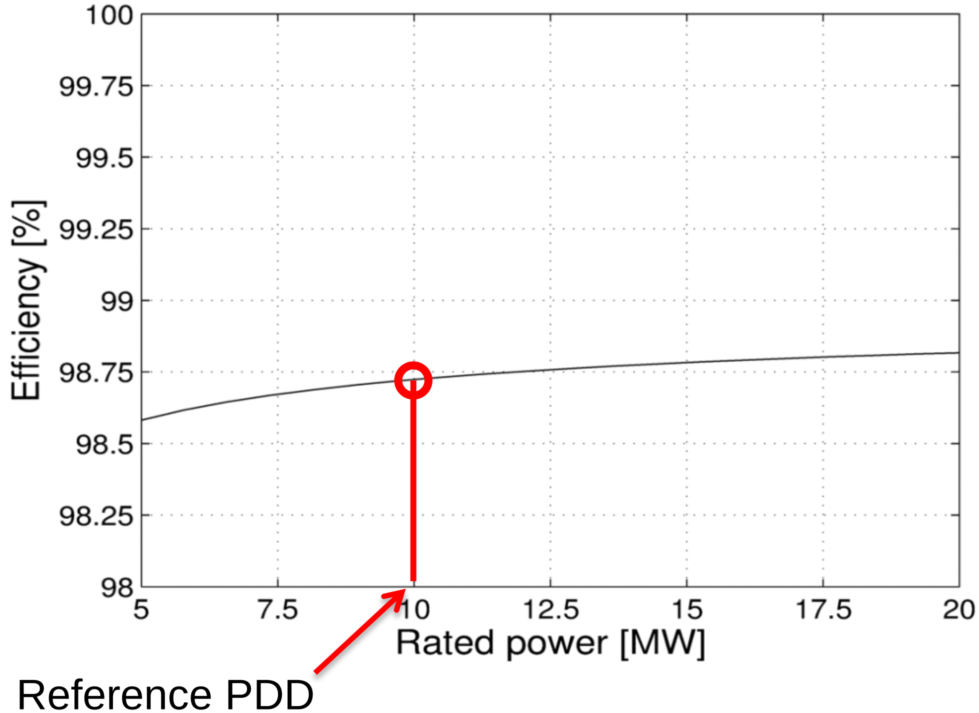


Scaling of the Pseudo-Direct Drive

Variation of losses with scaling



Variation of efficiency with scaling



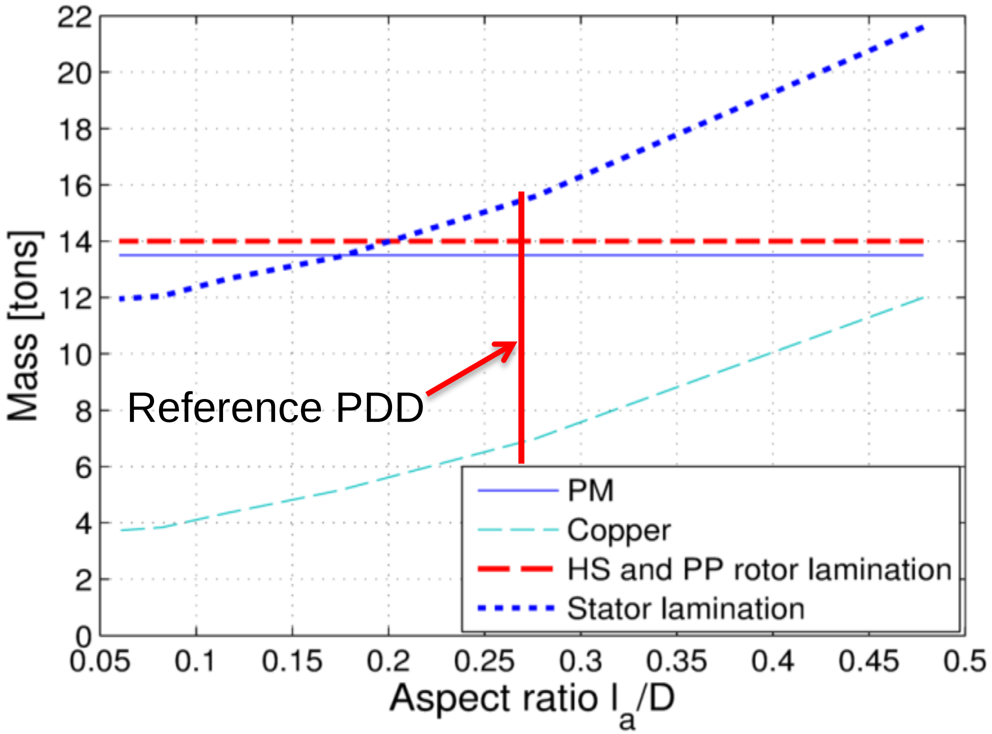
- The radial and axial dimensions of the magnetic gear component have been scaled.
- The rated current density has been fixed.

Further design refinements

Improvements may be achieved by adjusting

- the aspect ratio of the magnetic gear component and the PDD.
- the rated current density and the amount of copper

Variation of active masses with the aspect ratio



- The torque and the power have been fixed.
- The rated current density has been fixed.

Thank you.