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Design of Large Scale Permanent Magnet Synchronous Generators for Wind Turbines

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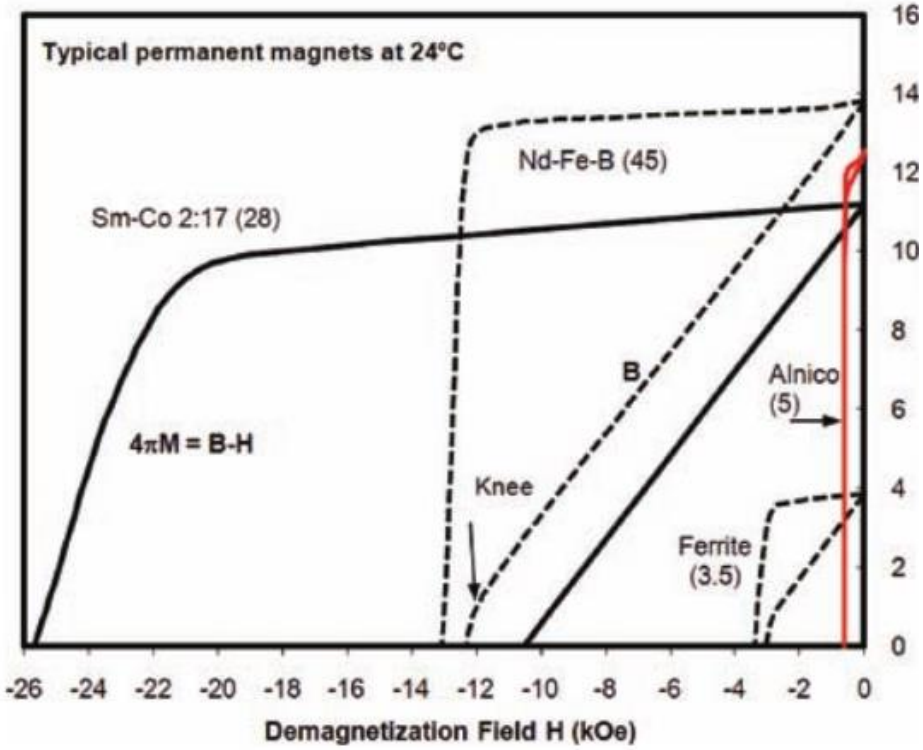
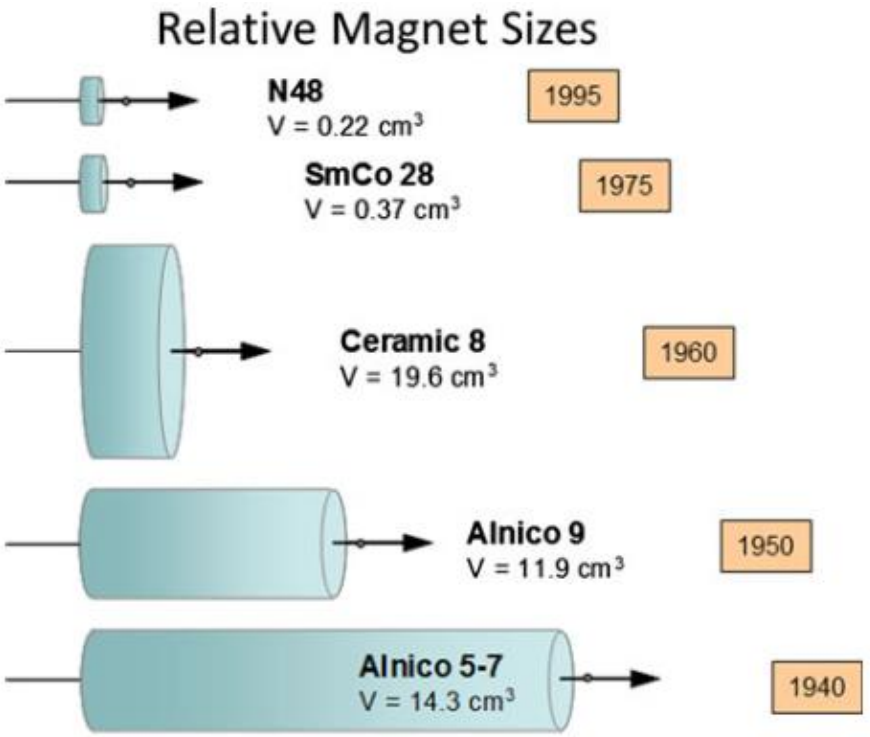
MAGNETICS RESEARCH GROUP

Permanent Magnets

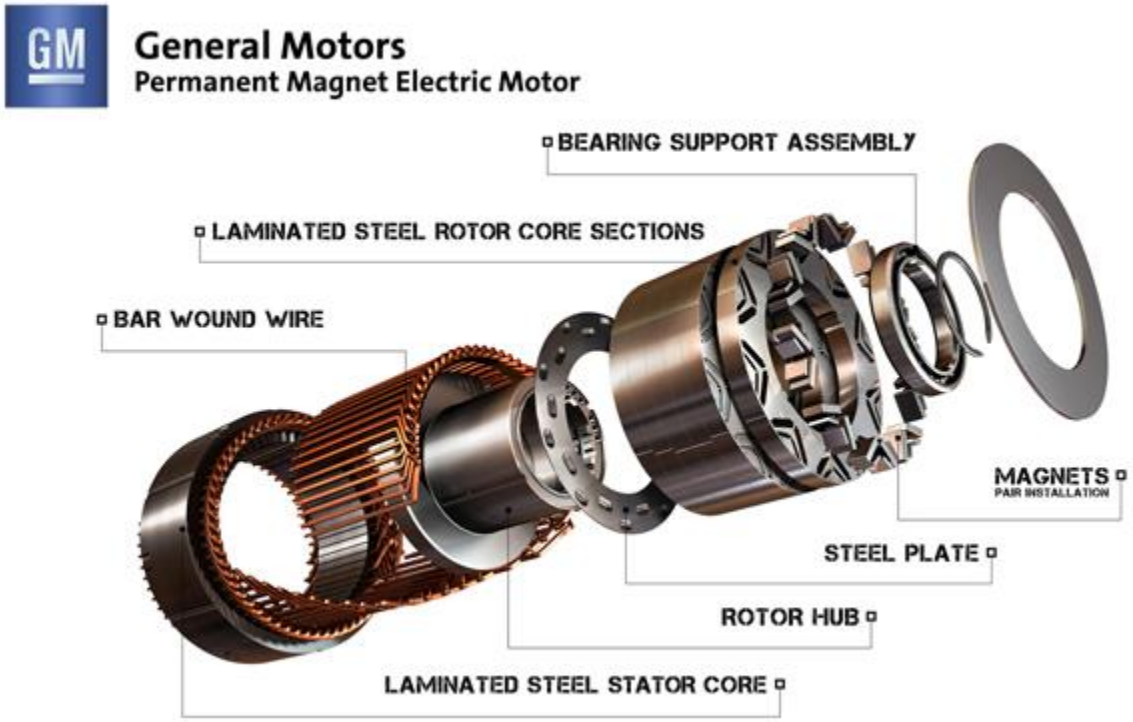


Source: O. Gutfleisch *et al. Adv. Mater*. 23, 2011, 821-842.

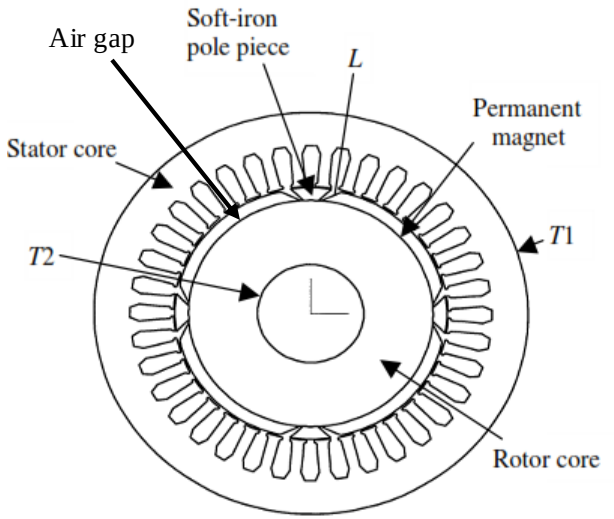


Source: Arnold Magnetic Technologies

Permanent Magnet Synchronous Generators (PMSGs)



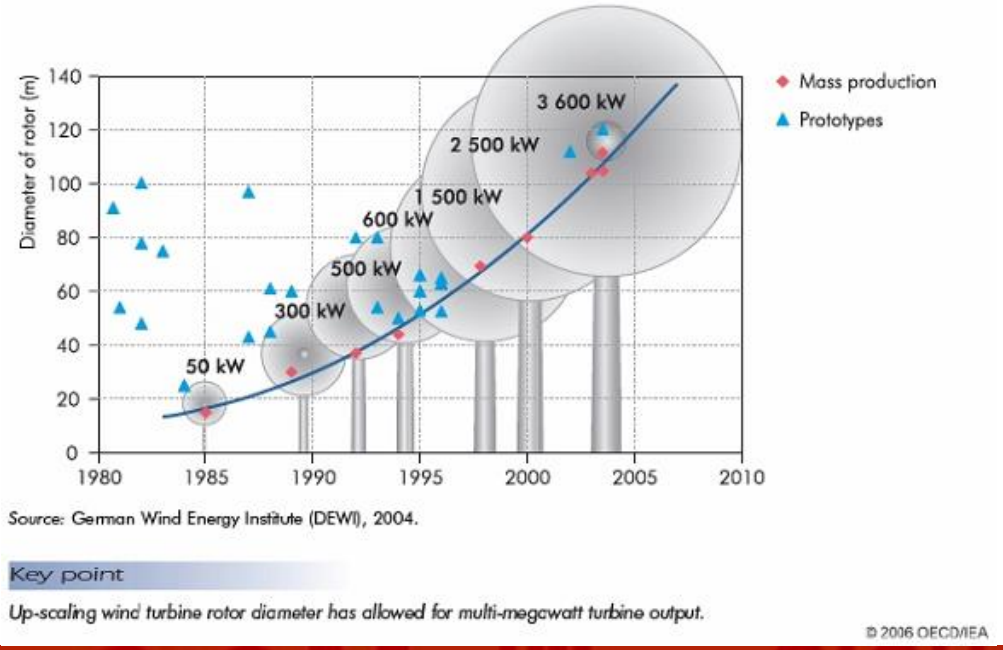
Source: http://www.digikey.com/en-US/articles/techzone/2012/sep/ev-drive-electronics-evolve-to-support-rare-earth-free-motor-technologies

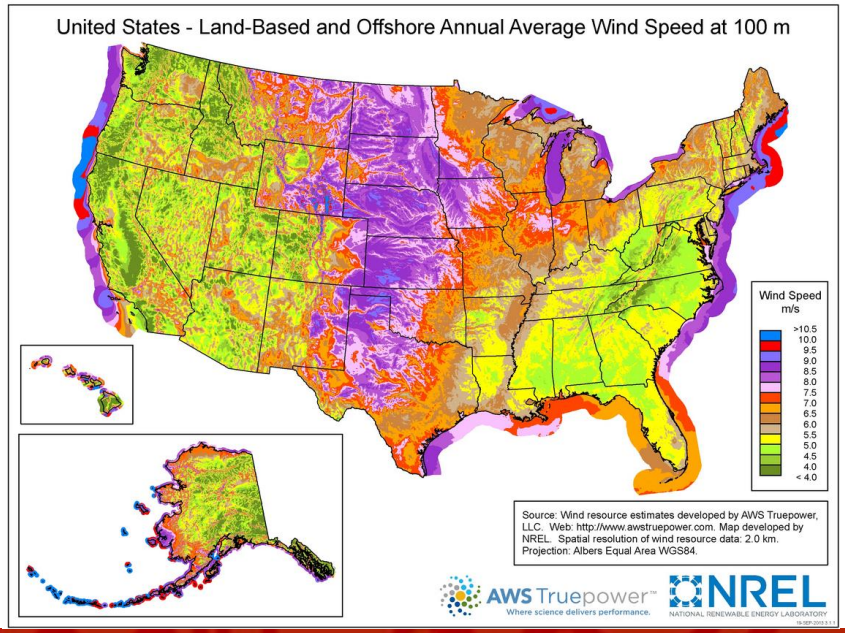


Source: T. Chan. *Power Engineering Society (PES) General Meeting, IEEE,* Tampa, FL, 2007, 1-6.

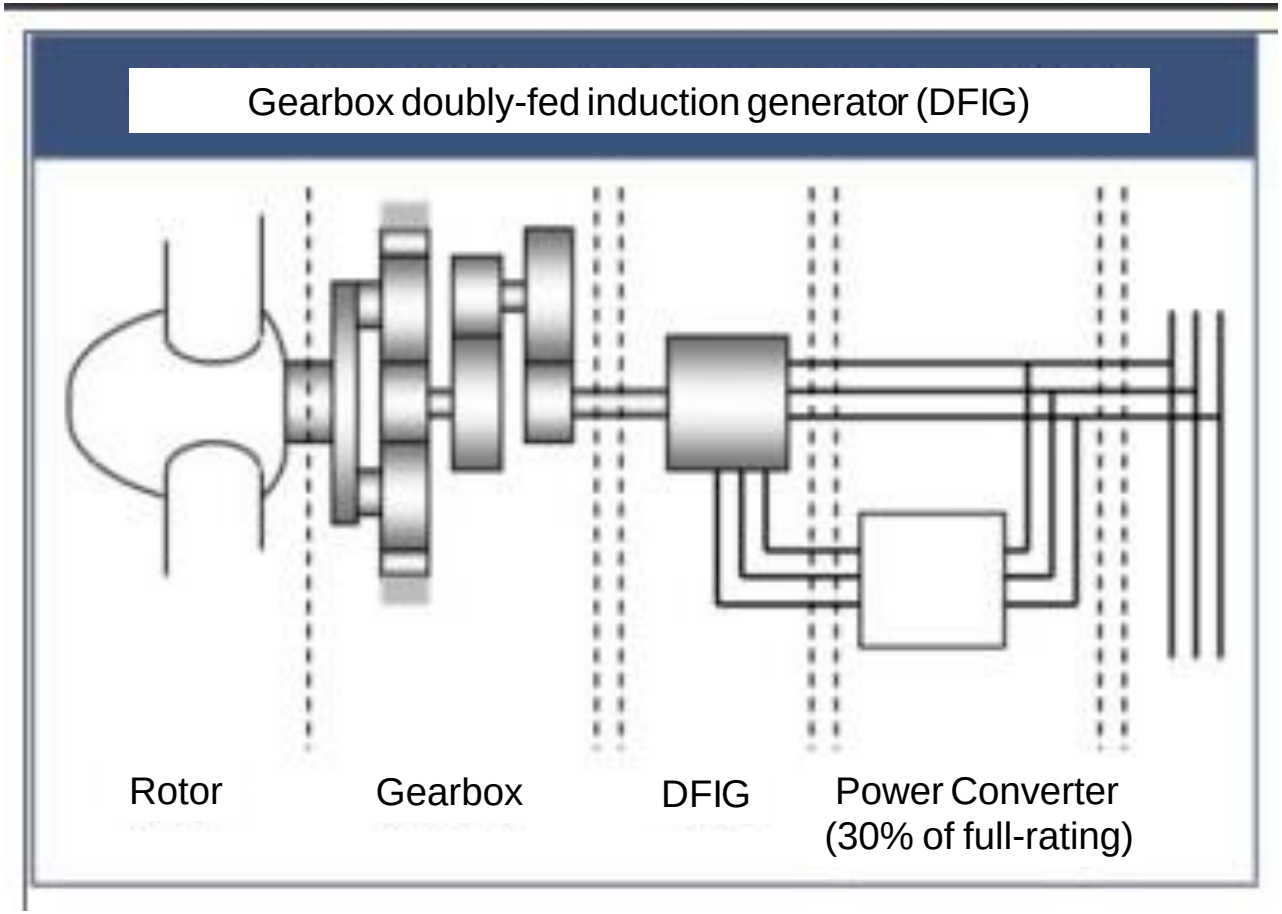
Problem Definition

- ~~Previously: Efficiency improvements of PMSGs by investigation of magnetic materials~~
- 20% wind energy electricity generation by 2030 proposed by Department of Energy
- Revisited: Innovative design of 10MW PMSG



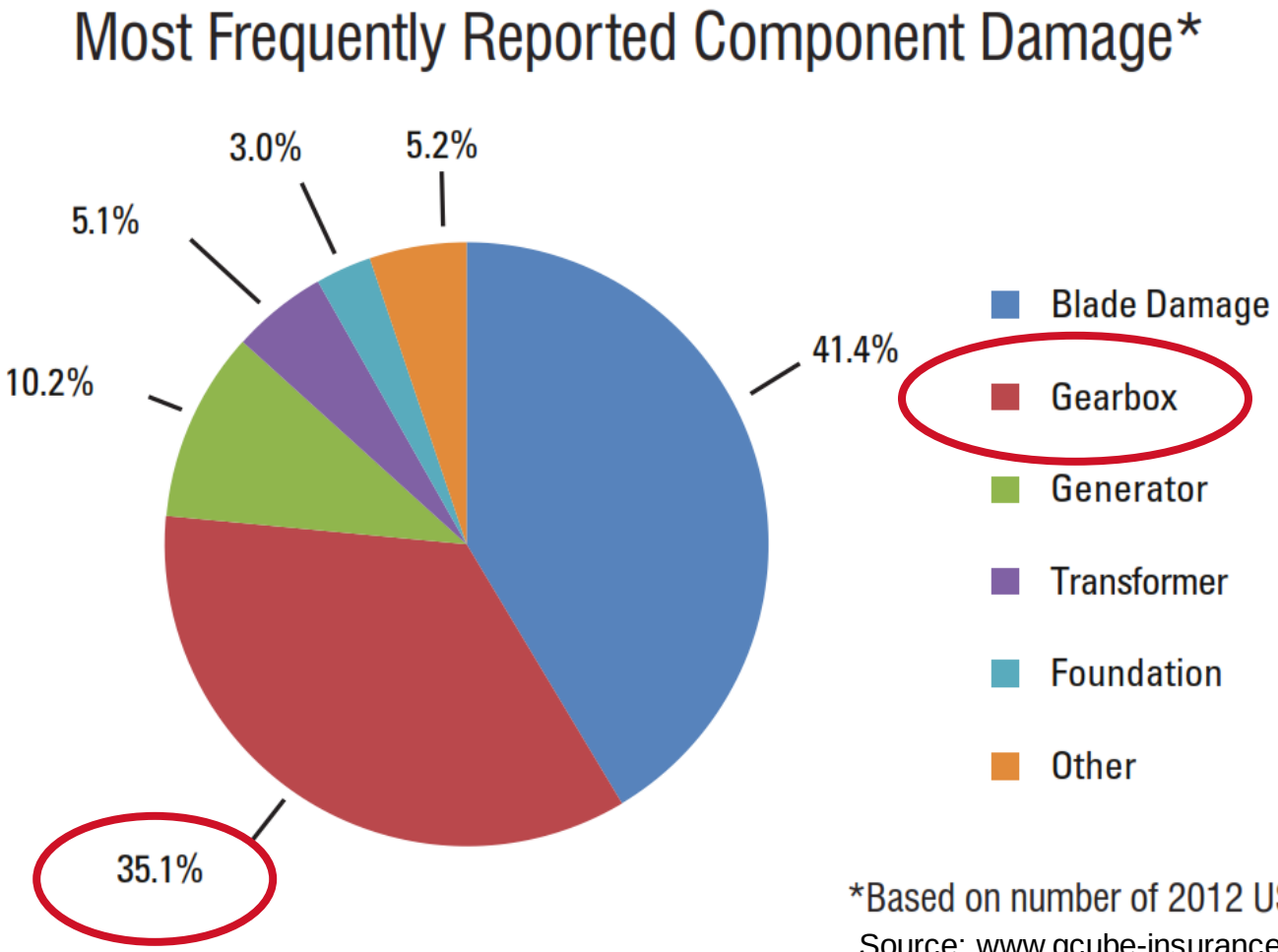


Doubly-Fed Induction Generators (DFIG)



Source: http://www.goldwindamerica.com/technology-capabilities/pmdd/

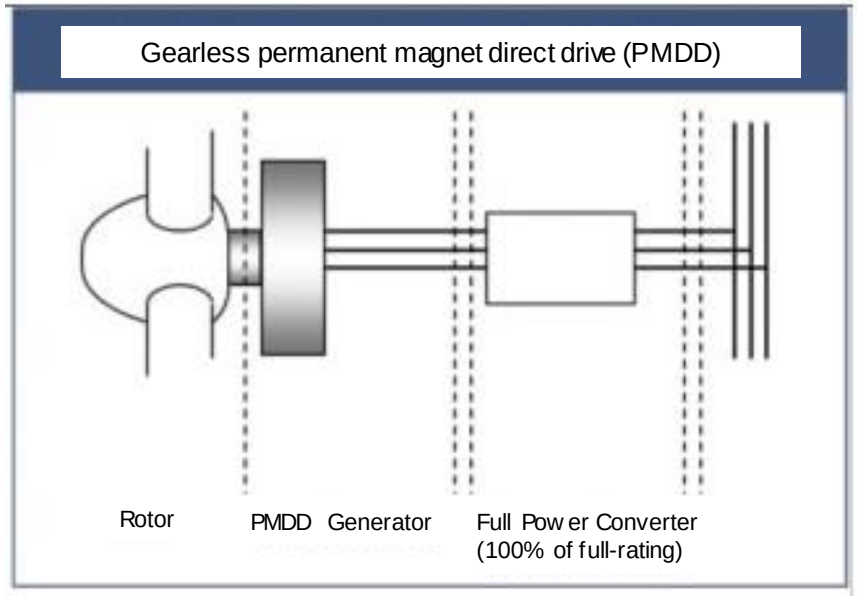
Wind Turbine Failure Rates



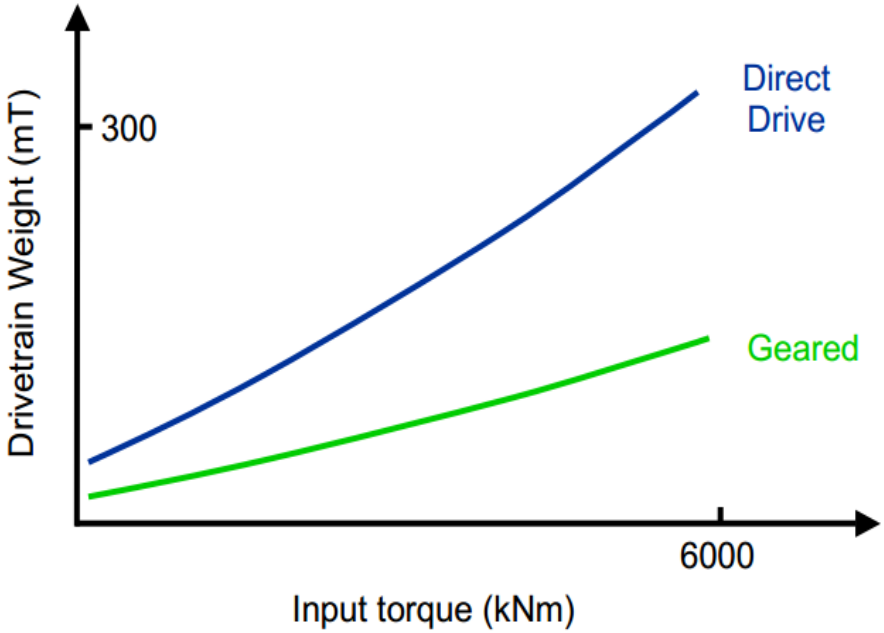
*Based on number of 2012 US reported claims

Source: www.gcube-insurance.com (Thanks Mat!)

Permanent Magnet Synchronous Generators



Source: http://www.goldwindamerica.com/technology-capabilities/pmdd/



Source: http://www.rpi.edu/cfes/news-and-events/Wind%20Workshop/Development%20Challenges%20of%20PM_Generator_RPI_Qu_v8.pdf

Problem Definition

- At 5.5MW Rated Power
  - Cost of Generator
    - PMSG ~ 1.3 times the cost of DFIG
    - PMSG < DFIG *including gearbox replacement*
- At 10MW Rated Power
  - Weight of PMSG becomes prohibitive

$$P \propto (T = KD^2L)$$

$$K = \frac{k_{wl}\pi^2}{4\sqrt{2}} \boldsymbol{B} A$$

P=power
T=torque
D=rotor diameter
L=stack length
B=average rotor surface flux density
A=electrical loading

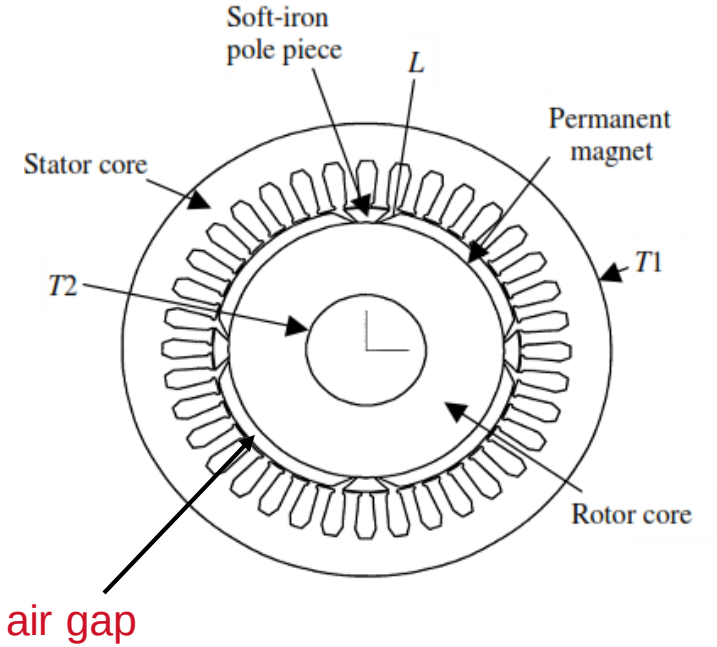
Can rotor surface flux density be increased to allow for a smaller generator?

Current Work

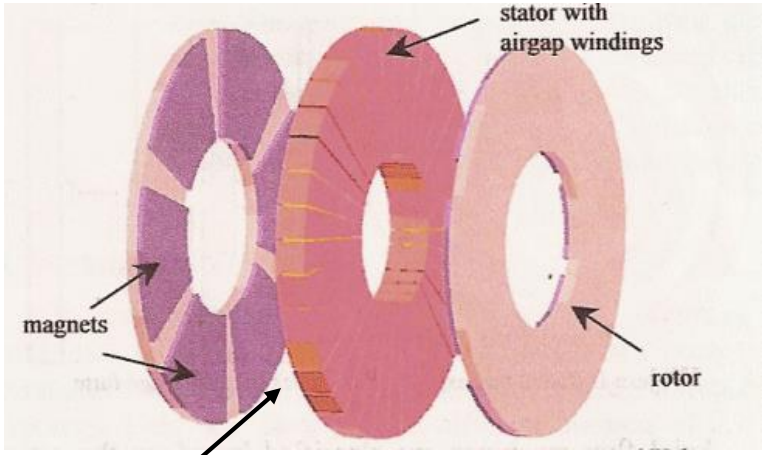
- Reduce weight of generator by 25%
  - **Reduce volume of permanent magnet?**
    - What are the theoretical magnetic properties to maintain power output with smaller permanent magnet volume?
    - Can this theoretical material allow for size reduction of the PMSG?

$$P \propto [\, T = f(BD^2L) \,]$$

Design Choice: Air Gap Orientation



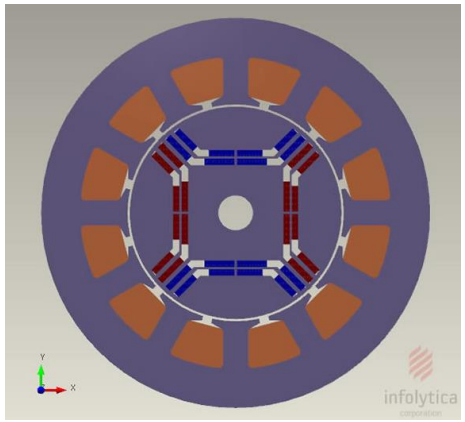
Radial



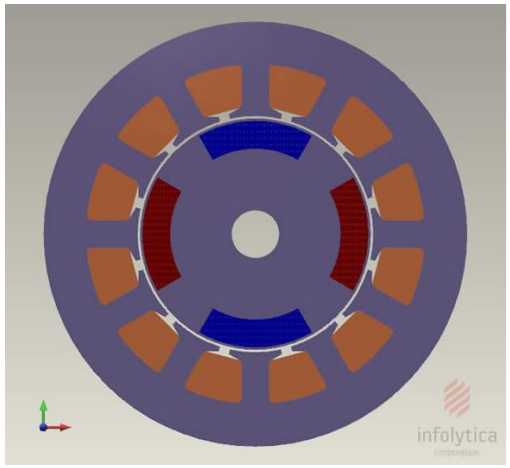
Axial

Source: Infolytica.com

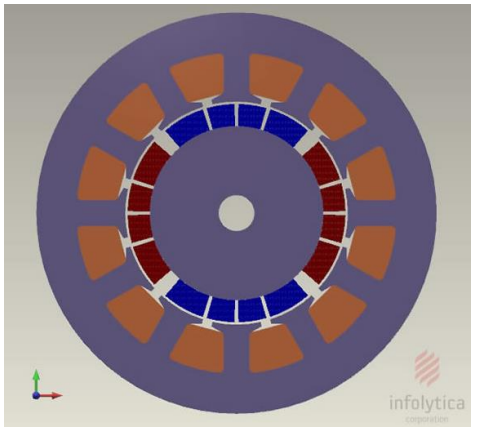
Design Choice: Permanent Magnet Topology



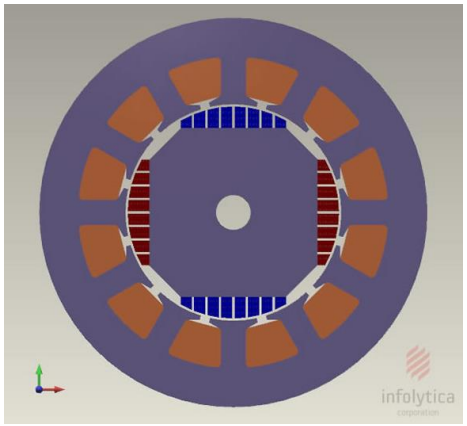
Interior



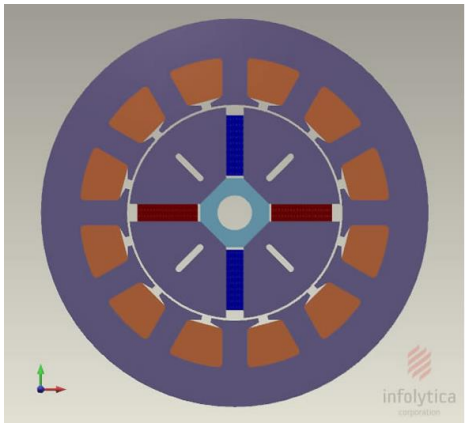
Inset



Surface mounted



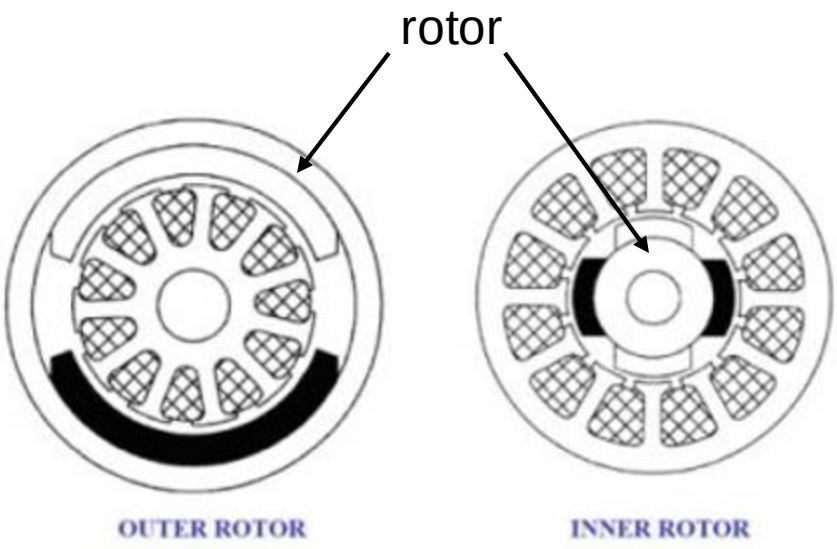
Bread loaf



Spoke

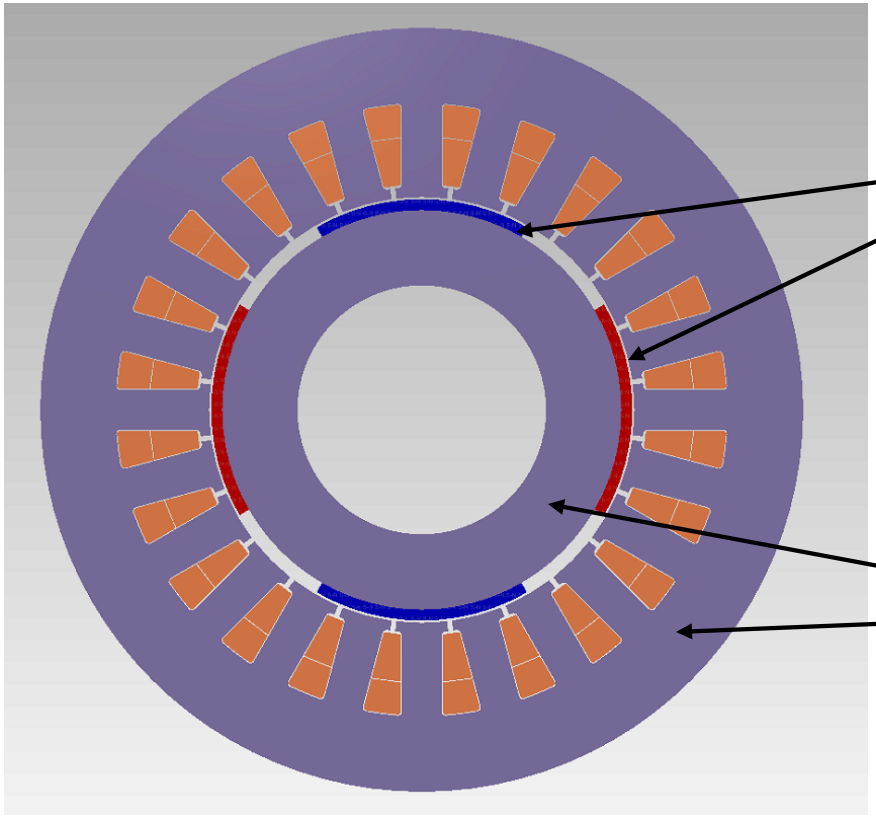
Selected Design Choices

- ABB Recommendations
  - **Inner** or outer rotor
    - Outer rotor preferred for direct-drive (size reduction advantages)
    - BUT use inner rotor for now (simpler)
  - Radial flux air gap
  - Surface mounted, inset or bread loaf permanent magnet topology
  - NdFeB permanent magnet grades:
    - N35SH
    - N35UH



Current Work

Radial, inner rotor, surface mounted PMG



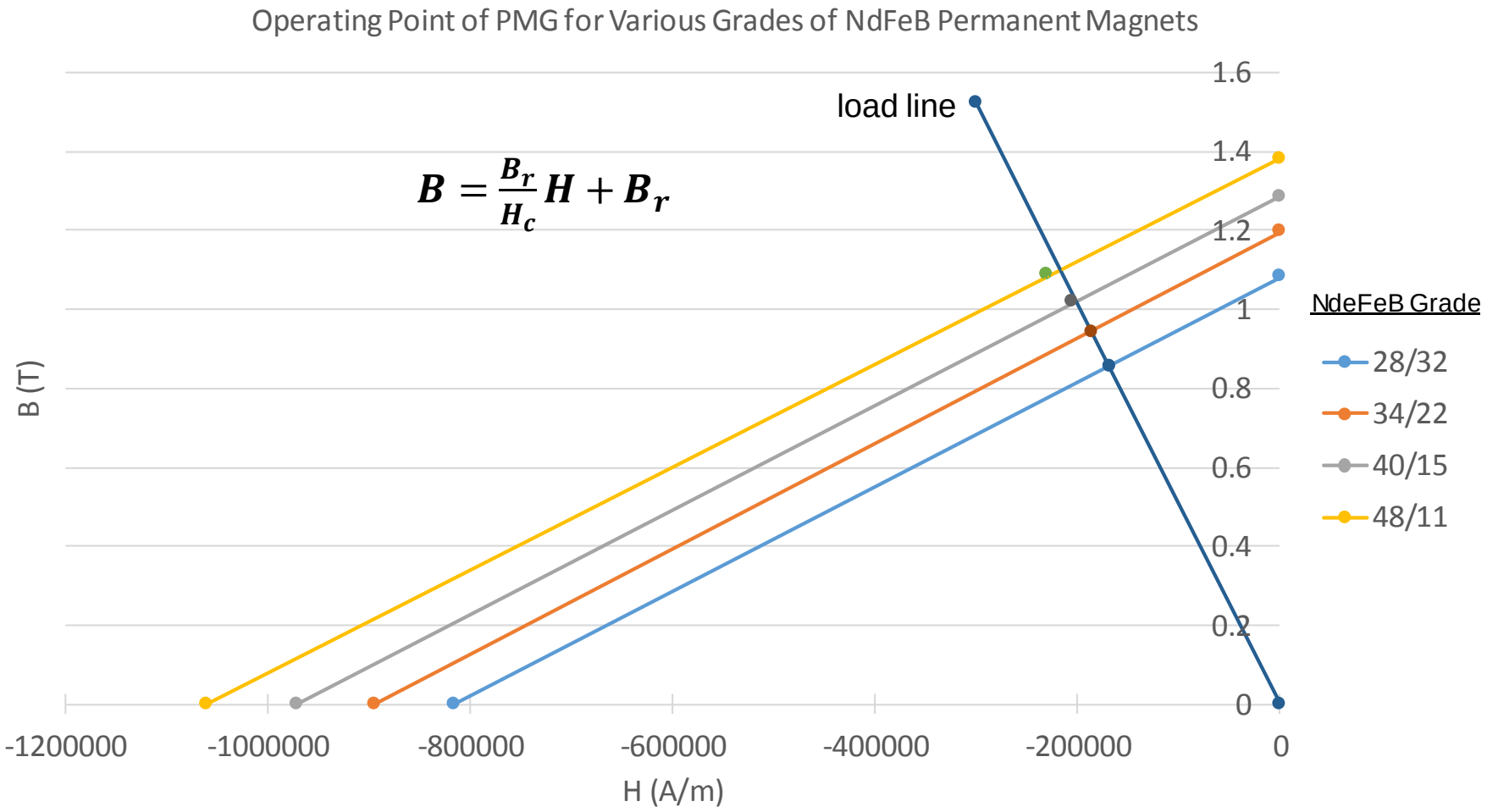
Material Properties of NdFeB Grades

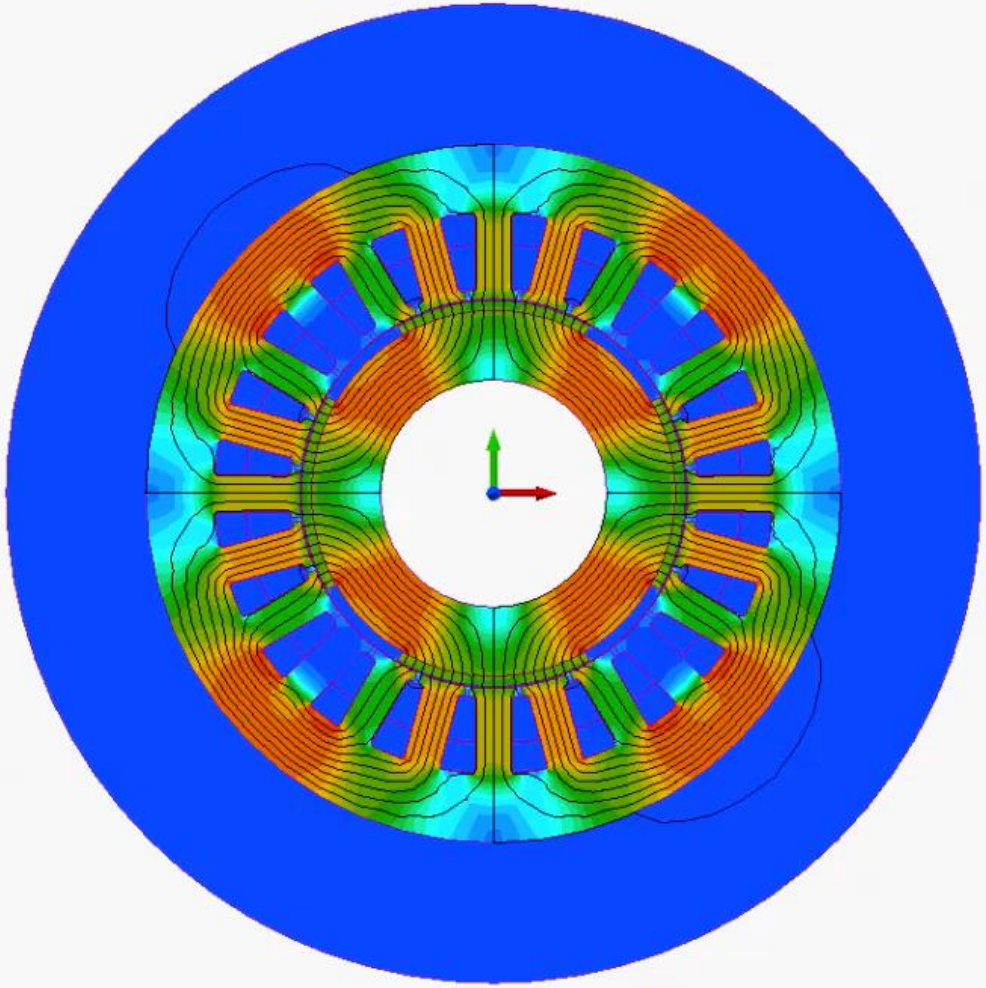
	NdFeB 28/32	NdFeB 34/22	NdFeB 40/15	NdFeB 48/11
B_r (T)	1.08	1.19	1.29	1.39
H_c (A/m)	-815539	-894591	-971014	-1060650
μ_r	1.05554	1.06427	1.05474	1.03967
$\lvert BH \rvert_{max}$ (kJ/m^3)	220.6	267.6	312.4	367.4

M19 26 Ga non-oriented Si-Fe

H. A. Khazdozian, R. L. Hadimani, D. C. Jiles, "Increased Efficiency of a Permanent Magnet Synchronous Generator through Optimization of NdFeB Magnet Arrays," presented at American Physical Society March Meeting 2014, Denver, CO., 2014.

Current Work




Shaded Plot
|B| smoothed
1
1.55236
1.24189
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0.620944
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Y
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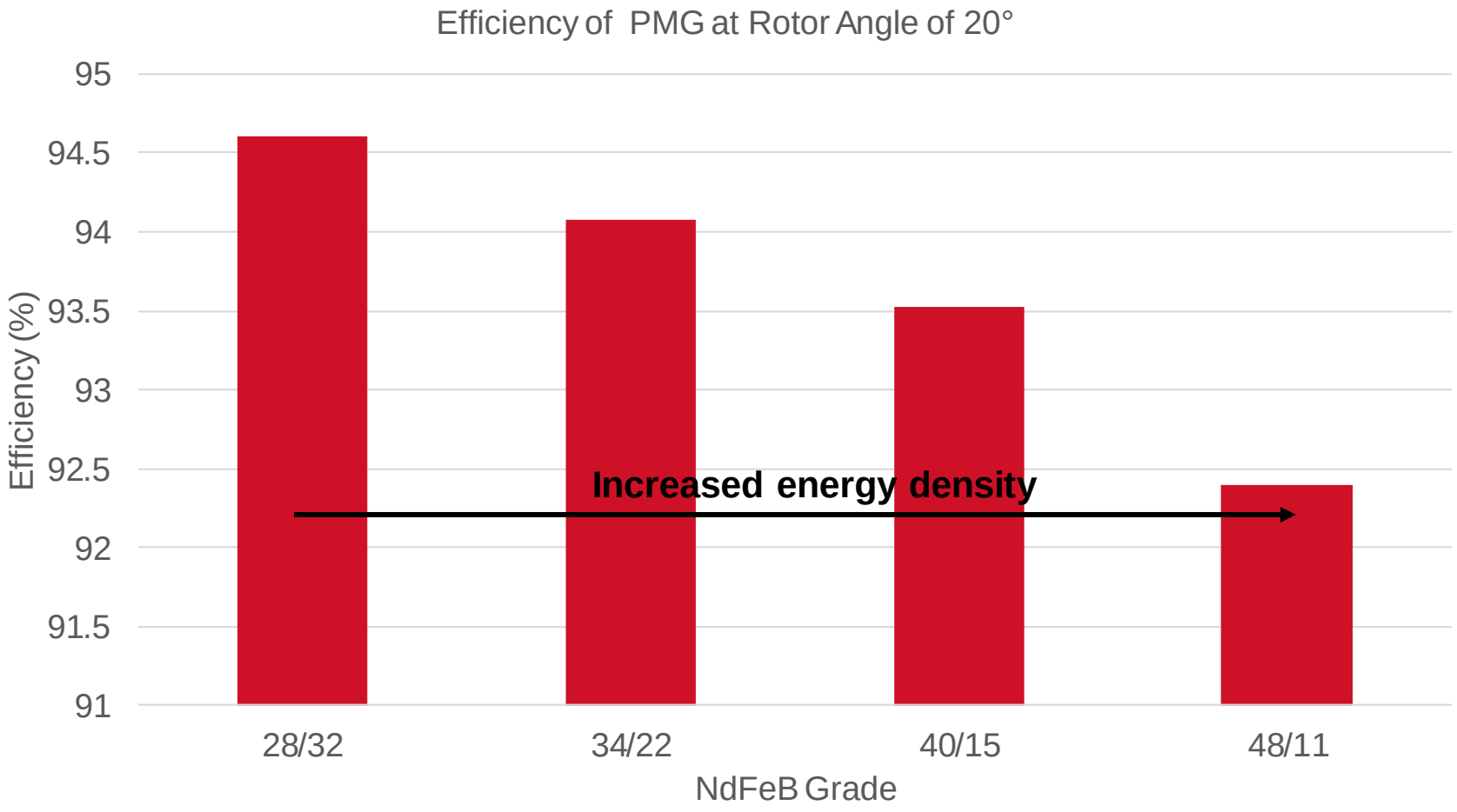
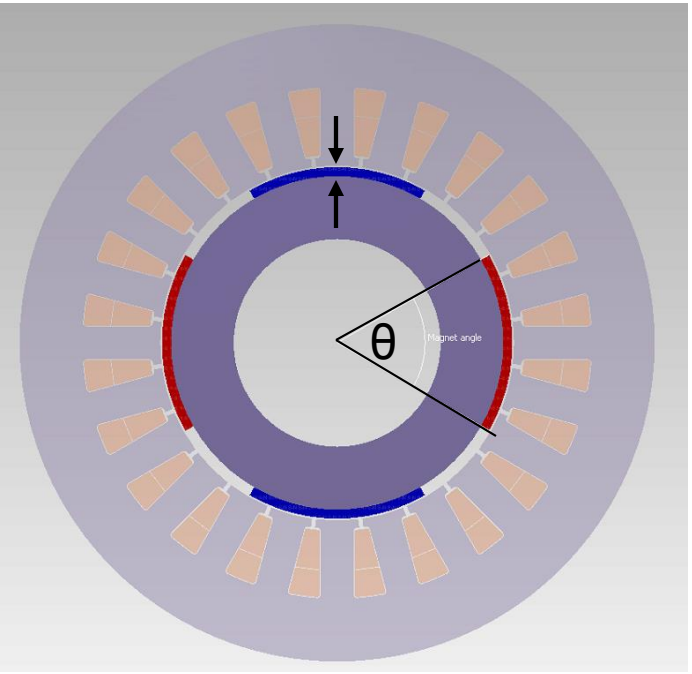
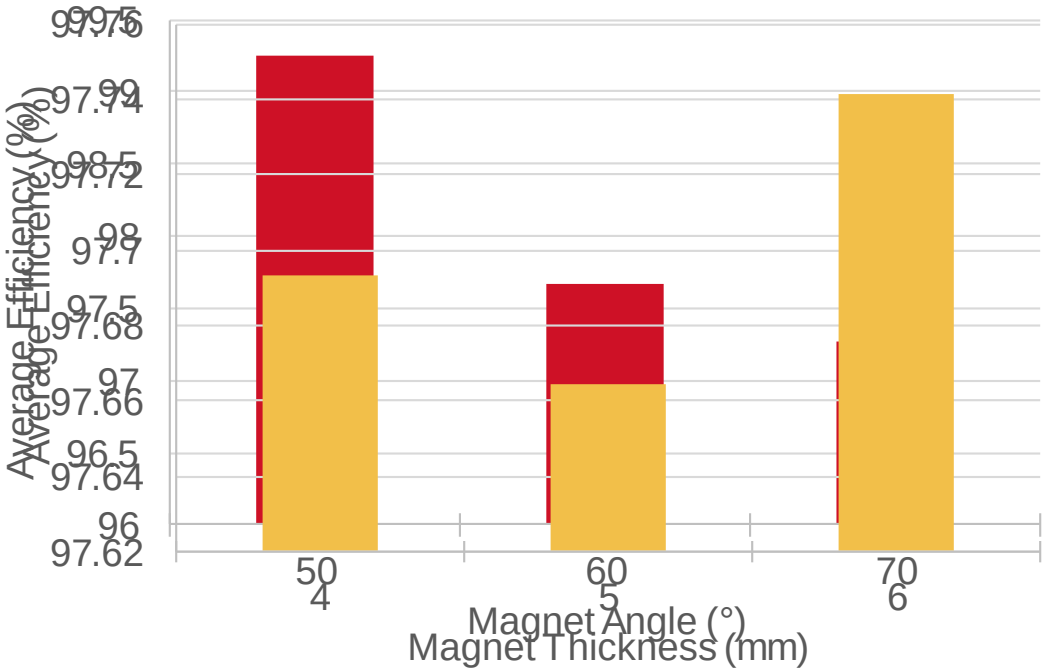
corporation
10.24.100.68
Research Edition

Results

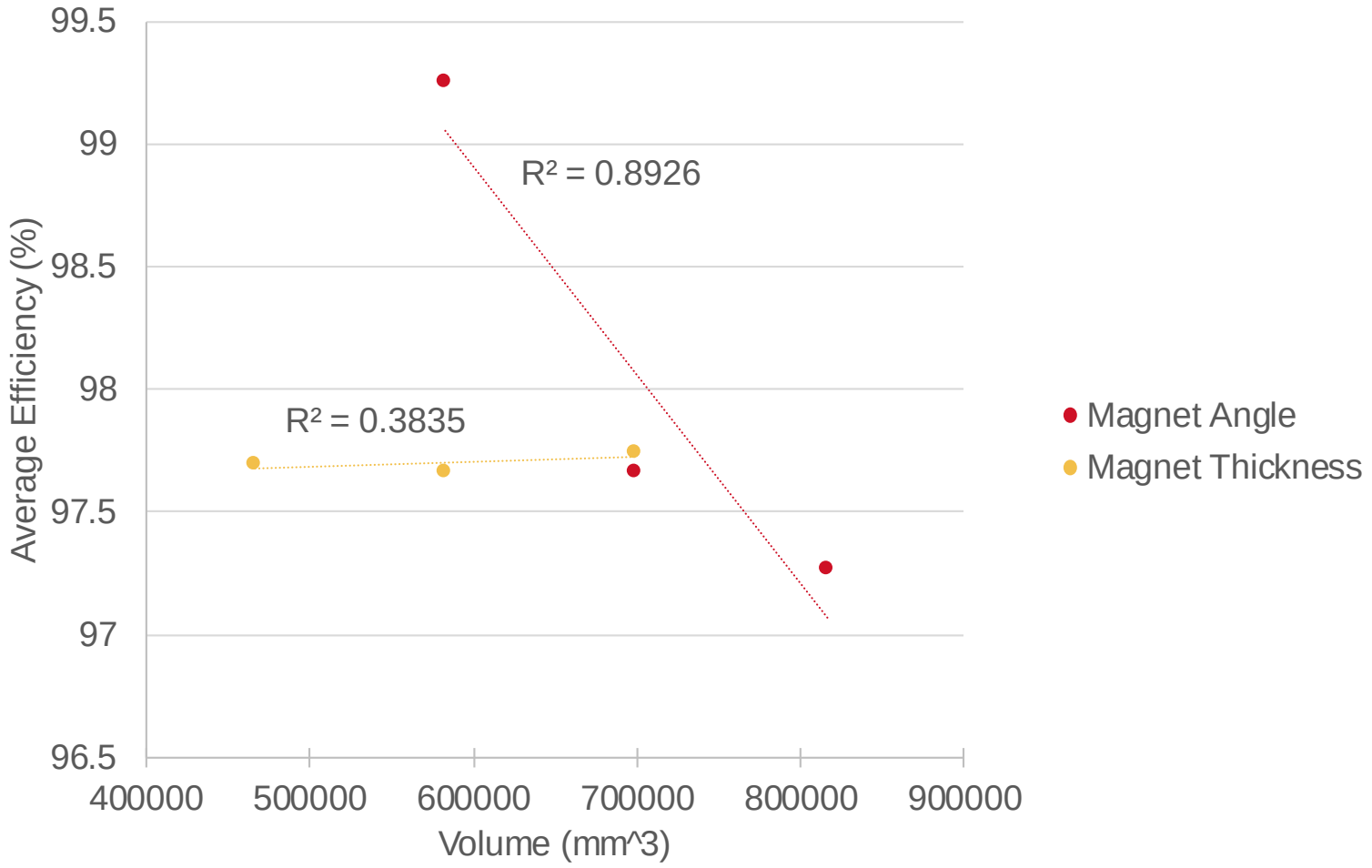

Efficiency of PMG at Rotor Angle of 20°
Efficiency (%)
95
94.5
94
93.5
93
92.5
92
91.5
91
Increased energy density
28/32
34/22
40/15
48/11
NdFeB Grade

Optimization



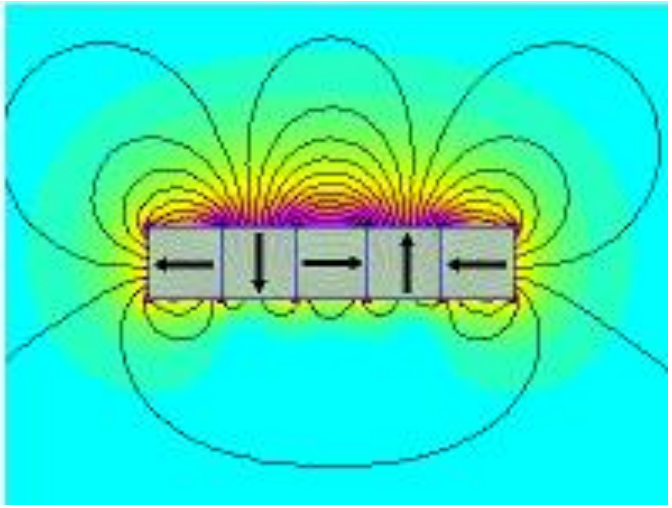


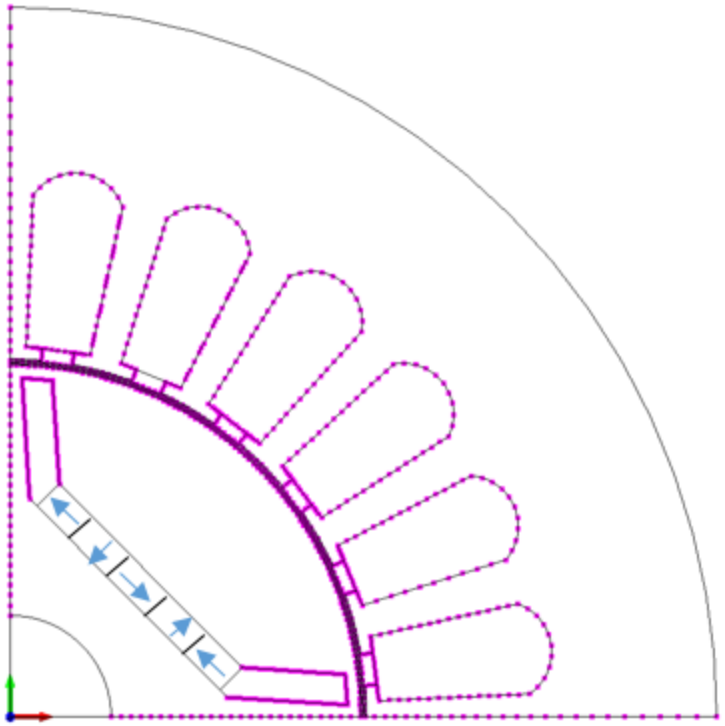
Implications



Future Work

- Influence of rare earths on stock market performance of wind energy
- Traction Motors
  - Suggestion from ABB
- Halbach Arrays
  - Could be used to focus flux





References

1. O. Gutfleisch *et al.* "Magnetic Materials and Devices for the 21st Centuery: Stronger, Lighter, and More Energy Efficient," *Adv. Mater*. 23, 2011, 821-842.
2. L. H. Lewis, F. Jiménez-Villacorta. "Perspectives on Permanent Magnetic Materials for Energy Conversion and Power Generation," *Metallurgical and Materials Trans. A 44A*, 2013, S2-S20.
3. T. Chan. "Permanent-Magnet Machines for Distributed Power Generation: A Review," *Power Engineering Society (PES) General Meeting, IEEE,* Tampa, FL, 2007, 1-6.
4. D. C. Hanselman. *Permanent-Magnet Motor Design*. McGraw-Hill Inc., New York, 1994.
5. J. R. Hendershot Jr., TJE Miller. *Design of Brushless Permanent-Magnet Motors*. Magna Physics Publications and Clarendon Press, Oxford, 1994.
6. H. A. Khazdozian, R. L. Hadimani, D. C. Jiles, "Increased Efficiency of a Permanent Magnet Synchronous Generator through Optimization of NdFeB Magnet Arrays," presented at American Physical Society March Meeting 2014, Denver, CO., 2014.

Thank you for your time

Questions?