New Generator Technology for offshore wind turbins

Presented by : Professor Rober Nilssen (NTNU)

Deepwind 2014

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Totally five types of generators are used in offshore wind farms

- Doubly-Fed induction Generator (DFG),
- Squirrel-Cage induction Generator (SCG),
- Wound-Rotor induction Generator (WRG),
- Permanent Magnet synchronous Generator (PMG)
- Electrically-Excited synchronous Generator (EEG)

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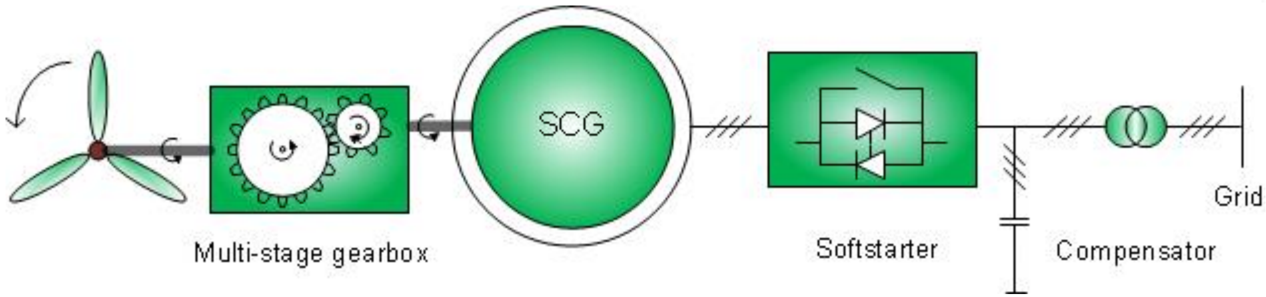
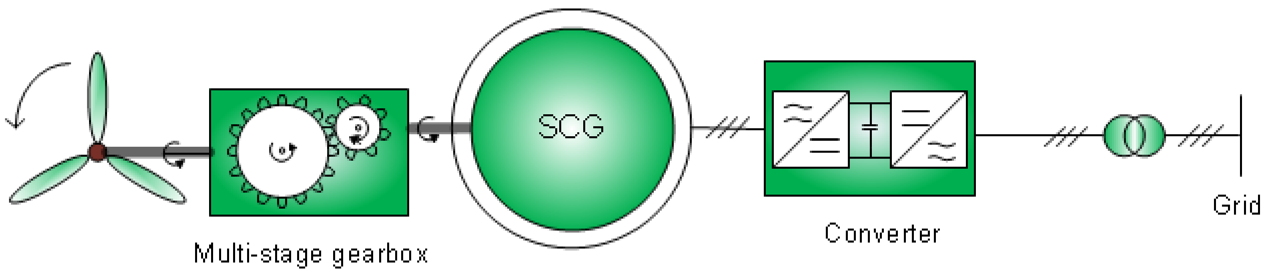
Gear /generator/converter concepts





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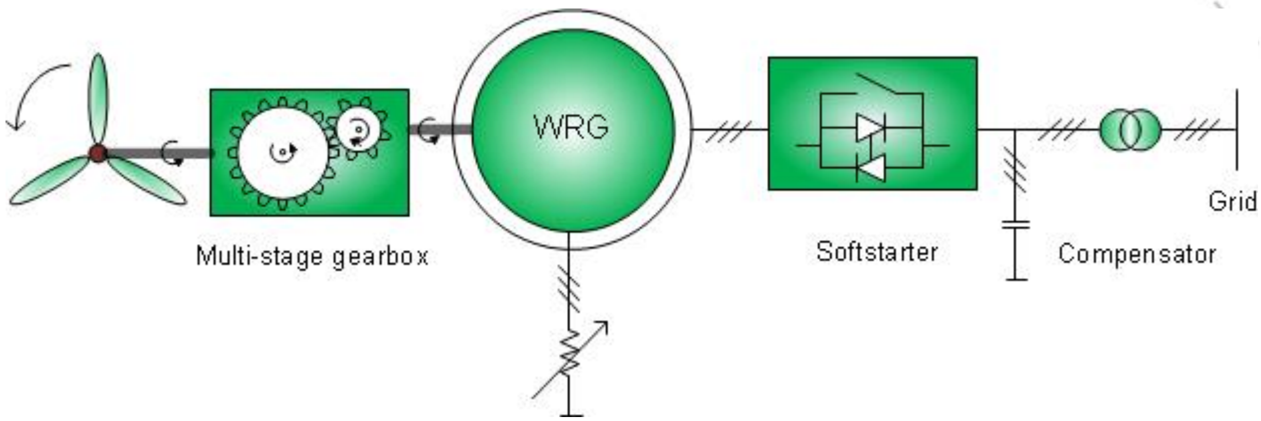

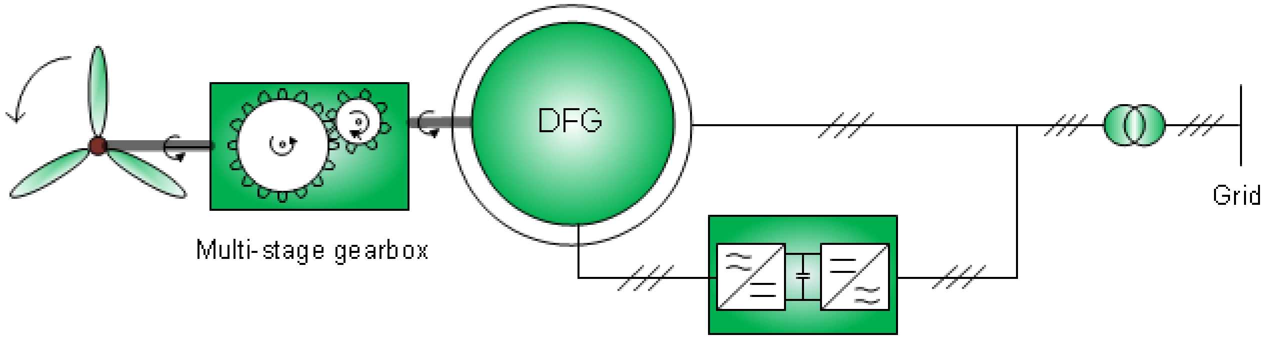

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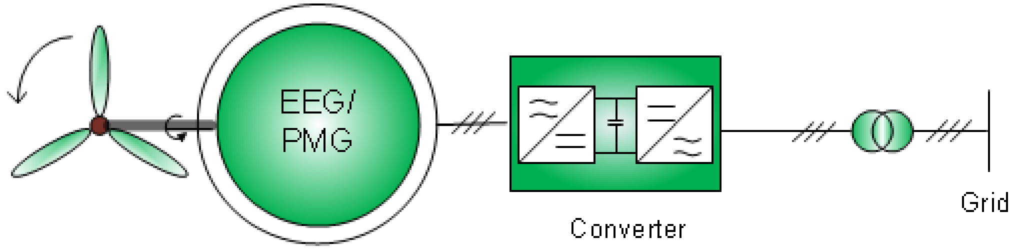

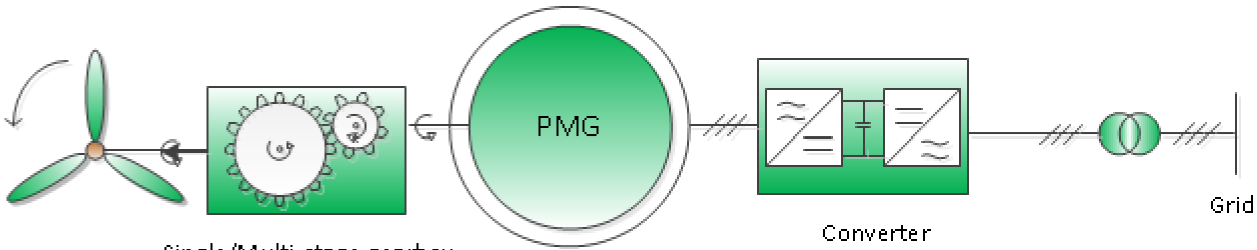

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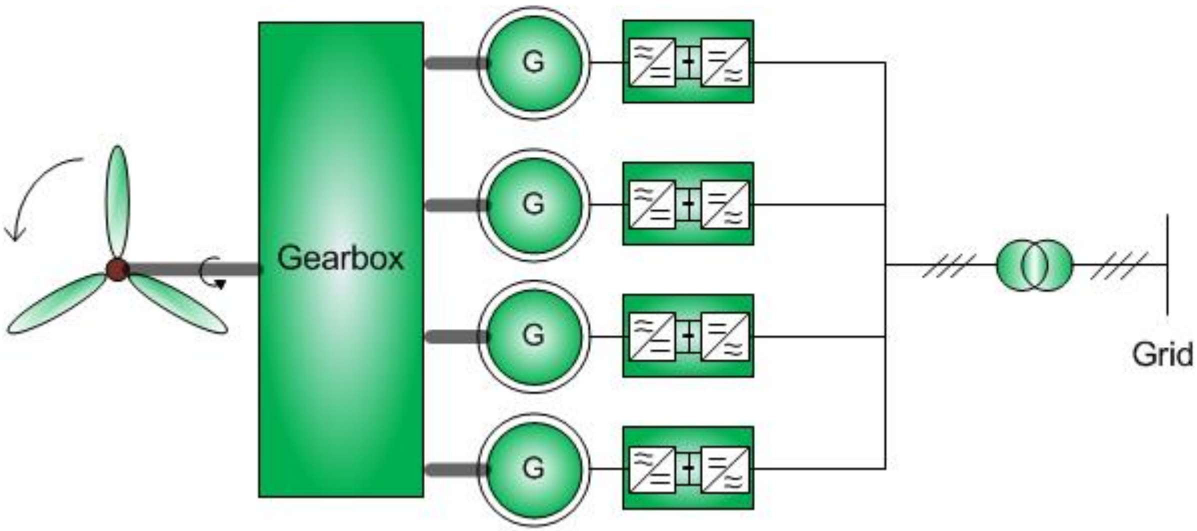
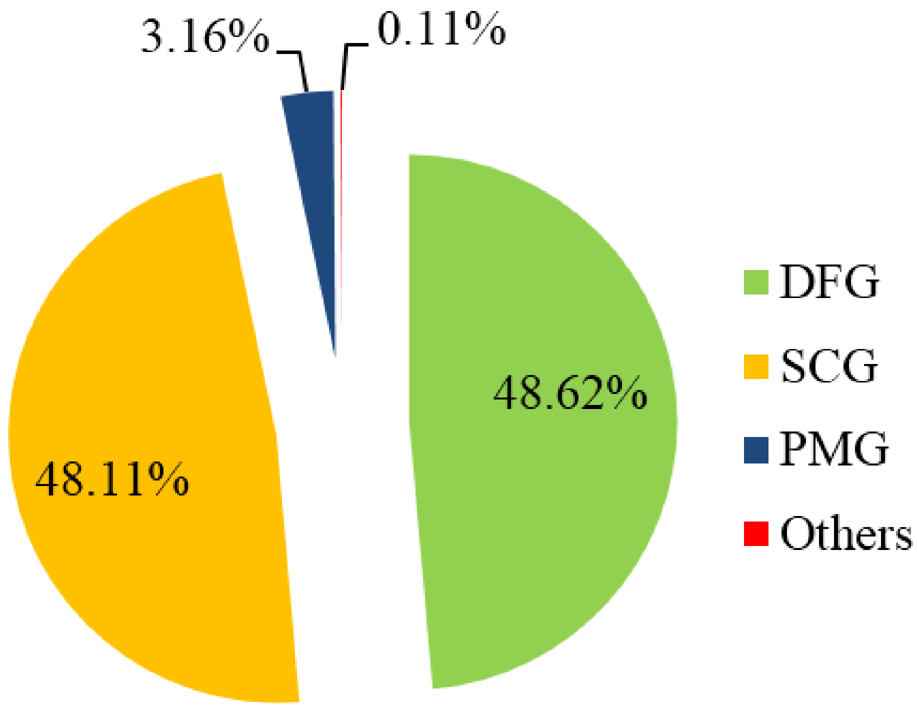
Gear /generator/converter concepts



Usage of generators



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Still focus on Direct Drives

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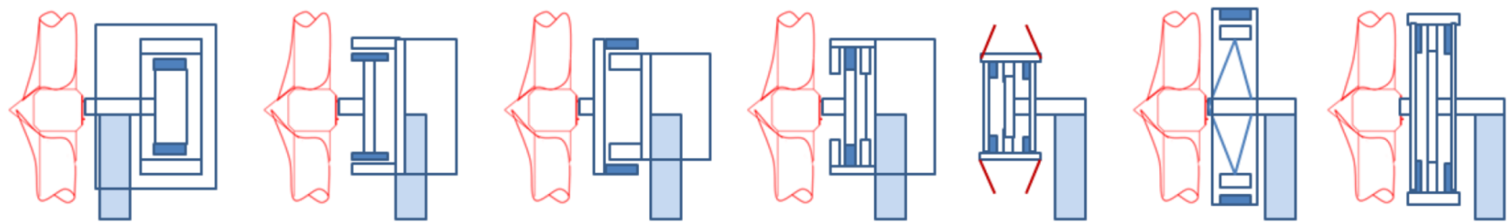
Integrated designs in focus

	Behind tower	Between blades&tower				No nacelle	
	Radial flux with iron cores			Axial-flux with iron cores		Ironless (air core)	
	Inner rotor, "stand-alone"	Integrated machine: Inner rotor	Integrated machine: Outer rotor	"stand-alone"	Integrated with blades	1 rotor, 1 stator	2 rotors, 1 stator
Companies →	GE, TheSwitch	Leitner, Vensys, Harakosan	TheSwitch, Siemens	Jeumont		NGenTech	
Cooling ↓							
Stator							
Liquid cooling	x	x	x	x	x	x	x
Slits for air flow & air pumped through	x						
Heat to carrying struc-ture then to the wind	x	x				x	x
External air flow		x				x	
Rotor							
Internal air circulation	x	x		x	x		
External air flow		x	x		x	x	x

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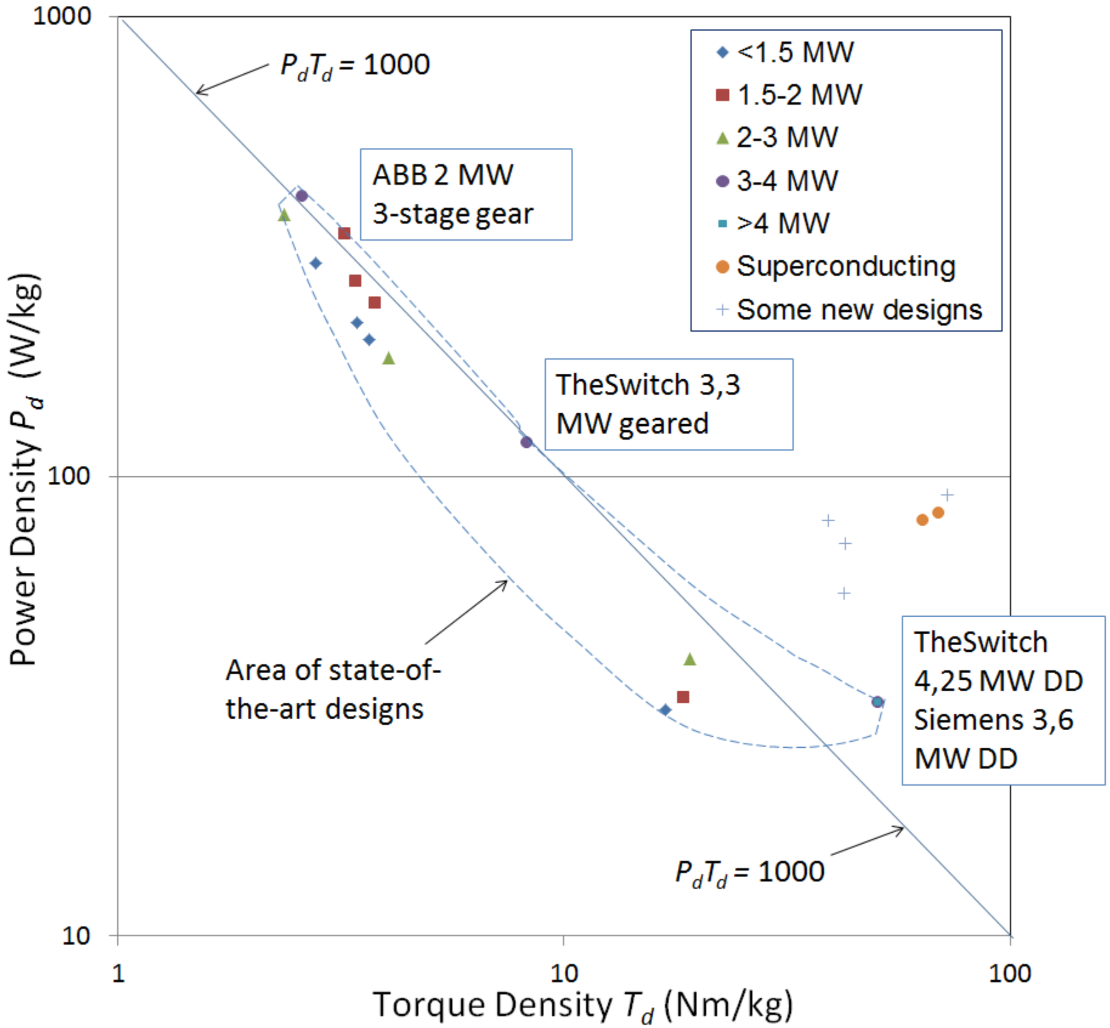
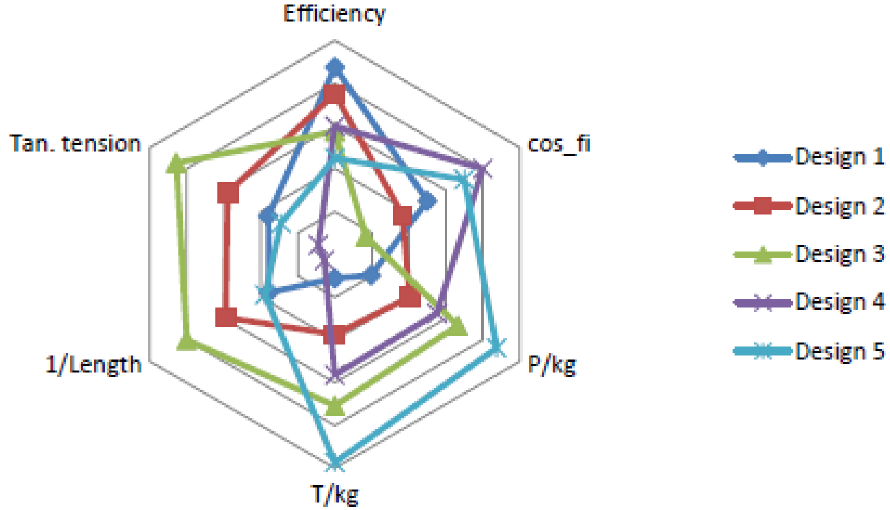
Characterization



Some conclusions

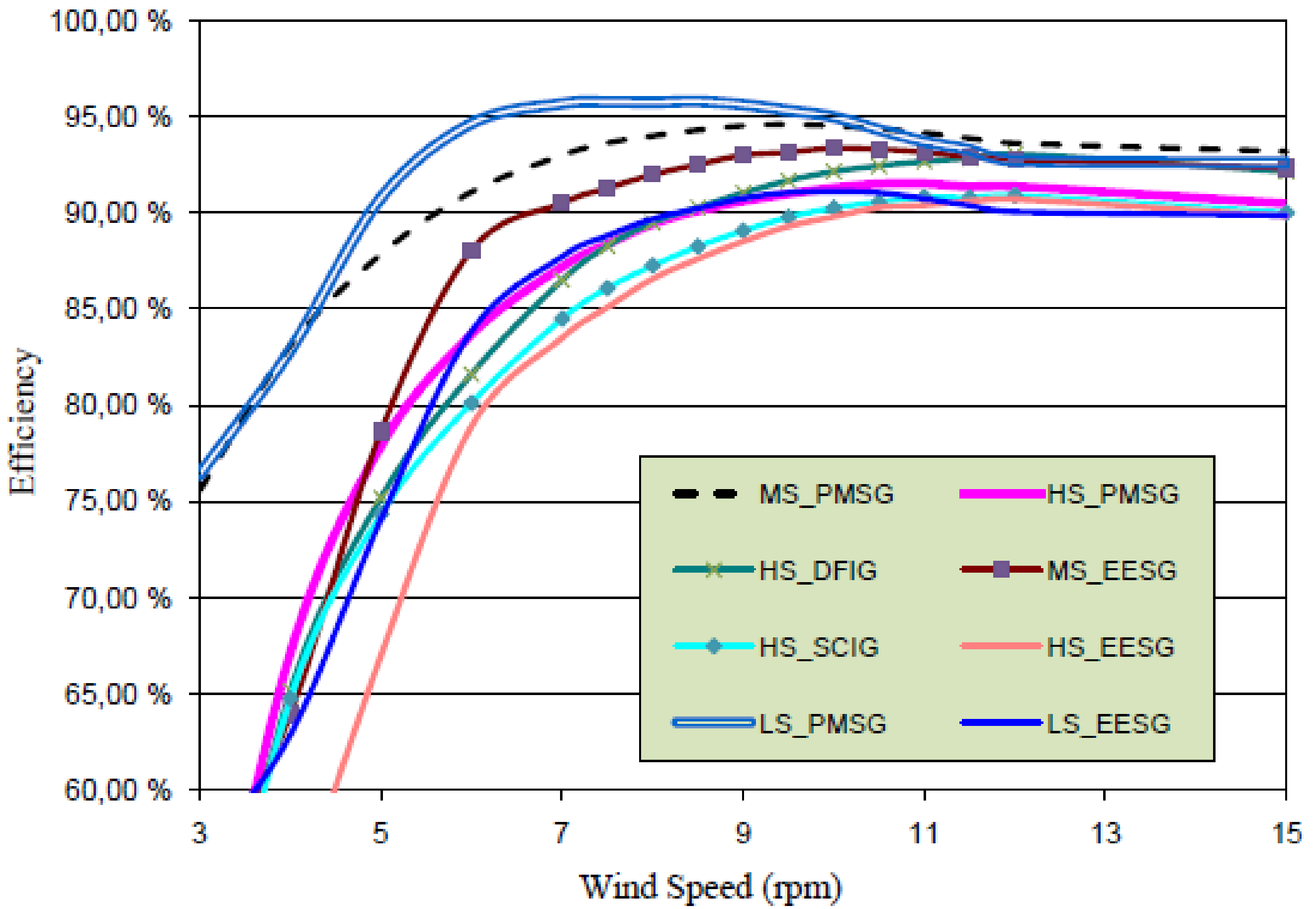
- Drive trains with PM generators have the best efficiency
  - Especially without gear (direct drive) and 1-stage gear
- However, there are other characteristics to take into account:
  - Weight
  - Cost
  - Power factor
  - Lifetime
  - Reliability
  - Manufacturability
  - ...



- Design means finding a trade-off between various criteria

Efficiency of different drive trains

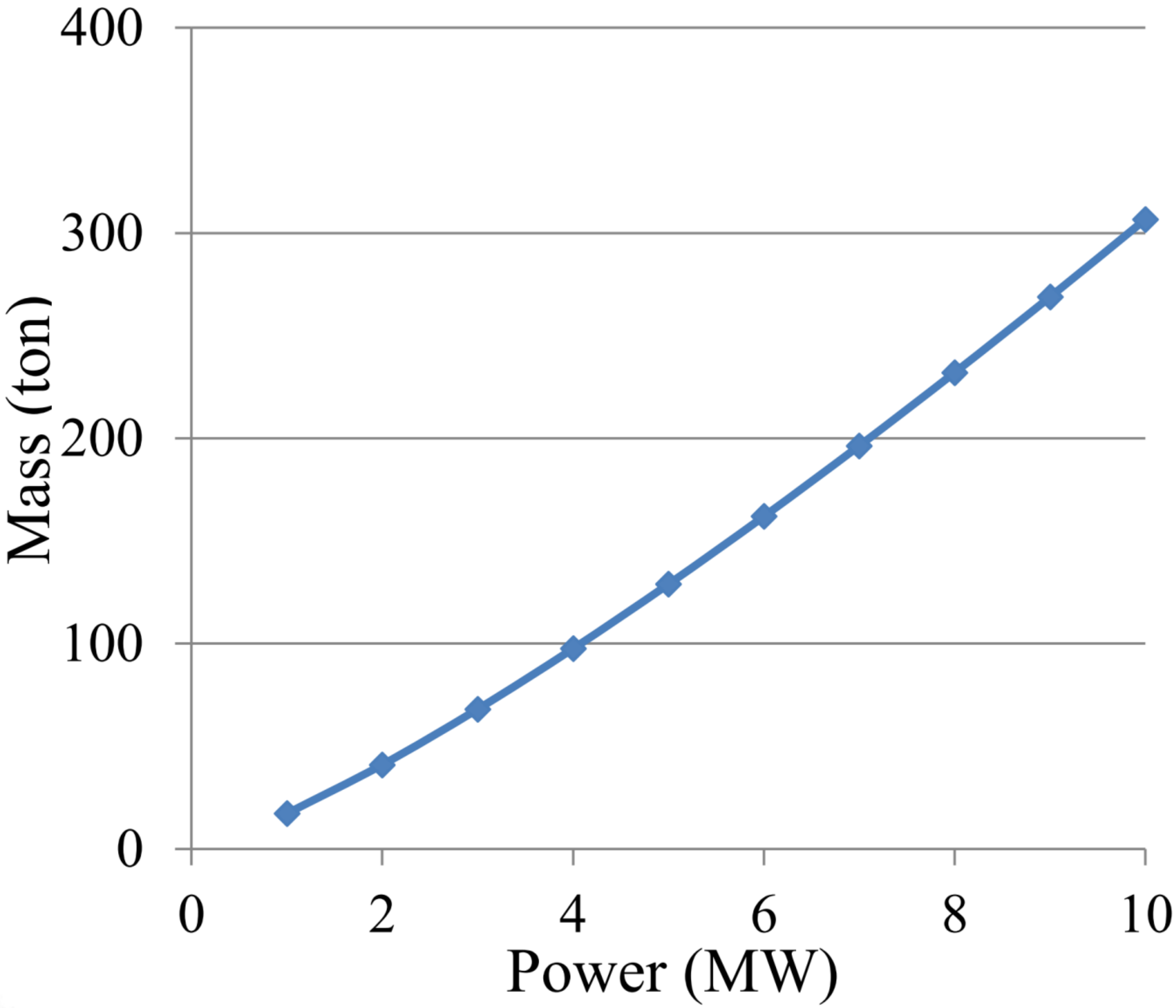
- Components included: gearbox, generator, converter, transformer
  - Direct driven PM generator solution gives the best efficiency at speeds below rated



LS – low speed
MS – medium speed
HS – high speed

PMSG – permanent magnet synchronous generator
DFIG – doubly-fed induction generator
EESG – electrically excited synchronous generator
SCIG – squirel-cage induction generator

Estimated weight for DD PM generators



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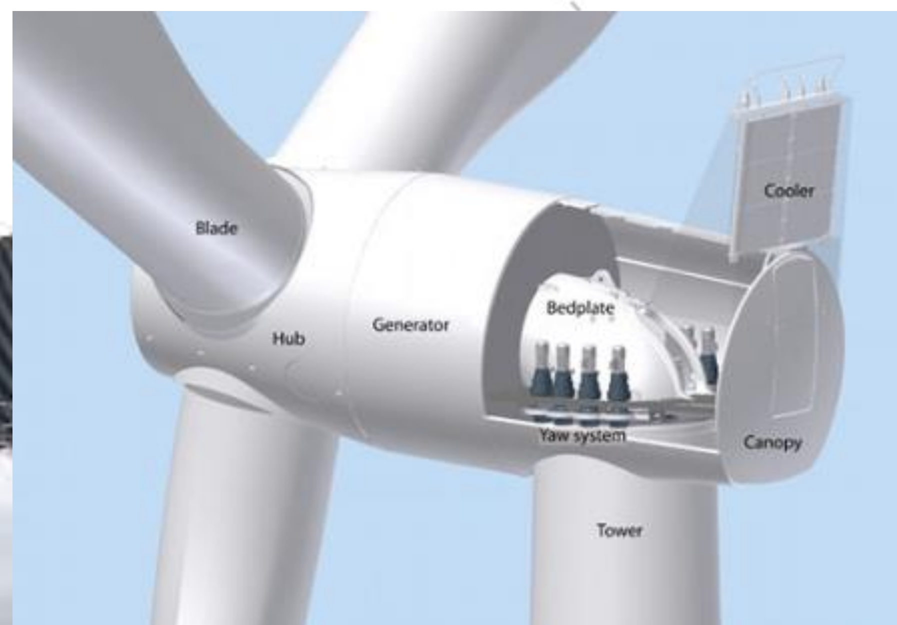
Direct driven generators are comming,

- but are they in the focus of commercial manufacturers?

“Secret” design from Siemens Januar 2010



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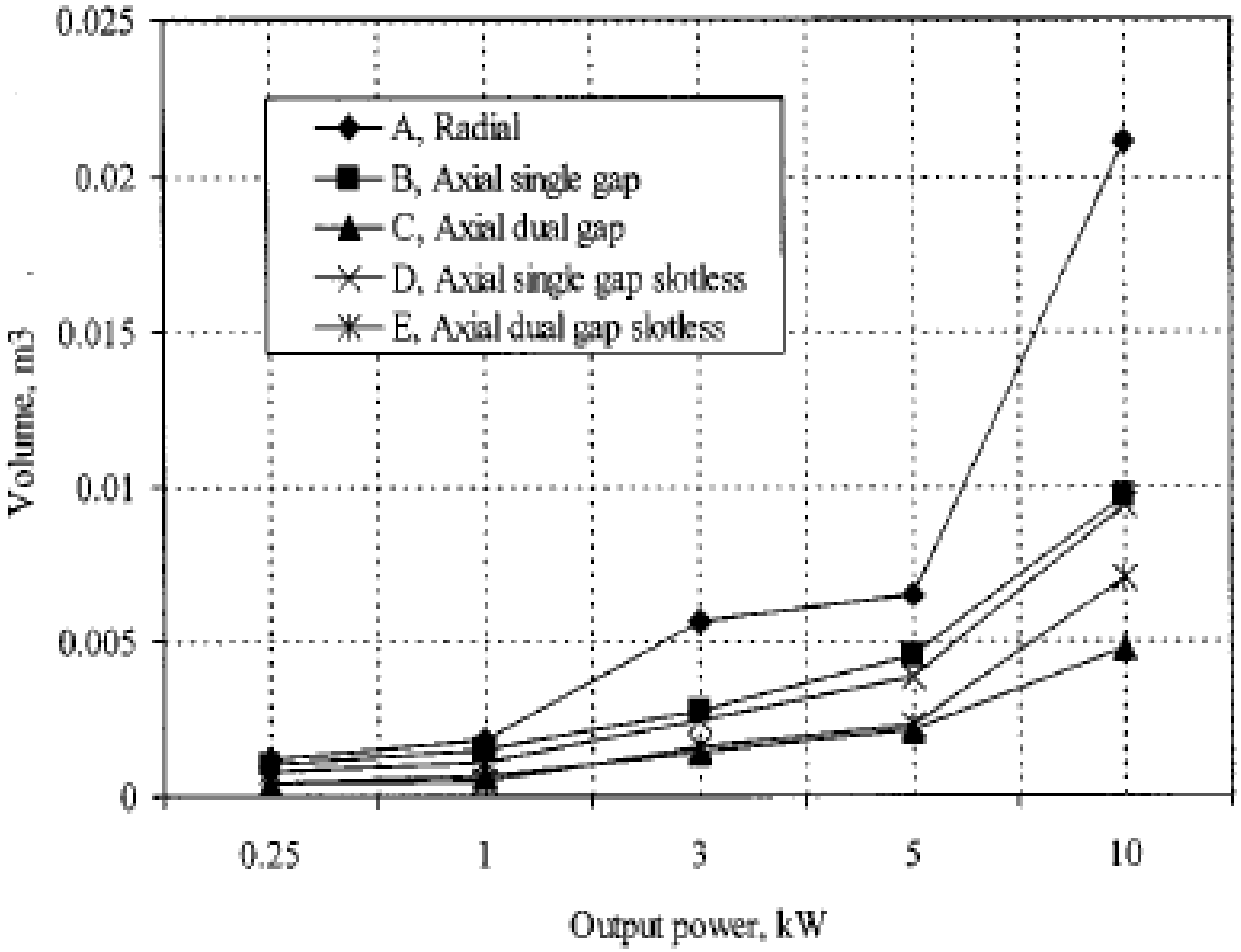
Expectations



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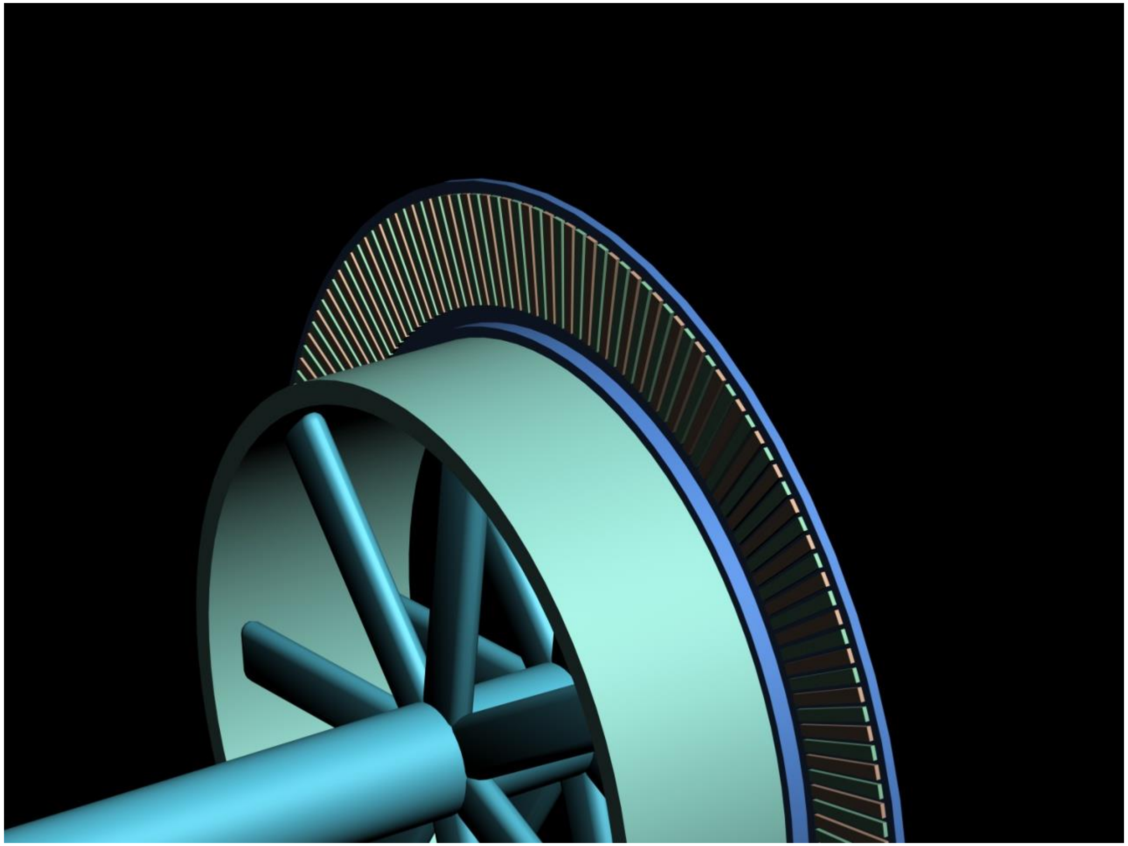
Multiple disc axially magnetized machines for wind applications?



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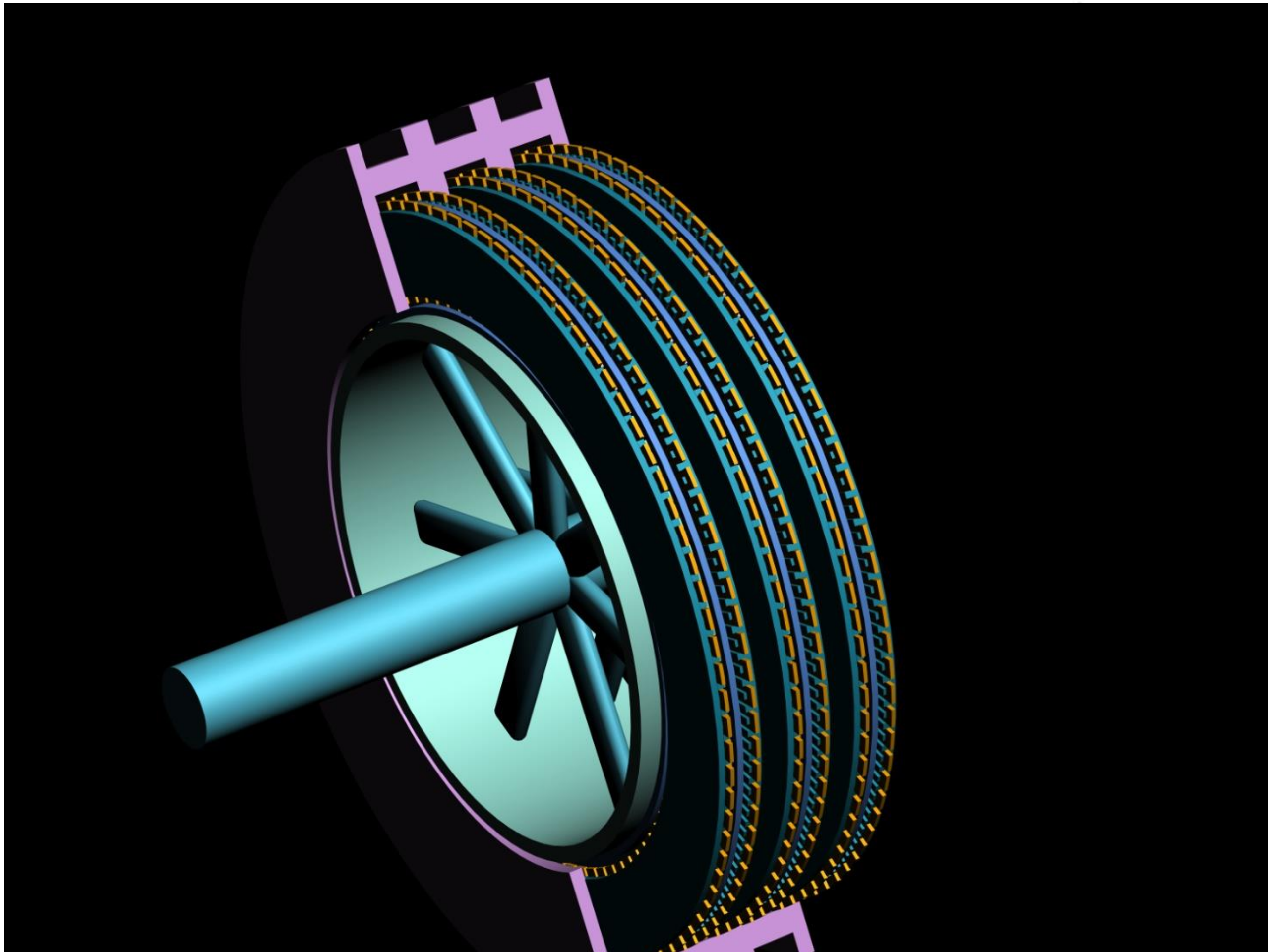
Compact designs - 3 times the power to volume ratio



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What about SWAY?

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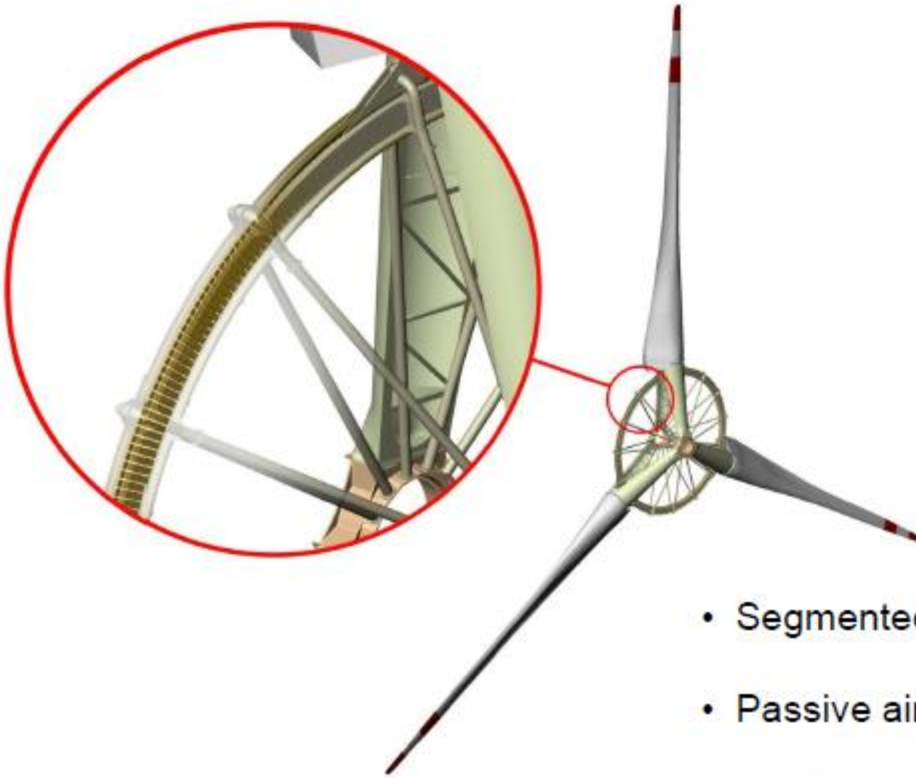
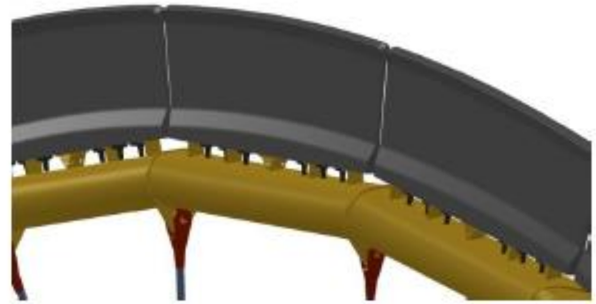
Main Features, Generator

SWAY TURBINE





- Segmented 25m diameter generator
- Passive air cooling through open air gap
- Both stator segments and rotor magnets totally encapsulated to resist the offshore environment

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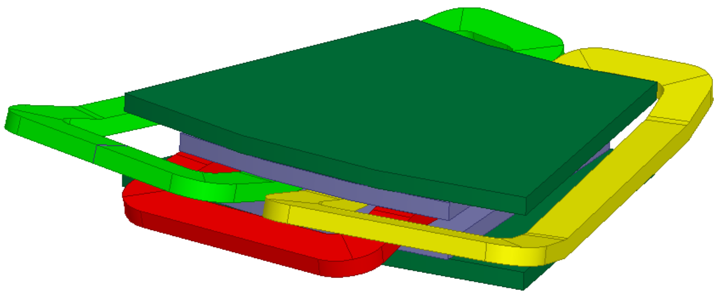
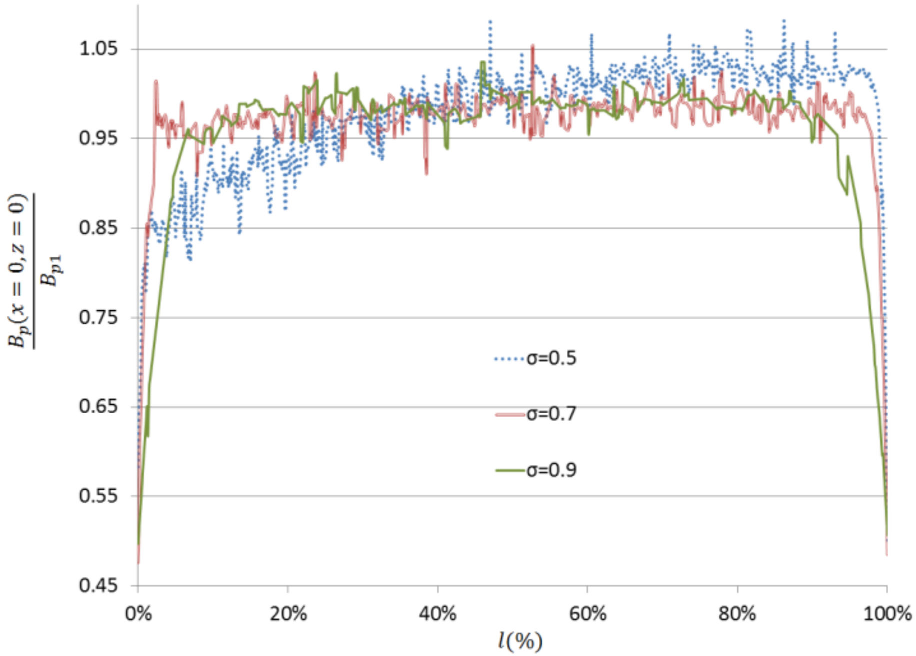
Torque calculation:

$$T = \begin{cases} \frac{\sqrt{2}}{8} k_{w1} k_{le} m n_s I_{ph\_s} N_1 B_{p1} D_o^2 (1 - \sigma^2), & AFPMSG \\ \frac{1}{\sqrt{2}} k_{w1} k_{le} m n_s I_{ph\_s} N_1 B_{p1} l D_a, & RFPMSG \end{cases}$$





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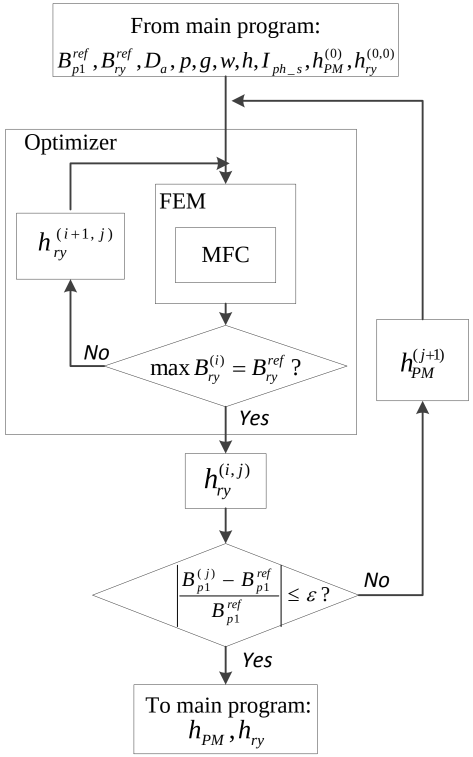
Modeling (3)- rotor sizing



total number of poles

$$p = qmp_{se}$$

thickness of permanent magnet

$$h_{PM}^{(j+1)} = h_{PM}^{(j)}\left(1 - \frac{B_{p1}^{(j)} - B_{p1}^{(ref)}}{B_{p1}^{ref}}\right)$$

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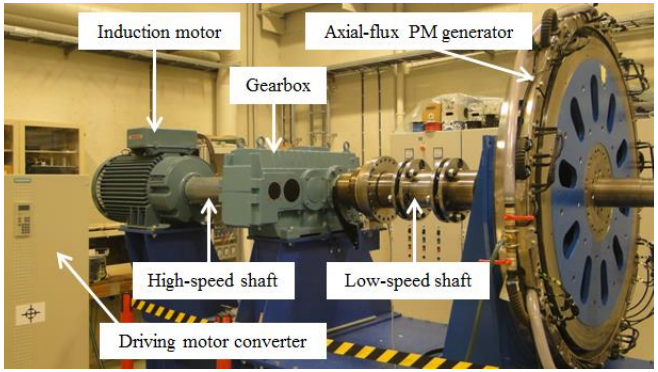
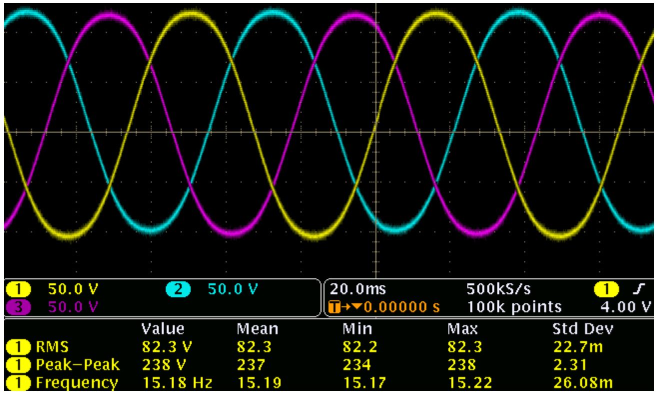
Test setup



1 stage, 48 pole, 23.2kW



	backEMF	Inductance
Calculation	78V	1.94mH
Measurement	82.3V	1.8mH

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Simulation results(1)

- Parametric study
- Free variables
  - Outer diameter
  - Pole numbers
  - Fundamental flux density in the airgap
  - ratio of PM width over pole pitch
- Constrains (see specification)
- Objective: mass, efficiency, and cost

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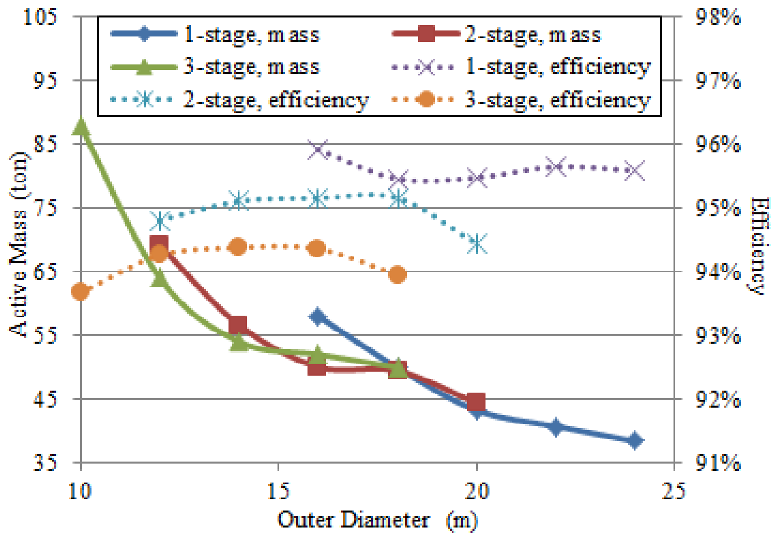
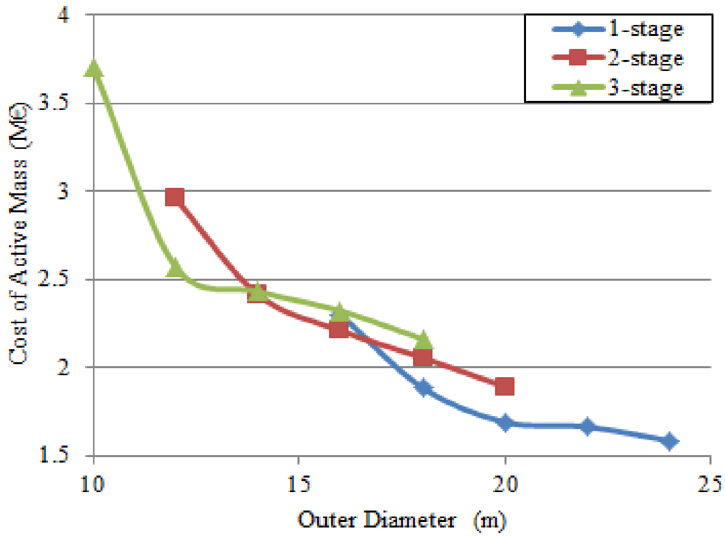
Simulation results (2)

- *The plots of efficiency only correspond to the designs that give lowest active mass*
- The first point on the left side of each curve shows the first feasible design as the outer diameter grows with a step of 2 m.





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Simulation results (3)

- Proper cooling plays vital role in the investigated type of machine.
- Higher current density leads to the thinner winding and smaller air gap. Consequently the permanent magnets do not need to be thick, and the cost is reduced.
- It is not free to cool the winding in the two surfaces that are vertical to the shaft because of the increased air gap.
- The empty space after removing the coils for segmentation and the end coil region provide an operational room for better cooling.

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Magnetic vibration challenges

- Maxwell's stress tensor:

$$f_r = \frac{1}{2\mu_0}({B_r}^2 - {B_t}^2)$$

$$f_t = \frac{1}{\mu_0}(B_r B_t)$$

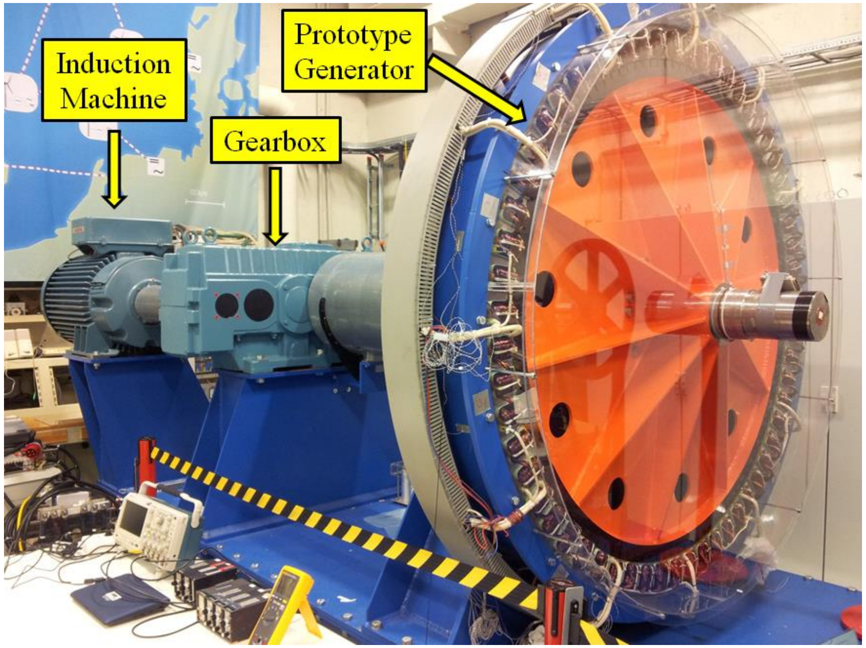
- Magnetic flux density distribution is computed using time-stepping FE analysis
- Radial magnetic force density wave:

$$f_r(\theta, t) = f_{r,max}\cos(m\theta - k\omega t)$$

- The dominant vibration mode is the lowest spatial harmonic in radial force density distribution.
- The lowest mode of vibration is 4 for the prototype machine.

Prototype generator

- 120slot/116pole
- Single-layer concentrated windings
- Nominal speed around 50 rpm



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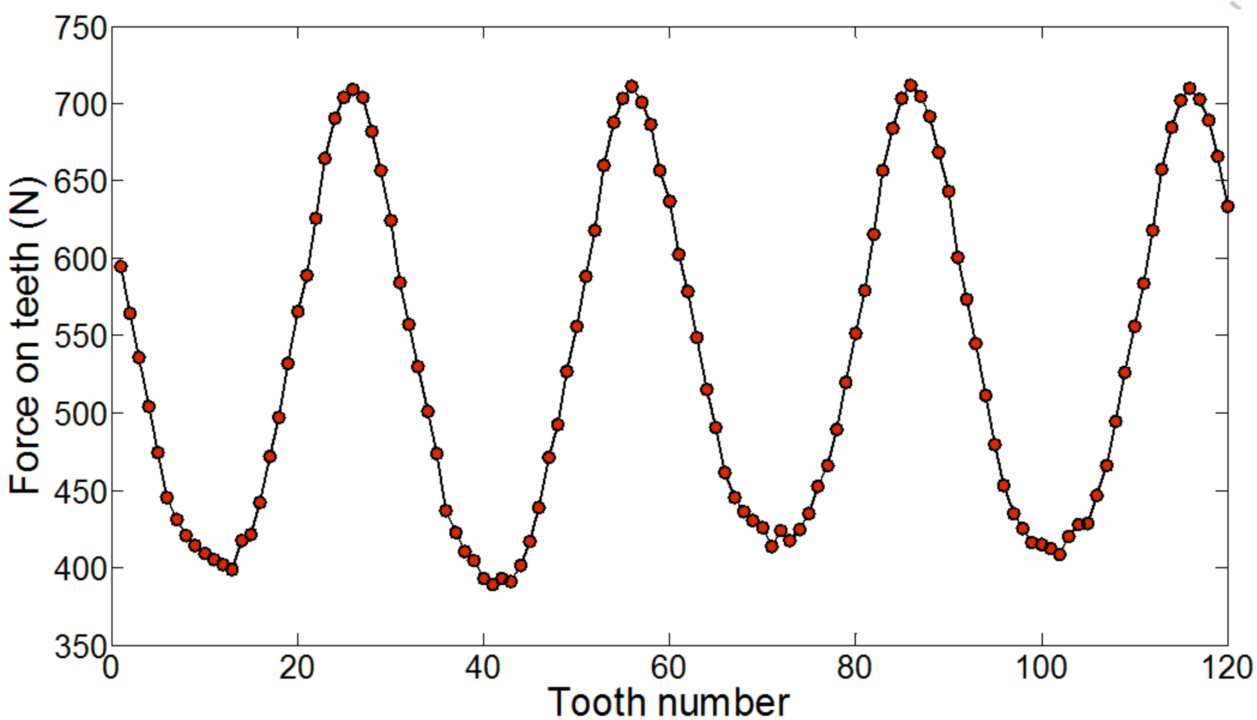
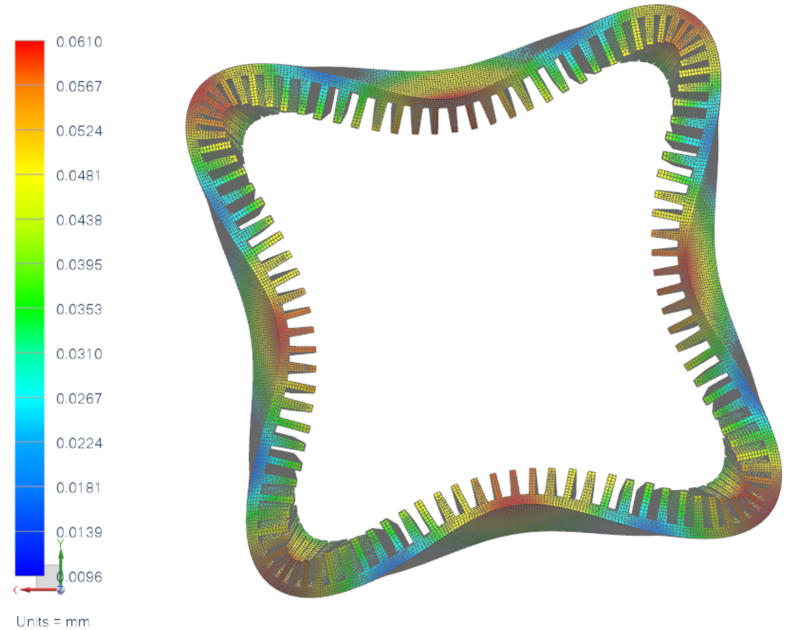
Magnetic simulations

- Time-stepping FE analysis



Structural analysis

- Modal analysis
- Static force analysis



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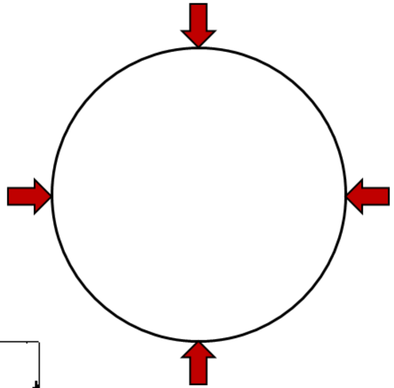
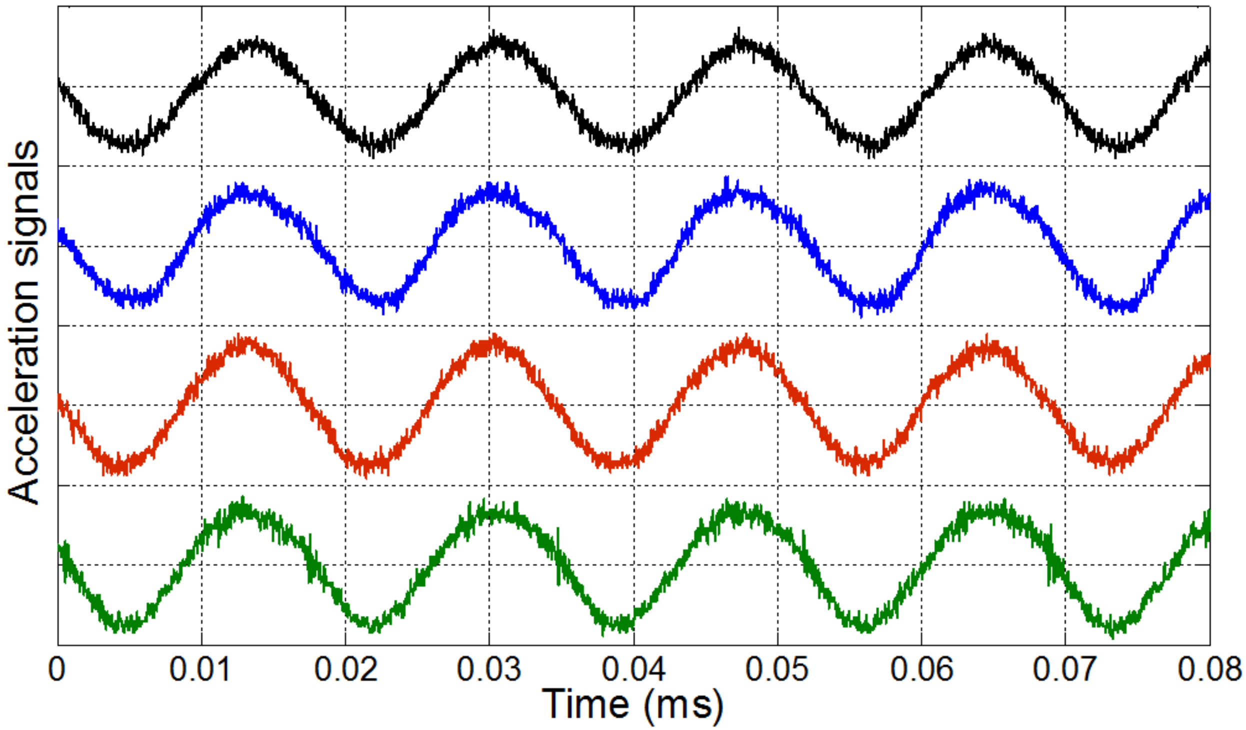
Experimental work

- Four accelerometers





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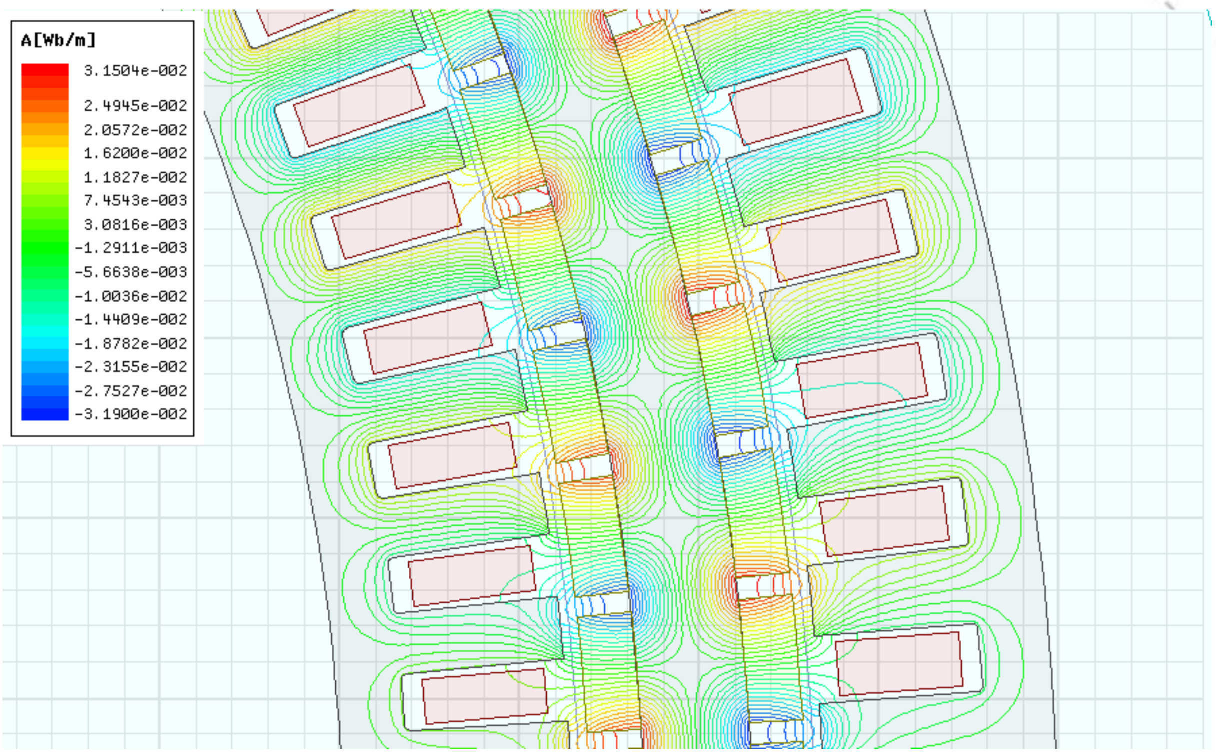
Multiple Airgap Machine

- 120slot/112pole double-stator single-rotor PM machine



magnetic rotor yoke

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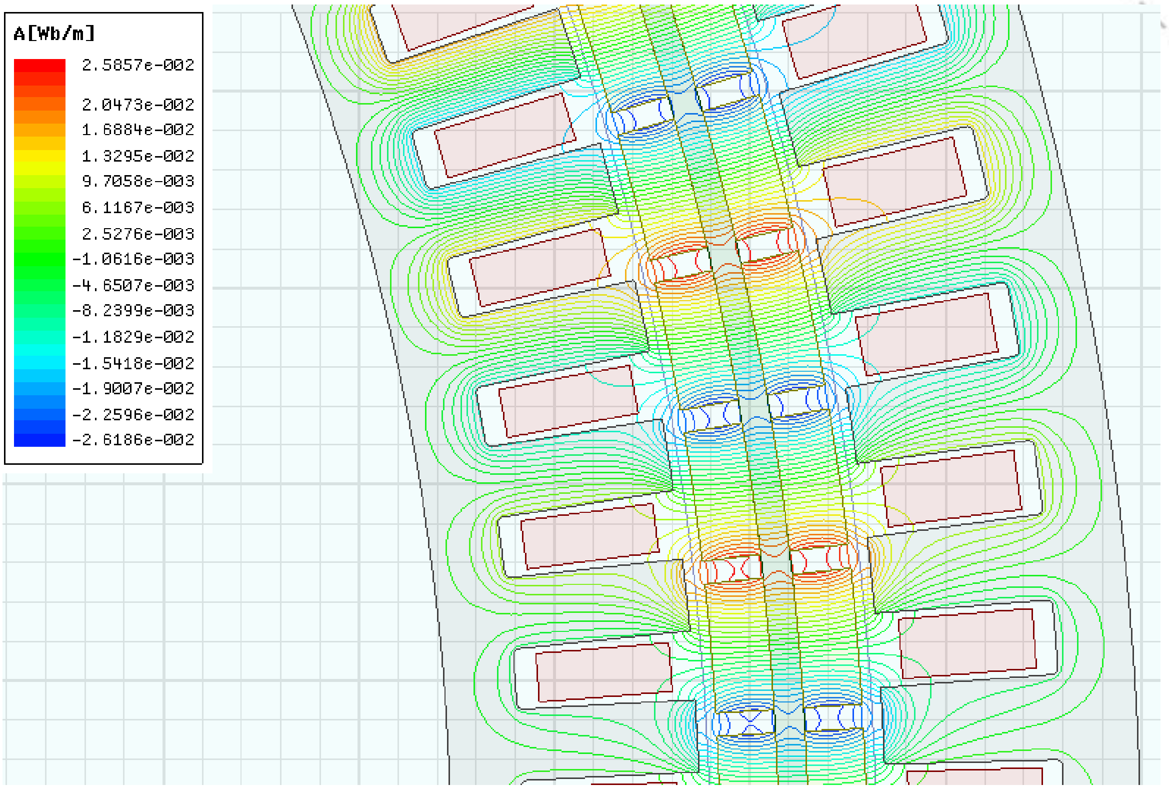

non-magnetic rotor yoke

Publications in 2013

- Influence of Slot Harmonics on Radial Magnetic Forces in Low-Speed PM Machine with Concentrated windings, *ICEMS 2013, Korea.*
- Analysis of a PM Wind Generator with Concentrated Windings in Eccentricity Conditions, *ICEMS 2013, Korea.*
- Influence of Pole and Slot Combinations on Magnetic Forces and Vibration in Low-Speed PM Wind Generators, *under review, IEEE Transactions on Magnetics.*

- Slot Harmonic Effect on Radial Magnetic Forces in Low-Speed PM Machine with Concentrated windings, *to be submitted to IEEE Transactions on Industry Applications.*
- Effects of Loading on Radial Magnetic Forces in Low-Speed Permanent Magnet Machine with Concentrated Windings, *to be submitted to IEEE Transactions on Magnetics.*