PO.ID 048

Assessment of the suitability of ferrite magnet excited synchronous generators for offshore wind turbines

Nurul Azim Bhuiyan, Alasdair McDonald
University of Strathclyde, Glasgow

Abstract

In recent years the use of permanent magnets (PM) for wind turbine generators has increased significantly. The price of rare earth metals such as neodymium is very unstable and increased more than 350% from August 2009 to August 2011 [1].This means that wind turbine manufacturers (who use permanent magnet generators) are faced with a significant cost uncertainty. The large price fluctuations encourage us to look at alternative PM materials. The main purpose of this paper is to assess the suitability or otherwise of ferrite magnet excited synchronous generators for offshore wind turbines.

Here, a generator design (for a 6 MW offshore turbine) using ferrite magnets is presented and compared with a generator using NdFeB magnets, in terms of costs, efficiency, availability and cost of energy. In order to do this a Ferrite magnet generator is designed and evaluated.

Objectives

This paper focuses on the potential downsides of using ferrite magnets such as increased generator mass, increased inertia and variation in loss mechanisms.

To assess these, the main objectives are to:

- Model permanent magnet generators with NdFeB and ferrite magnets (with the same airgap flux density).
- Optimise the ferrite magnet generator improving to reduce the inertia.
- Calculate and compare generator losses for the two machine types
- Examine the loss of turbine rotor energy capture due to increased generator inertia.

Methods

Generator modelling

This paper builds on the work of Eriksson and Bernhoff [1] and Hart *et al.* [2] with an emphasis on a typical 6 MW offshore wind turbine. In order to assess the suitability of ferrite magnets, two 6 MW wind turbine were designed: one with a surface mounted NdFeB (rare earth magnet) rotor and one with a flux concentrating ferrite magnet rotor with same stator. The electromagnetic design is done using a lumped parameter magnetic circuit model which is verified using finite element software. For the same amount of flux crossing the air gap, the difference in rotor masses, rotor losses, moment of inertia are examined.

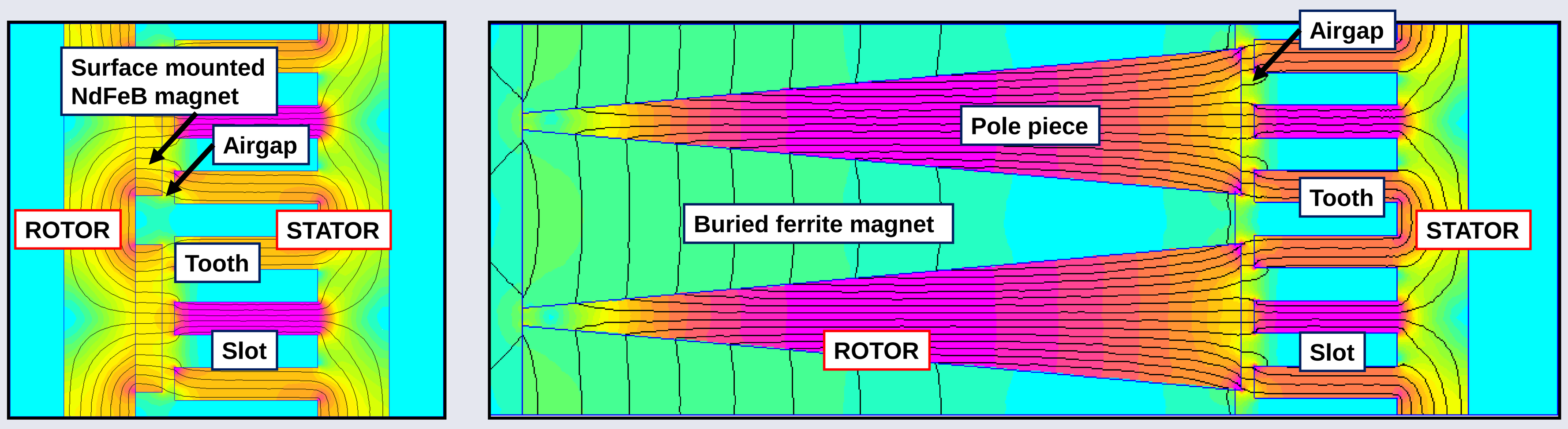


Figure 1: Magnetostatic finite element analysis of surface mounted NdFeB generator (left) and flux concentrating ferrite generator (right). 0T → 1.5T . Software is FEMM (www.femm.info)

A FFT is then performed on the airgap flux density waveforms to see the ensure same fundamental induced EMF. An equivalent circuit approach is used to calculate output power at each wind speed.

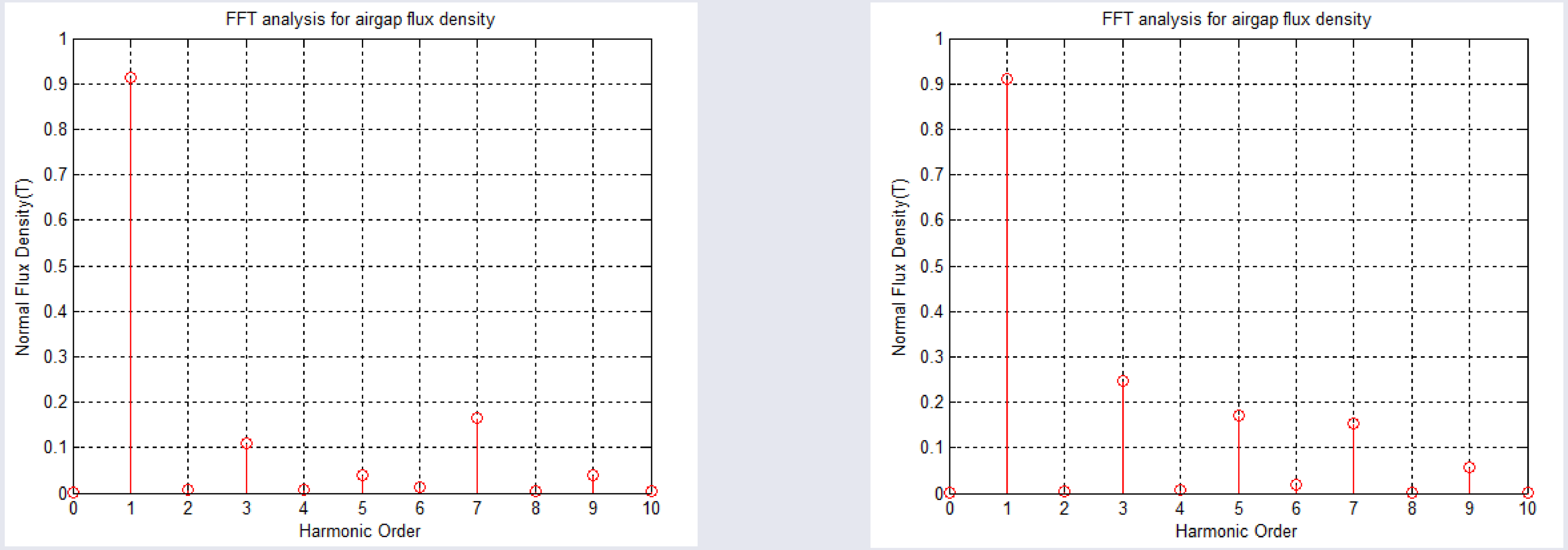


Figure 2: FFT analysis of airgap flux density waveform for surface mounted NdFeB generator (left) and flux concentrating ferrite generator (right).

Energy capture modelling

The effect of increased of inertia is modelled by modifying a 6MW turbine model in Bladed software. A number of wind speed time series (for different mean wind speeds) are used to analyse energy capture for turbines with each generator type.

Results

Generator modelling

With a fixed pole width and number of pole pairs, the flux concentrating magnet geometry was optimised to minimise magnet mass while achieving the same fundamental flux density and the same pole width. Increasing the magnet width at the inner radius leads to the angle θ increasing. Figure 3 shows that for a constant magnet mass, higher airgap flux density can be found with $\theta=\theta_{max}=6.2^{\circ}$. Adopting this angle allowed the magnet to mass to be minimised.

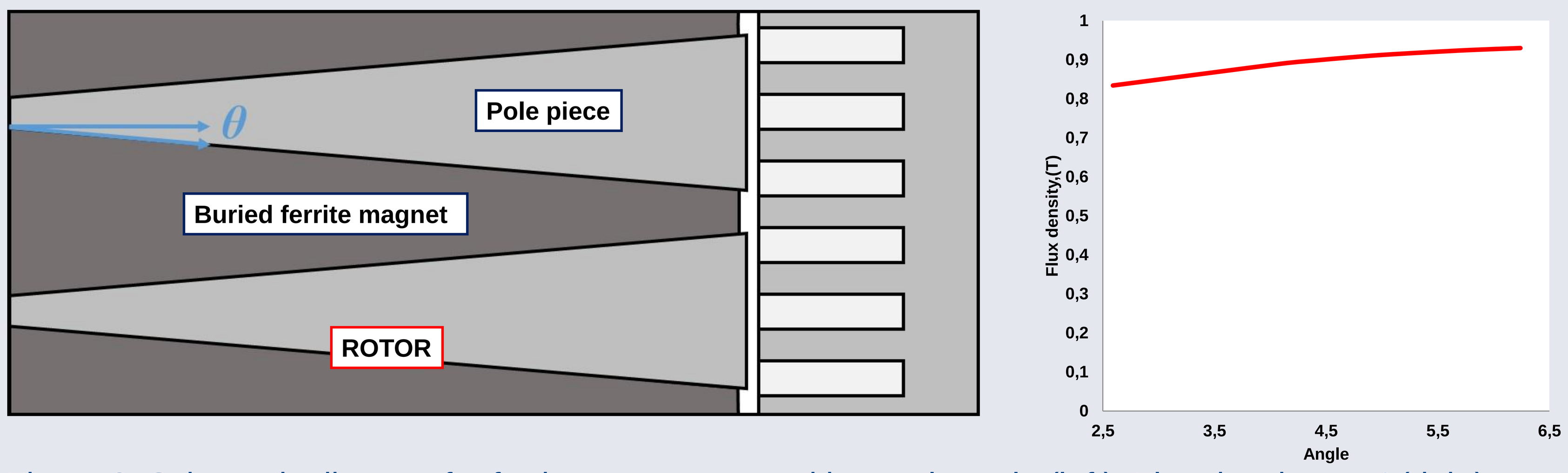


Figure 3: Schematic diagram for ferrite magnet rotor with angular pole (left), Flux density vs. θ (right)

To further minimise magnet mass, contour plots of magnet mass and airgap flux density from surface mounted NdFeB and flux concentrating ferrite rotors are plotted against different magnet width and height in Figure 4.

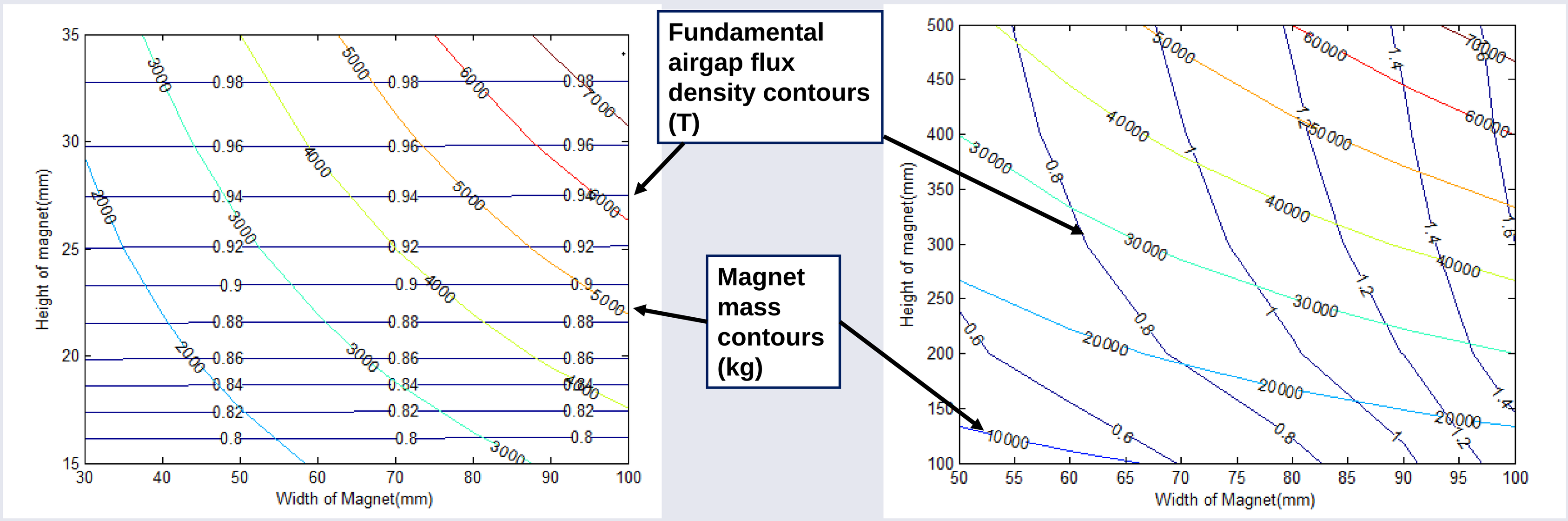


Figure 4: Contour plot of airgap flux density and masses surface mounted NdFeB rotor (left) and flux concentrating ferrite magnet rotor (right)

Magnet mass and airgap flux for the two machines are plotted in Figure 5:

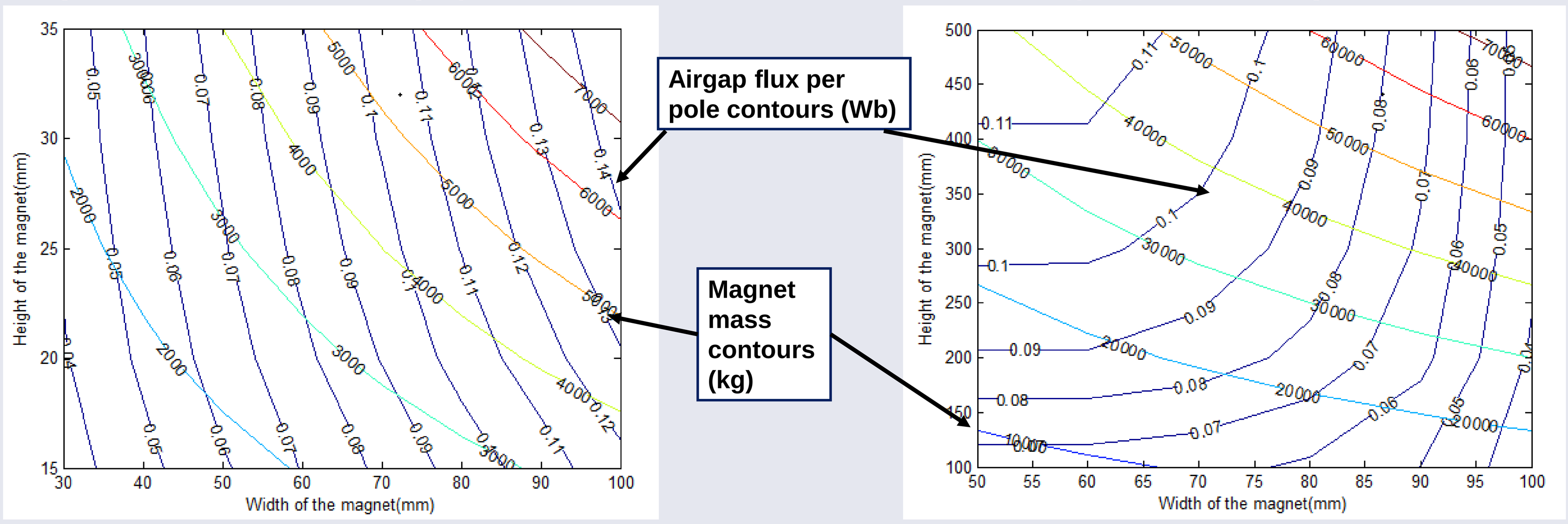
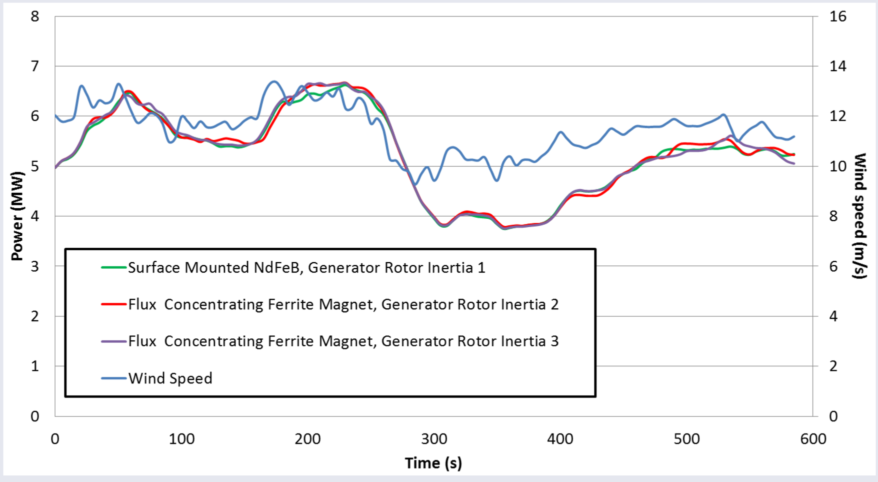


Figure 5: Contour plot of airgap flux and masses surface mounted NdFeB rotor (left) and flux concentrating ferrite magnet rotor (right)



There are modest differences in machine efficiency due to rotor losses and inductance.

Energy modelling

Time series modelling in Bladed shows that increased generator rotor inertia leads to modest changes in Annual Energy Production (~0.1-0.5%)

Figure 6: Time series model of wind speed and power output for 3 generator rotor inertias (Inertia 1 = 1.5×10^{5}kgm^{2} ; Inertia 2 = 1.26×10^{6}kgm^{2} ; Inertia 3 = 1.89×10^{5}kgm^{2})

Conclusions

Generators with flux concentrating ferrite magnets can be a suitable alternative to reduce NdFeB permanent magnet use in wind turbine generator. Reduction in turbine rotor energy capture (due to increased inertia with ferrites) is small. With similar generator efficiencies the differences in Cost of Energy comes from the relative cost in magnet materials.

References

1. S. Eriksson and H. Bernhoff, "Rotor design for PM generators reflecting the unstable neodymium price," in *Electrical Machines (ICEM), 2012 XXth International Conference on*, 2012, pp. 1419-1423.
2. K. Hart, A. McDonald, H. Polinder, E. Corr, and J. Carroll, "Improved cost of energy comparison of permanent magnet generator for large offshore wind turbines," *EWEA annual conference*,2014.