Wind Turbine Generators with Reduced Reliance on Rare Earth Magnets

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Introduction

- Motivation and goal
  - Recent volatile trends in the rare earth supply chain have been observed.
  - Powerful rare earth permanent magnets (REPM) are the key ingredients to many modern, highly-efficient wind turbine generators (WTG).
  - In this three-year project, finding the best wind turbine topology to use in the event that REPM usage becomes impractical is the ultimate goal.
- Strategy
  - Establish the baseline performance of wind turbines employing REPM.
  - Optimize some alternative generators and compare to the baseline results.
  - Pick a winner, and verify the concept through design and construction of a scaled prototype.

Wind turbine drivetrains: to gear, or not to gear?

- Many drivetrain configurations are currently being marketed:
  - High-speed gearing (classic solution)
  - Direct-drive (newer)
  - "Hybrid" drivetrain (newest)

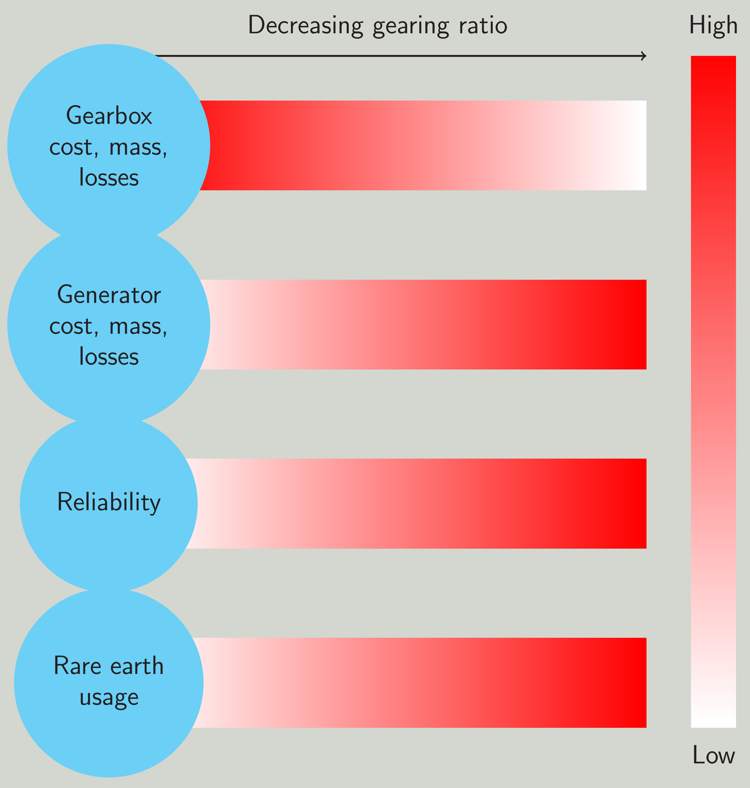
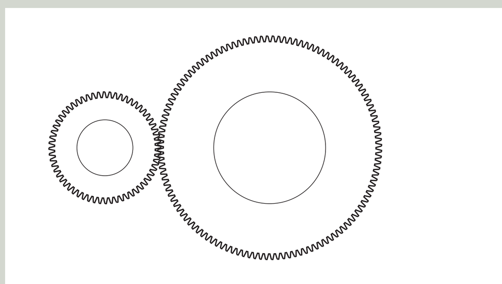
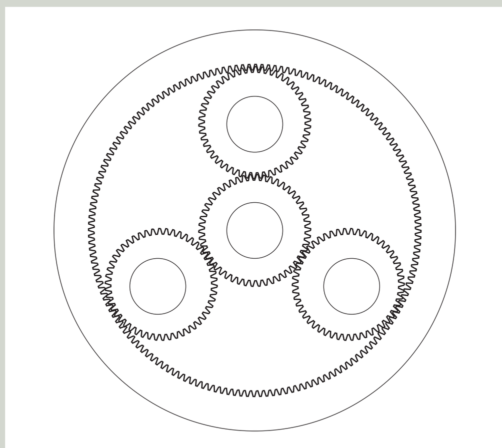


Figure 1 : Generalized trends. Note that little information on reliability of modern commercial wind turbines is available.

- Wind turbine gearboxes can be very reliable, however reducing the number of stages or removing the gearbox may increase the overall system reliability.



(a) Parallel stage



(b) Planetary stage

Figure 2 : Wind turbine gearboxes are composed of one or more planetary or parallel stages.

- A "hidden cost" associated with the direct-drive concept is the need for a robust support structure to maintain the air gap.

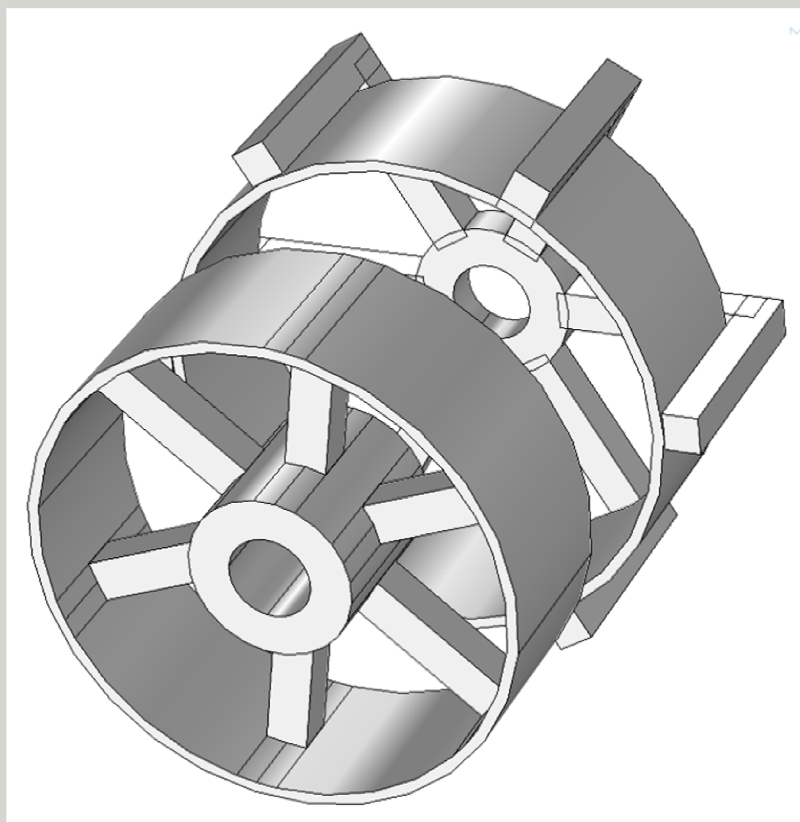


Figure 3 : Examples of support structures for a rotor and stator of a direct-drive wind turbine

- Air gap deformation should be limited to 10-20%, which presents a significant challenge.

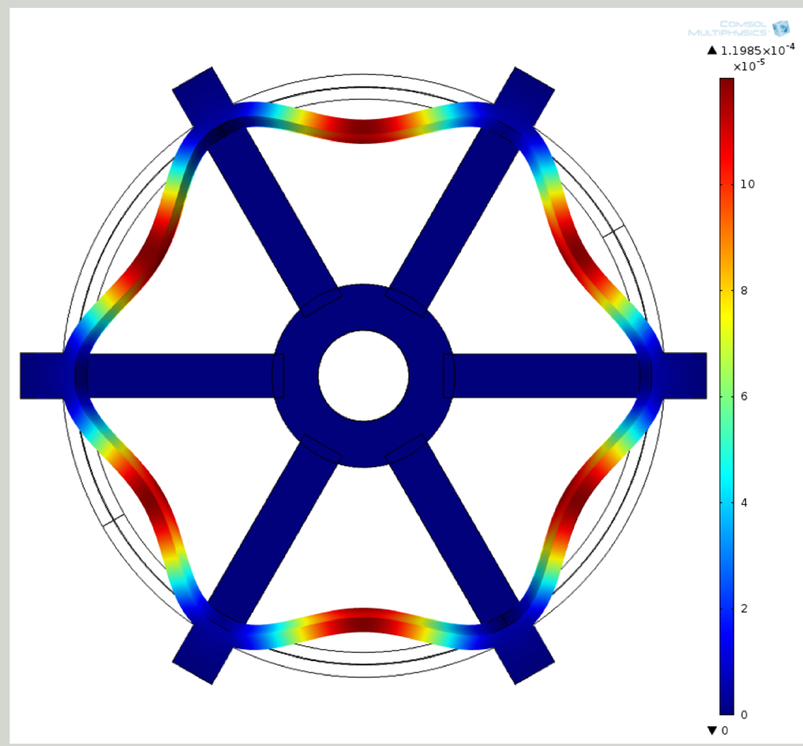


Figure 4 : Estimated displacement (m) due to attractive force between rotor and stator of a direct-drive wind turbine

Baseline study: synchronous machines with REPM

- Advantages:
  - Torque density
  - High efficiency at partial load
- Disadvantages:
  - Rare earth prices
  - Demagnetization can occur.

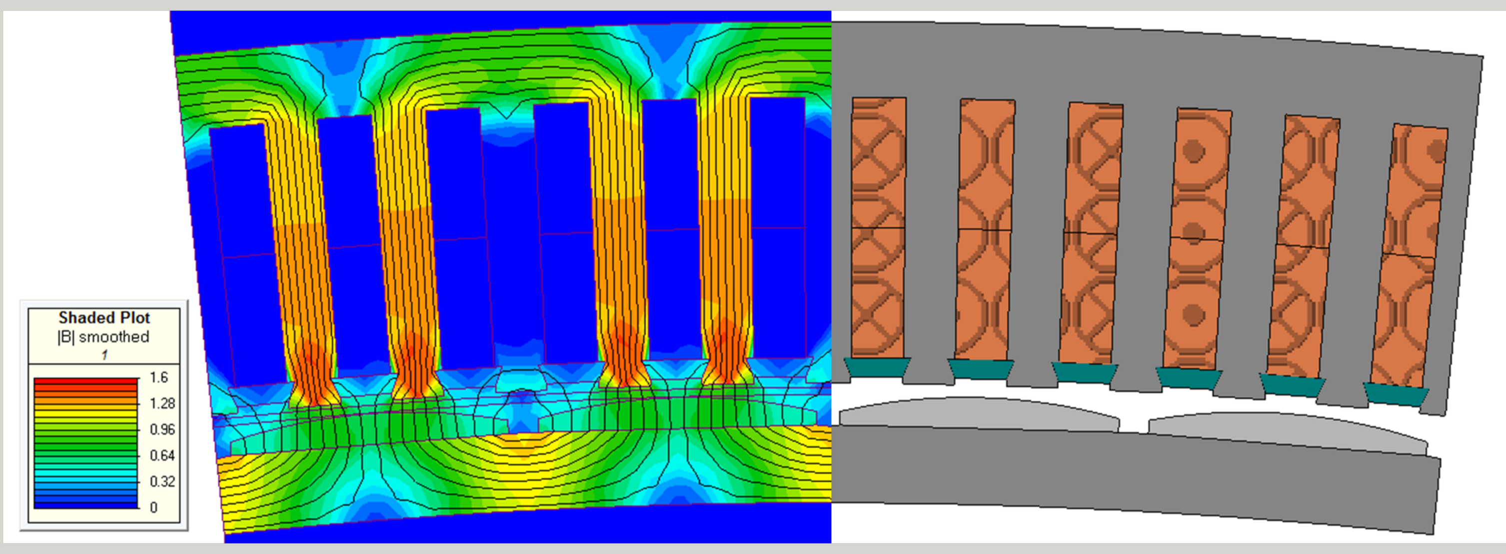


Figure 5 : Cross sectional view of a 3MW DDPMSG. Radius at air gap is 2.3m, length is 1.6m, rated torque is 1.9MNm. Plot on left shows flux lines and flux density at no-load.

Synchronous reluctance machines

- Advantages:
  - No magnets
  - Potentially a robust construction
- Disadvantages:
  - Poor power factor
  - Torque ripple may be an issue.

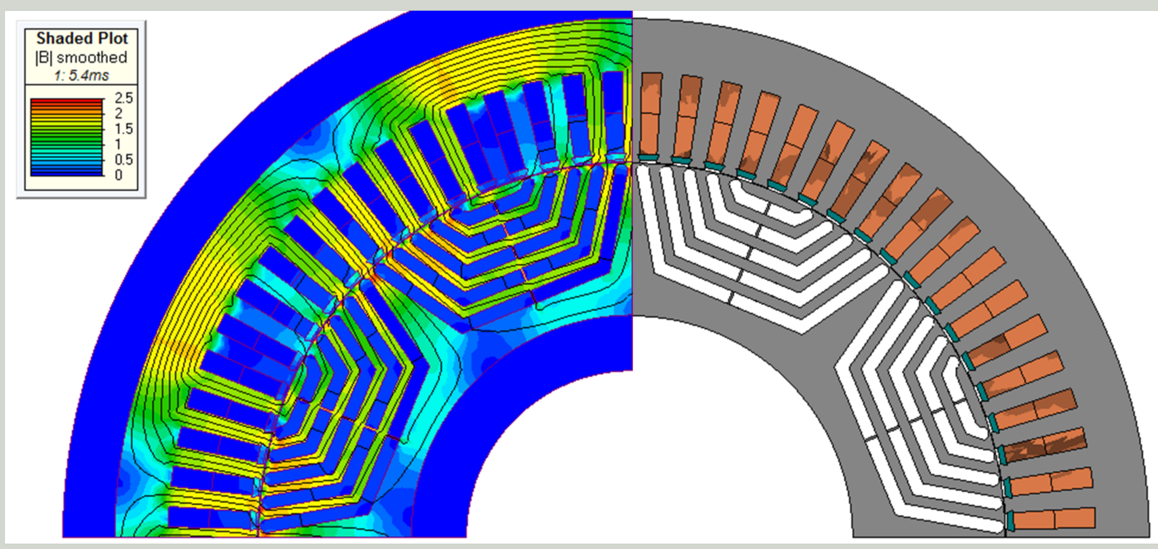


Figure 6 : Cross sectional view of a 3MW SynRM. Radius at air gap is 0.7m, length is 0.8m, rated torque is 28kNm. Plot on left shows flux lines and flux density at full-load.

Synchronous machines with ferrite magnets

- Advantages:
  - Ferrite magnets are low in cost.
  - Flux concentrating arrangements can be used to generate a high flux density in the air gap.
- Disadvantages:
  - Machine is likely to be heavier.
  - May be more sensitive to demagnetization currents

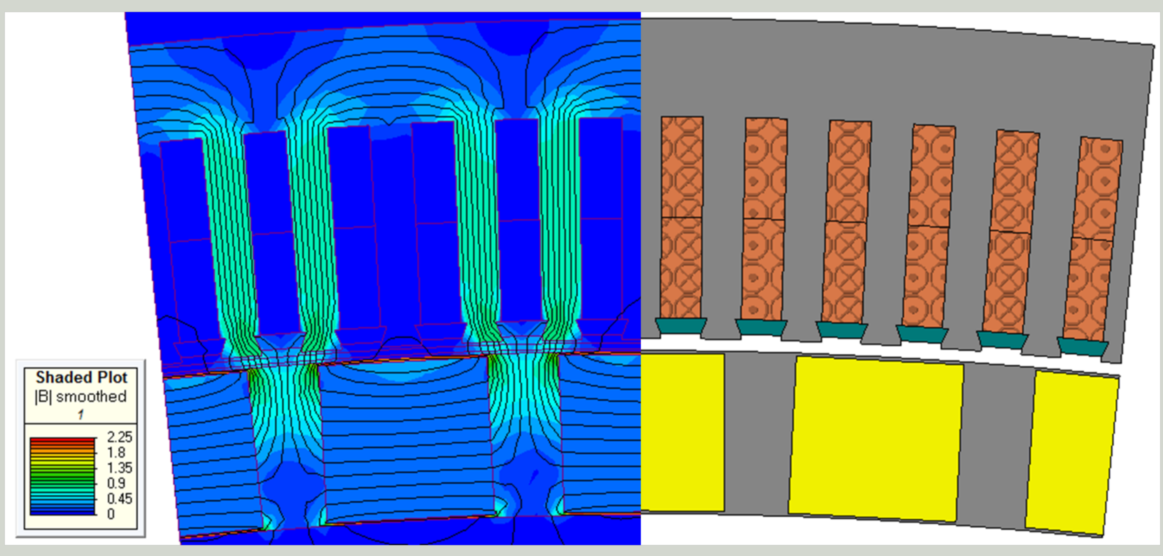


Figure 7 : Ferrite magnets arranged in a spoke manner can produce an air gap flux density higher than their remanent flux density, which is likely to be 0.3-0.4 Tesla.

Future Work

- Consider additional generator concepts:
  - Induction machines
  - Electrically-excited synchronous machines
  - Others?
- Endorsement of best option or options
- Construction and testing of scaled prototype

Acknowledgement

- Thanks to DONG Energy for their contributions in funding and advising of this project.
- Testing of the prototype machine will take place at PowerLabDK.