Scaling of Pseudo Direct-Drives for Wind Turbine Application

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Scaling of Pseudo Direct-Drives for Wind Turbine Application

**Principle of the magnetic gear**

- **Fundamental flux density** $B_f$

- **Graph**
  - Flux density in the inner airgap due to the stator PMs
  - Flux density in the outer airgap due to the HS rotor

- **High-speed rotor**
- **Pole-piece rotor**
- **Low-speed rotor**
Integration with a permanent magnet machine to form a Pseudo-Direct Drive

- Contact less gearing effect
- Inherent overload protection
- Torque density of PDDs may be several times higher than conventional PM machines.

Scaling of Pseudo Direct-Drives for Wind Turbine Application

- Reduction of maintenance cost
- Only the maximum torque of the magnetic gear (Pullout torque) can be transmitted to the turbine.

The Electrical Machines & Drives Research Group
Upscaling of the wind turbine

Comparison of PMDD and PDD for the 10MW power class

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated efficiency [%]</td>
<td>97.0</td>
<td>98.7</td>
</tr>
<tr>
<td>Copper mass [tons]</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>PM mass [tons]</td>
<td>6</td>
<td>13.5</td>
</tr>
<tr>
<td>Laminated steel mass [tons]</td>
<td>47</td>
<td>19.5</td>
</tr>
<tr>
<td>Airgap diameter [m]</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Axial length [m]</td>
<td>1.6</td>
<td>1.66</td>
</tr>
</tbody>
</table>

[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.
Flux density for a given region:

\[ \vec{B} = \nabla \times \vec{A} \]

Assumptions:
• infinitely permeable steel
• 2D \( \rightarrow \) only z-component \( A \) remains
• current sheet at bore radius

\( A \) can be expressed as a Fourier series:

\[ A(r, \theta) = \sum_{n=1}^{\infty} \left( f_{c,n}(r) \right) \cdot \left( \cos(n\theta) \right) \cdot \left( \sin(n\theta) \right) \]

• Solutions are given for arbitrary magnetisations that depend on the circumferential coordinate.
**Solving process**

1. Apply the boundary conditions for the flux density at the interfaces between the regions.
   
2. Connect the vector potential coefficients of the various regions.
   
3. Solve matrix equation to calculate the coefficients:
   \[
   \mathbf{M} \hat{\mathbf{c}} = \hat{\mathbf{v}}
   \]

- \( \hat{\mathbf{c}} \) is a list of the coefficients
- Excitation vector \( \hat{\mathbf{v}} \) depends on the magnetisation and the current sheet.
- Correlation matrix \( \mathbf{M} \) 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 $\tilde{M}$ and excitation vector $\tilde{v}$ constant

- **Fundamental flux density $B_f$ constant**

- **Pseudo Direct Drive**
  - current loading constant
  - correlation matrix $\tilde{M}$ and excitation vector $\tilde{v}$ constant

**Constant quantities**
- Flux density $\vec{B}$ in the airgap and PM regions
- Airgap shear stress
- Permanent magnet mass per unit torque
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Validation with finite element analysis

Parameters of a 10MW PDD

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>10 MW</td>
</tr>
<tr>
<td>Analytical pullout torque</td>
<td>11.9 MNm</td>
</tr>
<tr>
<td>Gear ratio</td>
<td>7.5</td>
</tr>
<tr>
<td>Rated speed of PP rotor</td>
<td>9.65 rpm</td>
</tr>
<tr>
<td>Pole-pairs on HS rotor</td>
<td>40</td>
</tr>
<tr>
<td>Airgap diameter</td>
<td>6.0 m</td>
</tr>
<tr>
<td>Active axial length</td>
<td>1.66 m</td>
</tr>
<tr>
<td>Permanent magnets</td>
<td>NdFeB</td>
</tr>
</tbody>
</table>

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

[Graph showing variation of active masses with scaling across different materials and rated power]
Scaling of Pseudo Direct-Drives for Wind Turbine Application

Scaling of the Pseudo-Direct Drive

Variation of losses with scaling

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

Variation of efficiency with scaling

Reference PDD
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.
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Thank you.