Coil Excited Magnetic Gears for Large Wind Turbines

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Introduction

Magnetic gears can be an alternative solution to mechanical gears in wind turbine drive trains. Because of the contactless torque transmission capability and the inherent overload protection, reliability can be significantly improved [1]. Furthermore, stator windings may be added to form a Pseudo-Direct Drive (PDD) [2], which could enable the realisation of compact and light-weight drive-train solutions for wind turbines [3].

Despite their many advantages a drawback remains the large volume of permanent magnets (PM) required for their realisation [4]. Therefore, it is proposed that in order to reduce the PM mass and introduce an extra degree of controllability, that the HS rotor is excited using coils supplied with a DC current. This work is an investigation into the performance of coil excited PDDs for large wind turbine applications. Analytical techniques have initially been employed for the investigation of the effects of the key design parameters [6]. However, two designs have been selected for a more detailed analysis, using finite element method. These designs have then been utilised to investigate into the effects of the the control strategy on the efficiency of the PDD.

Control of the PDD

The coil excited high-speed rotor can be actively controlled so as to minimize the electromagnetic losses, while satisfying the operational requirements/constraints as follows:

\[ T_{\text{null}} \geq 1.2 \times \text{turbine torque} \]
\[ I_s \leq \text{rated stator current} \]
\[ E_{\text{MF}} \geq \text{minimum EMF} \]

\[ I_s \leq \text{rated HS rotor current} \]

Loss analysis

In order to avoid time consuming finite element analysis the iron losses have been assumed to be given by the following analytical expression of \( I_s \), \( I_r \) and the rotational speed \( \Omega \):

\[ I_r (\Omega) = \Omega (c_{s1} I_s^2 + c_{s2} I_r^2) \]
\[ + \Omega^2 (c_{i1} I_s^2 + c_{i2} I_r^2) \]
\[ + \Omega^3 (c_{s1} I_s^2 + c_{s2} I_r^2) \]

\[ \text{(hysteresis)} \]
\[ \text{(classical eddy currents)} \]
\[ \text{(excess eddy currents)} \]

The annual energy efficiency is calculated by employing a Weibull probability distribution that has been fitted to a measured wind profile [5].

Results

• An active DC control allows for the employment of a passive diode rectifier, resulting in less costly, simpler and more reliable power electronics than if a active rectifier is employed.

• The efficiency can be improved if the PDD is allowed to operate closer to the pullout torque.

• The selection of the minimum EMF has a significant effect on the annual energy efficiency and this should be considered, when a control strategy and a converter topology are selected.

Design of a 10MW PDD

Design analysis using analytical methods:

• Analytical techniques developed for the prediction of the flux density distribution in PDDs with PM excitation [6] have been extended to accommodate the HS rotor windings.

• Effects of the leading design parameters on the active masses and the efficiency have been investigated.

Results

• A minimum PM mass is required to avoid saturation in the HS rotor teeth.

• For a larger diameter a lower PM mass may be required.

Since the analytical method doesn’t take into account of saturation, finite element has subsequently been used in order to further optimize the two selected designs shown in the table.

Conclusion

A PDD with coil excited HS rotor has been presented. It has been shown, that when applied to a 10MW wind turbine, significant reductions in PM mass can be achieved, albeit at the expense of increased total active mass and reduced efficiency. It is also shown that the control strategy, more specifically the variation of the DC excitation current with wind speed, can result in significant improvements in efficiency.