UpWind

Transmission & Conversion

- Workpackage activities and findings -

Mid Term Workshop

Thursday 19th October 2008, Brussels

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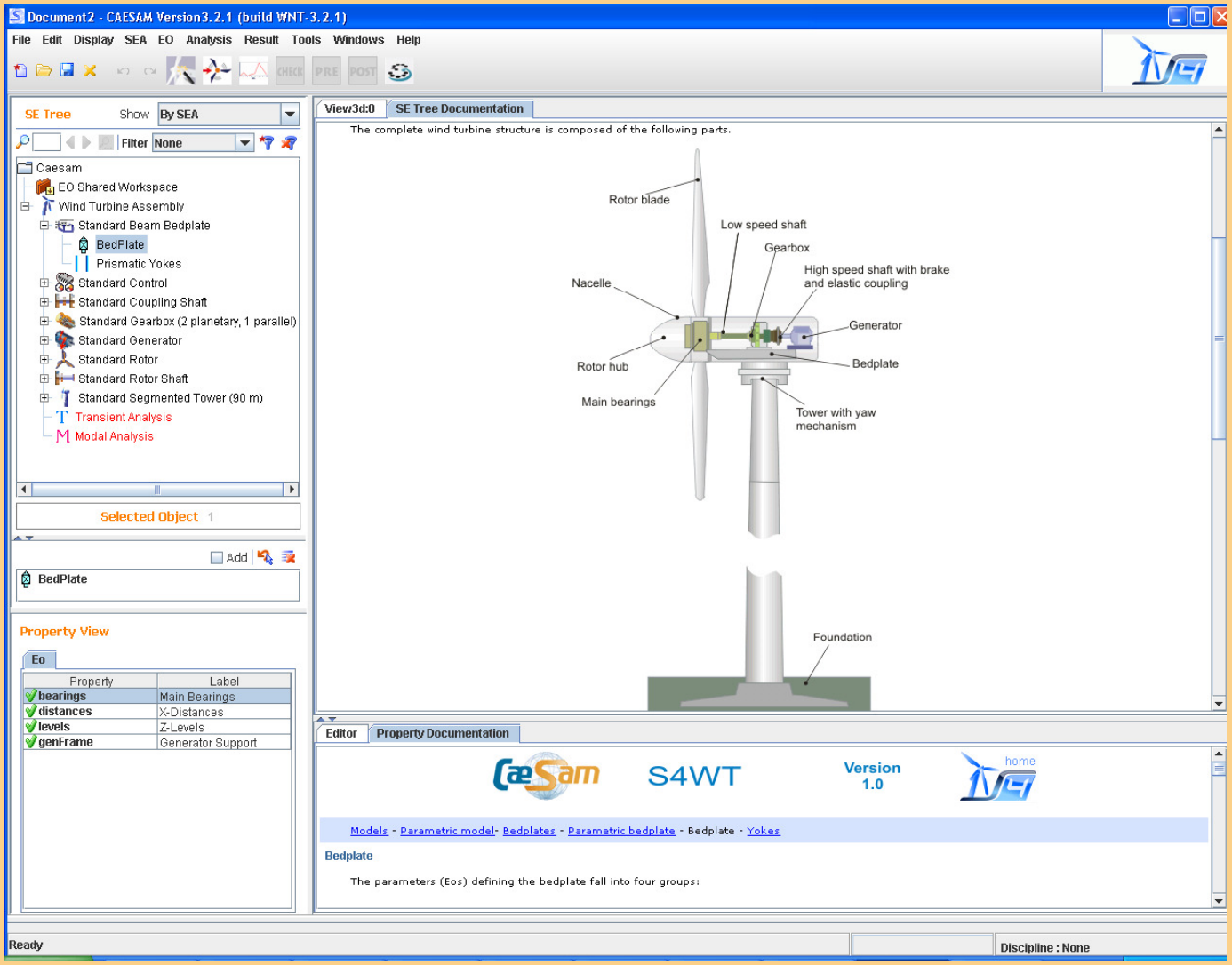
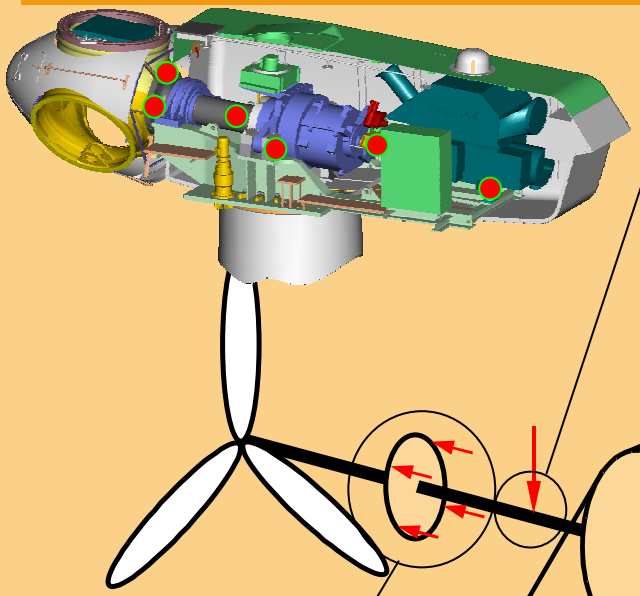
Outline

- Mechanical Transmission
  - Comparison of turbine measurements with simulation
- Generators
  - Comparison of different generator configurations
  - Electromagnetic optimization
  - Optimization of the mechanical structure
- Power Electronics
  - Converter topologies

Multi-body simulation platform



Sensors locations: measurement, simulation



detail

Measurement points
inside gearbox not shown

coupling_torque

Main shaft sensors are
placed between main
bearing and gearbox

input_torque

1

2

rotor_bending_B
bending sensors
have 90 ° offset

A

B

rotor_move_R
rotor_move_R
deflection sensors
have 90 ° offset

+z R +x +y

+z +x +y L

gear_move

+z +x +y B

+z +x +y R

+z +x +y L

generator_move

+z B +x +y

detail

hub flange

A

B

rotor_move_X

D

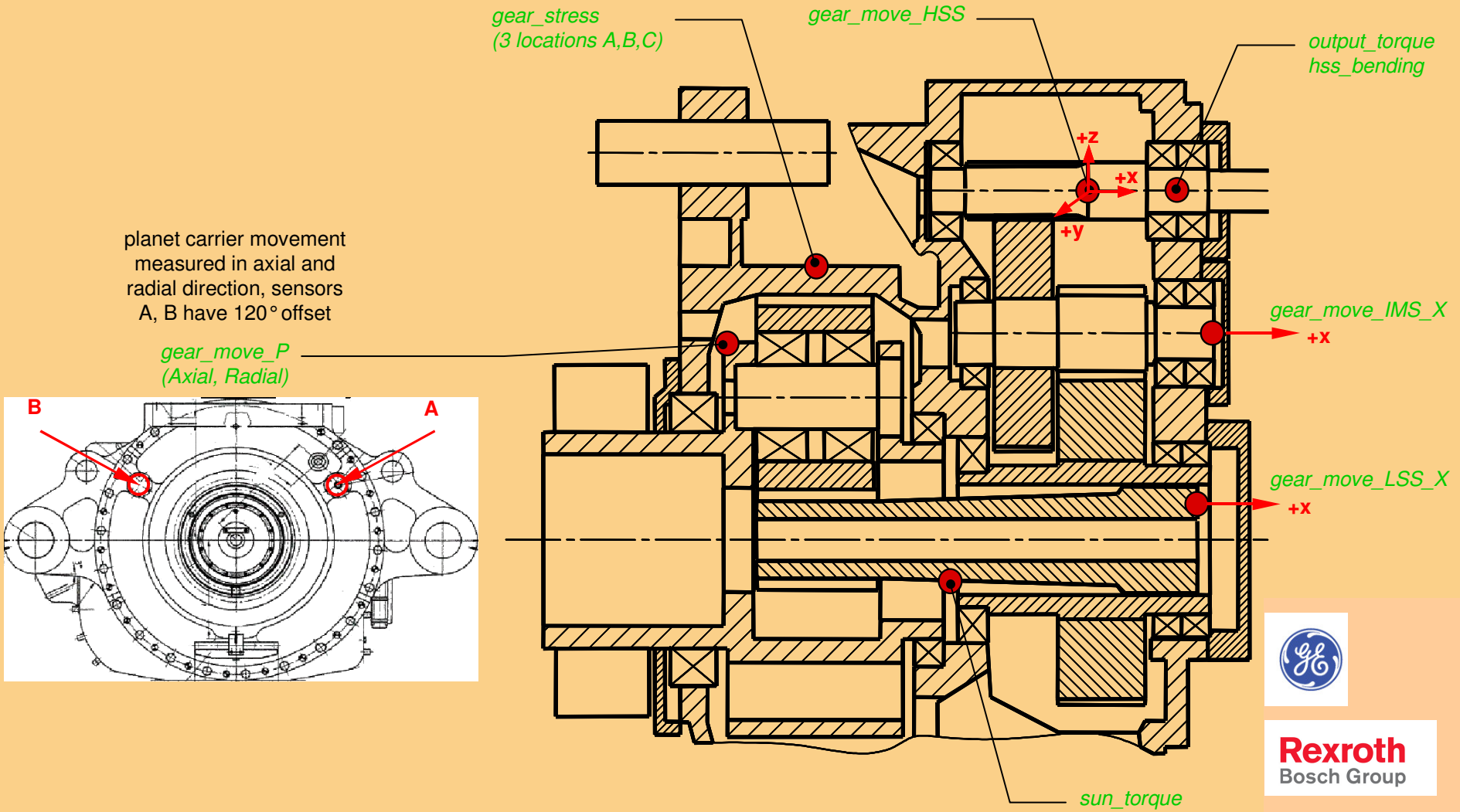
C

d

bearing

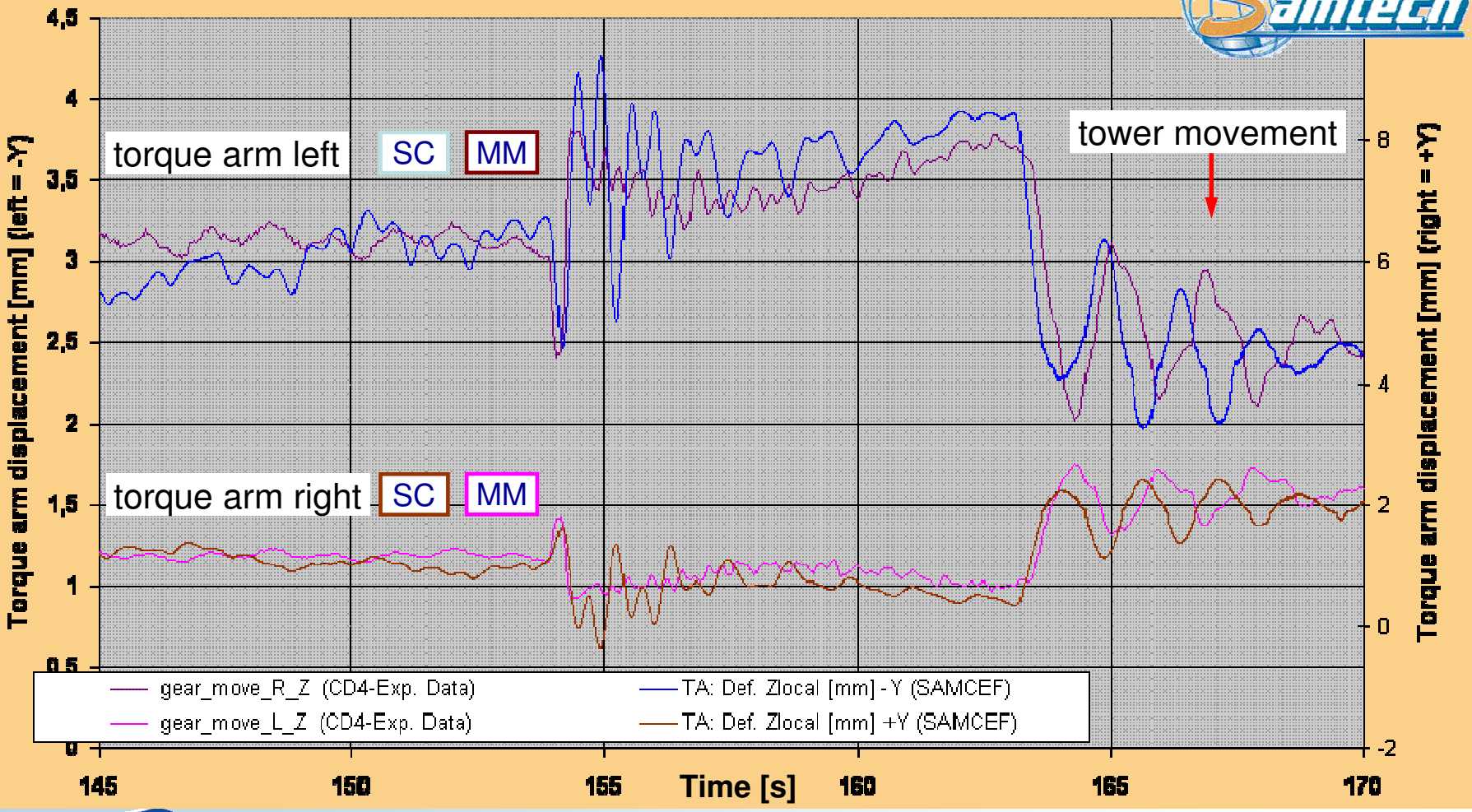
Measurement of distance d between bearing housing and hub flange at 4 points

Sensors locations within gearbox



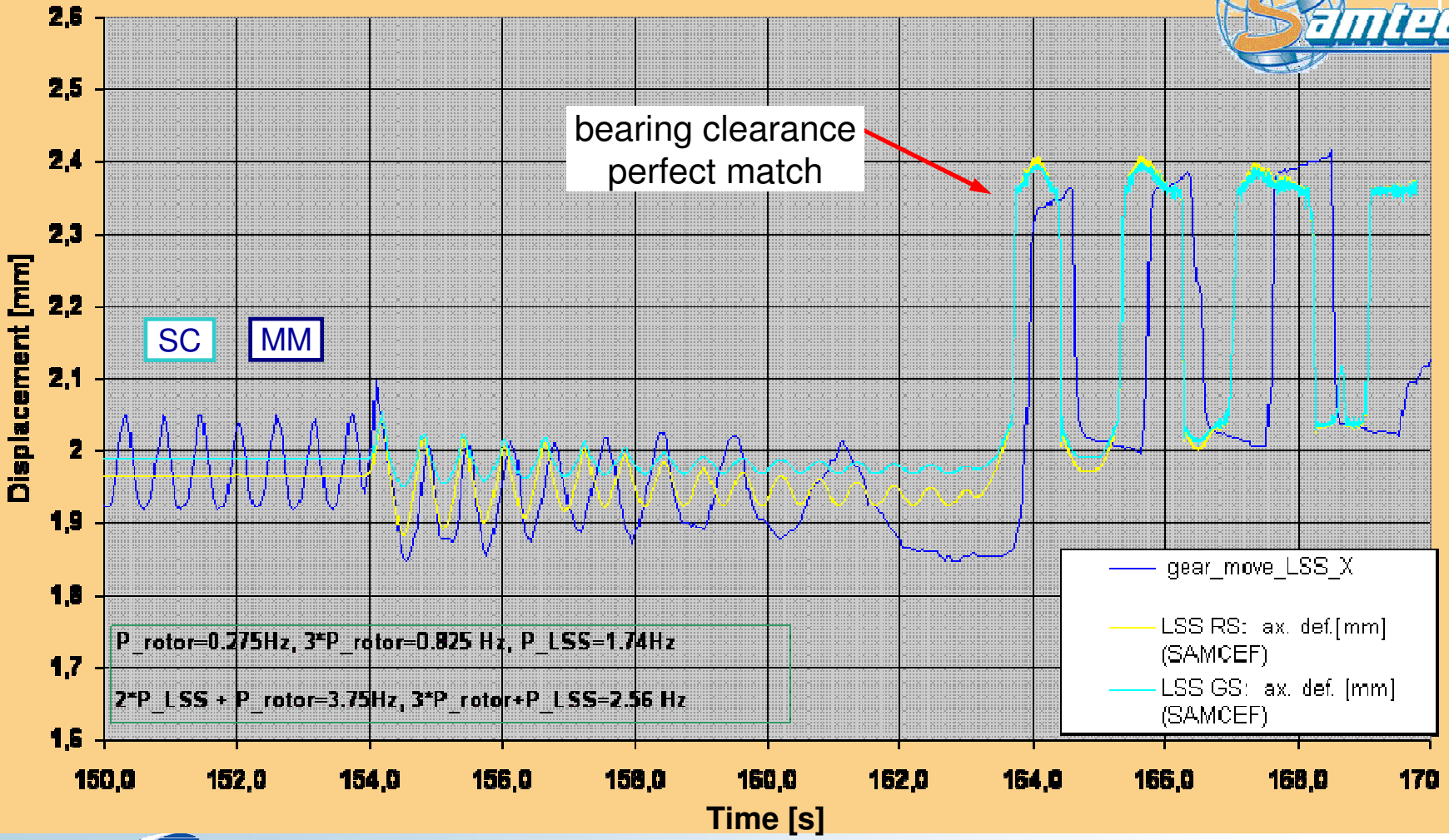
Torque arm displacement - longitudinal

Estop



Low speed shaft displacement - axial

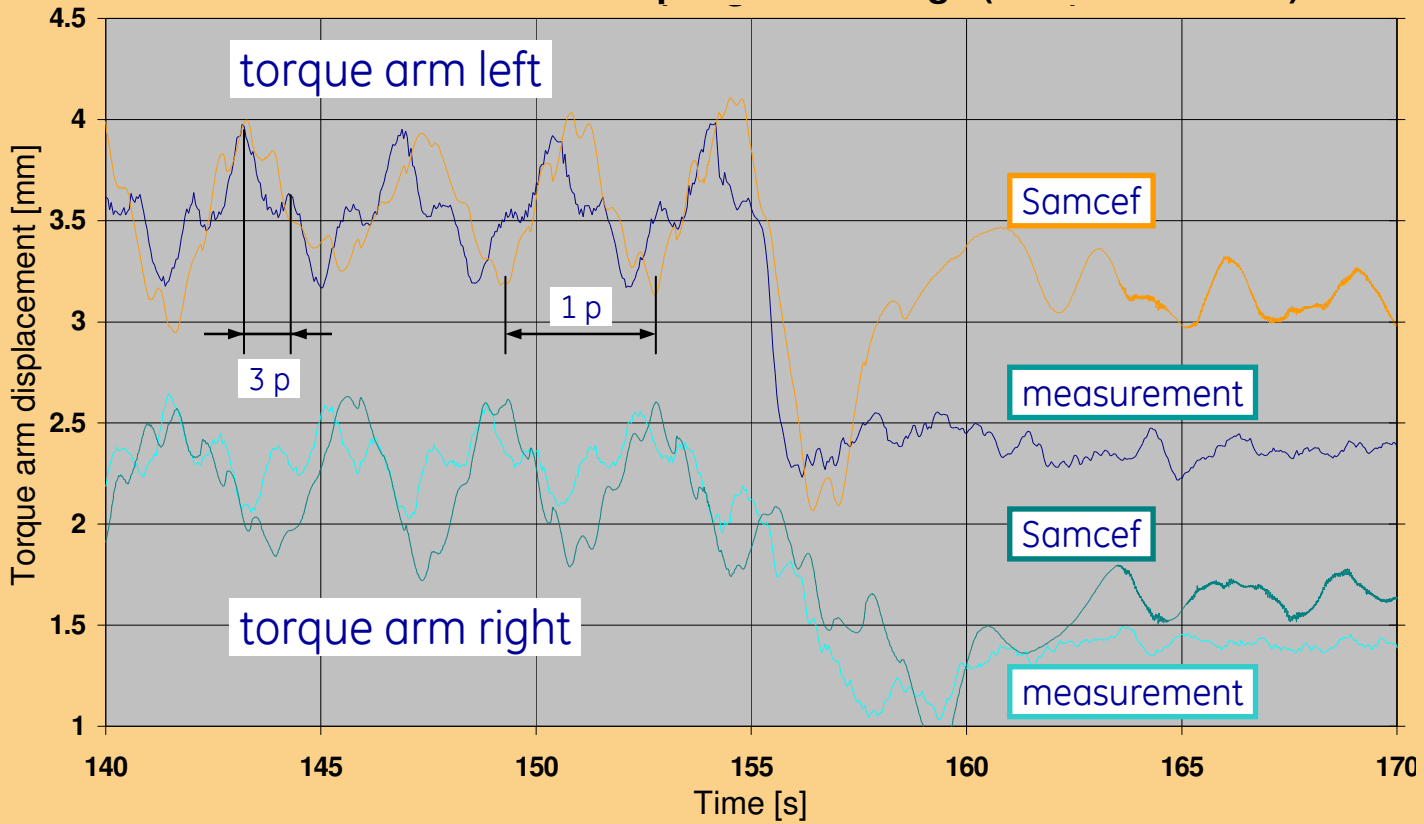
Estop (V_avg = 7.0 m/s)

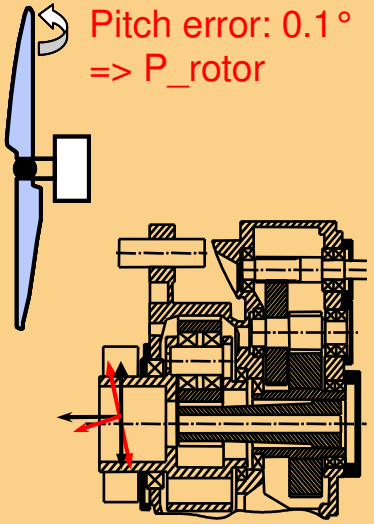


Pitch error & misalignment of main shaft

Torque arm displacements show:
3P_rotor : tower shadow (0.825 Hz)
1P_rotor : pitch error (0.275Hz)

Comparison of measurements with SAMCEF results
Gearbox movement at Torque Arm bushings (in wind direction)





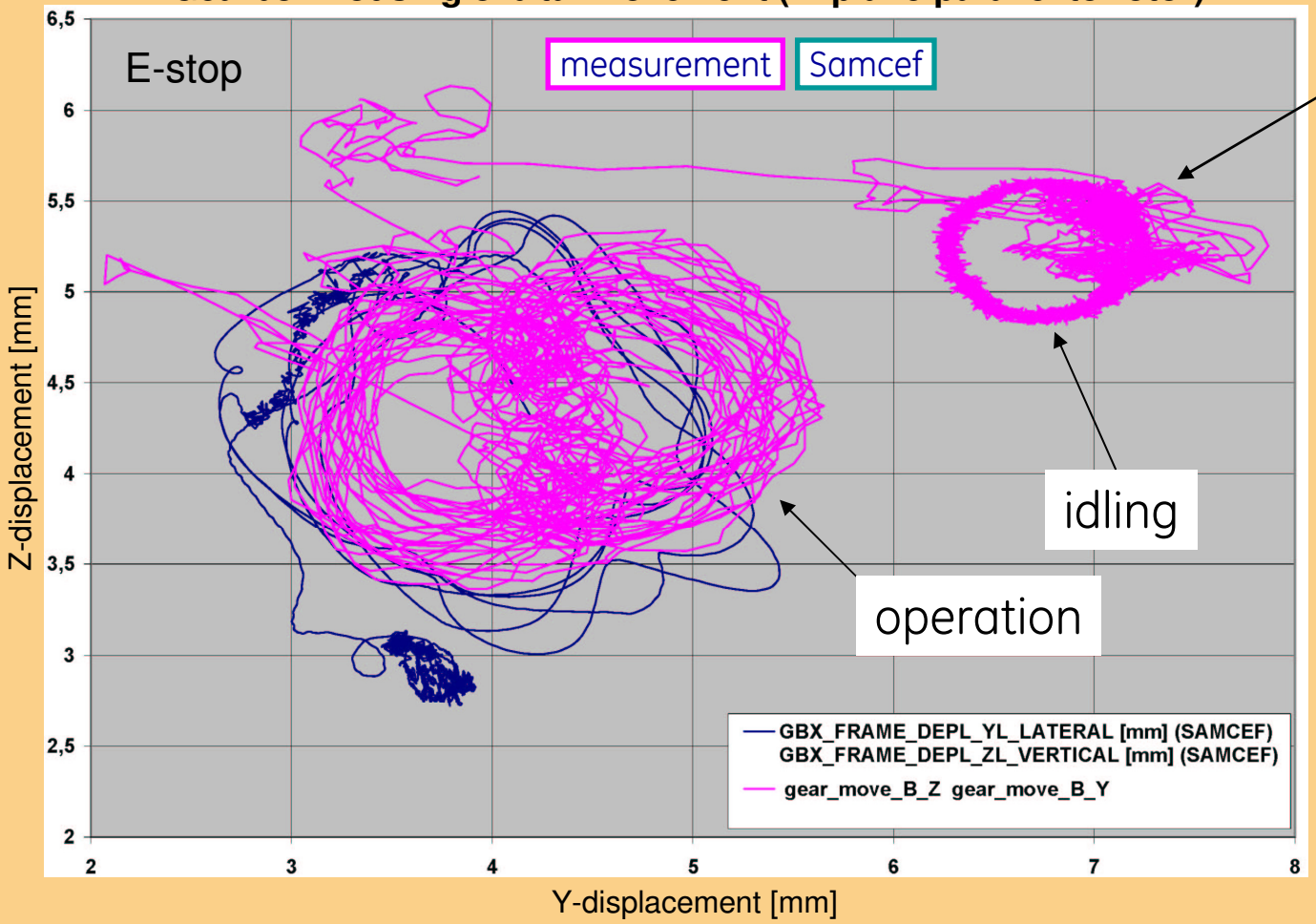
Pitch error: 0.1°
=> P_rotor

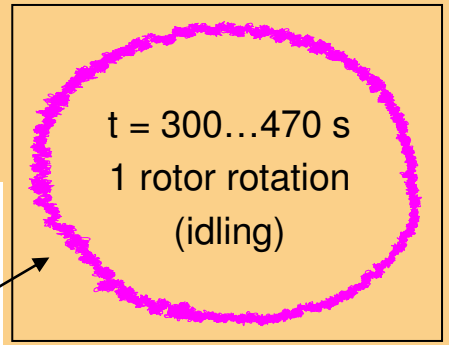
Main shaft & planet carrier coupling misalignement: 0.05°
=> P_rotor

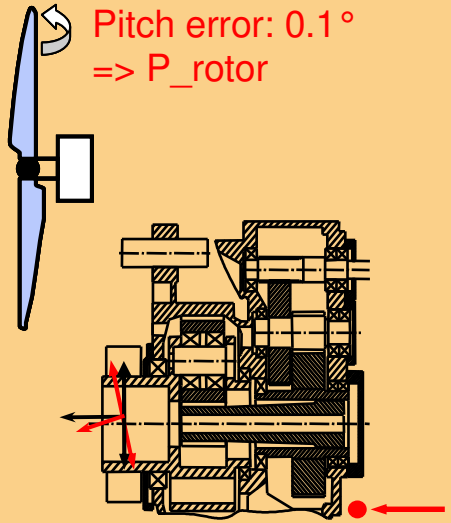
Pitch error and misalignment produces torque arm displacement of frequency P_rotor

Gearbox rear – orbital movement

Gearbox housing orbital movement (in plane parallel to rotor)







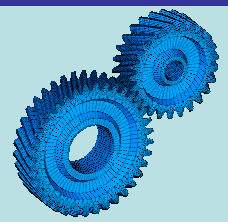
Pitch error: 0.1°
=> P_rotor

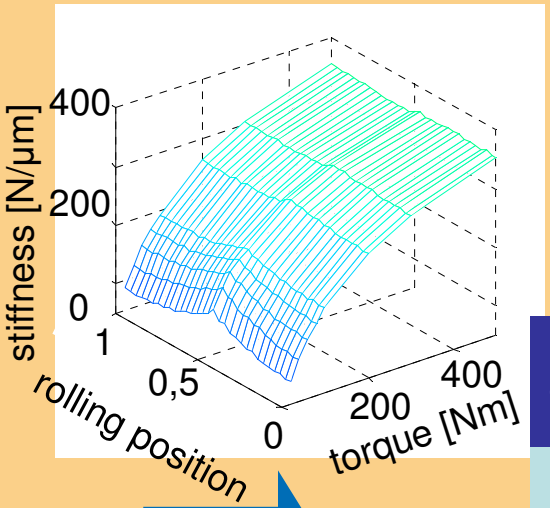
Main shaft & planet carrier coupling misalignement: 0.05°
=> P_rotor

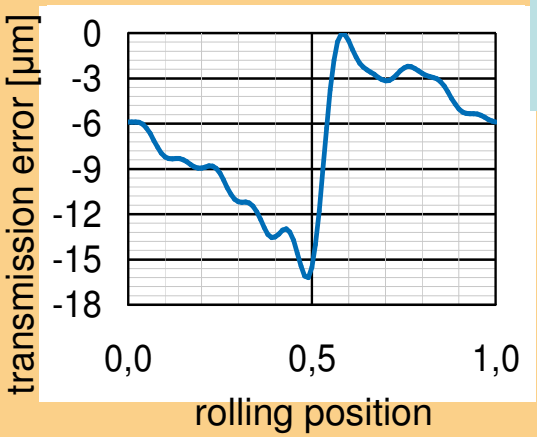
Pitch error and misalignment of main shaft produces gearbox displacement of frequency P_rotor

Linking of Gear- with System Dynamic

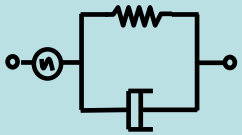
tooth contact analysis



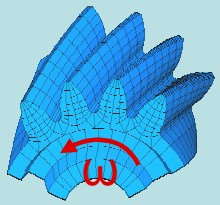




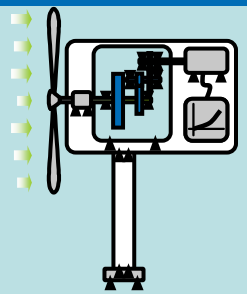
model of the tooth contact



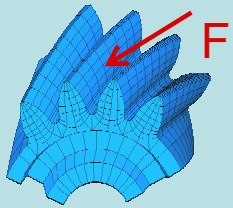
movement of the gears



MBS model

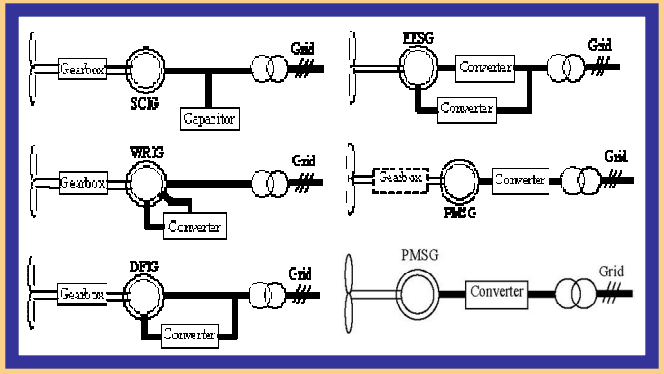


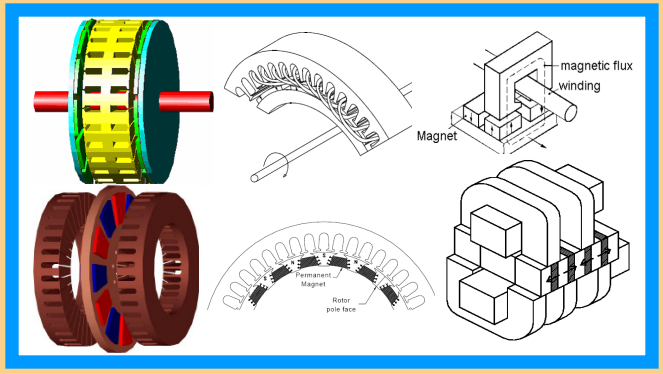
forces

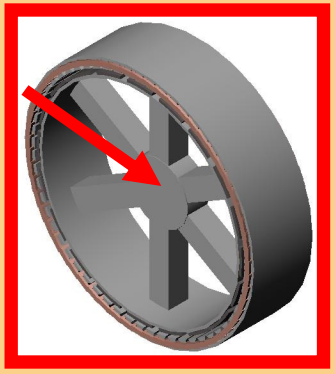


Generators

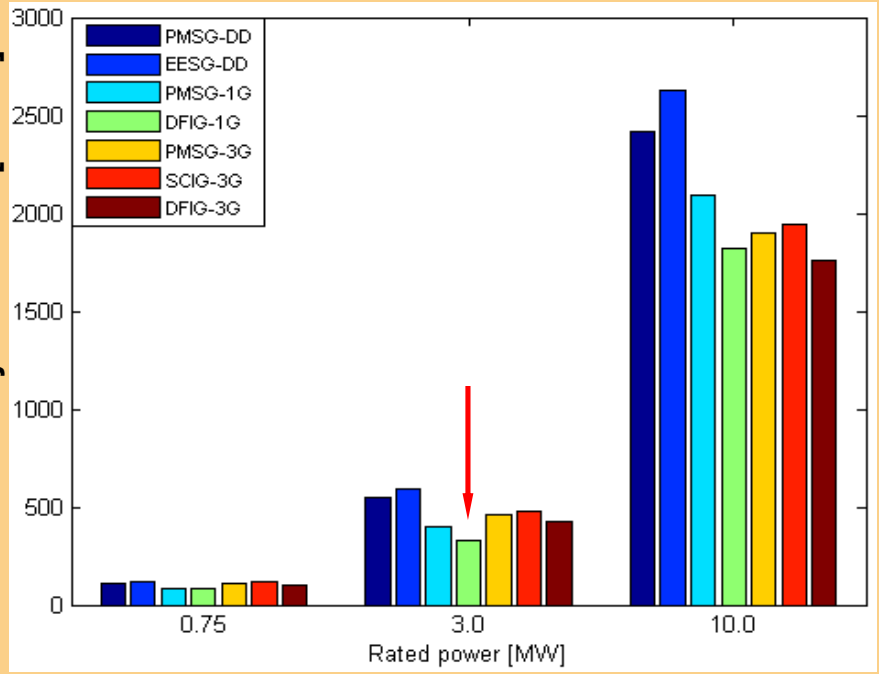
- **Aalborg University:**
  Comparison of different generator configurations
- **Delft University of Technology:**
  Electromagnetic optimization of direct-drive generators
- **University of Edinburgh:**
  Optimization of the mechanical structure of direct-drive generators

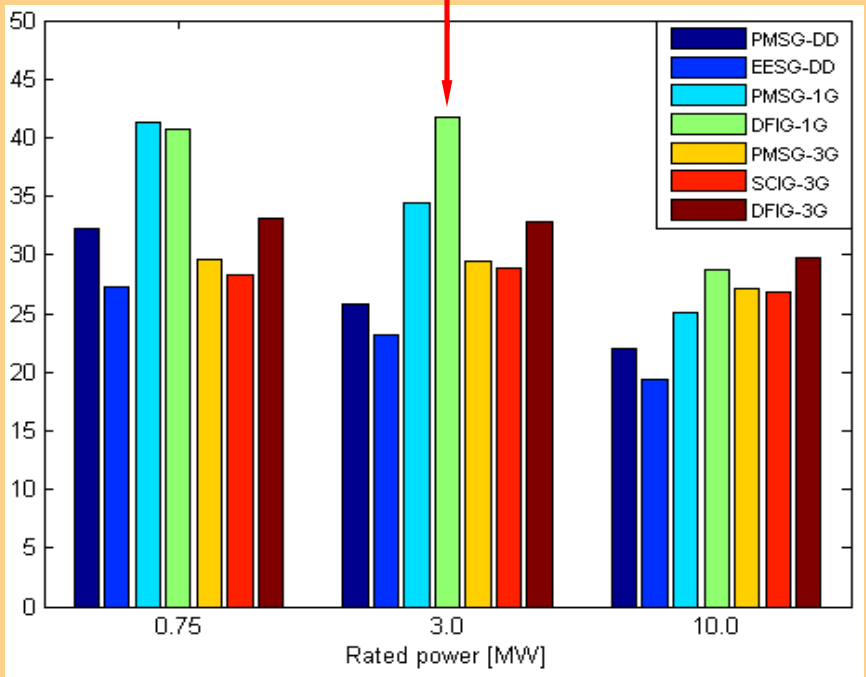






System cost / AEP per cost





	PMSG_DD	PM synchronous
	EESG_DD	Wound rotor synchronous
	PMSG_1G	PM synchronous single gear stage
	DFIG_1G	Wound rotor induction single gear stage
	PMSG_3G	PM synchronous three gear stages
	DFIG_3G	Wound rotor induction three gear stages
	SCIG_3G	Squirrel cage induction three gear stages

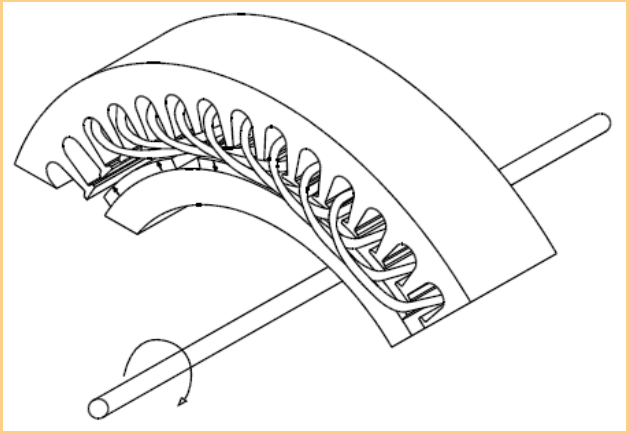
- system cost includes:
  - active material
  - structural
  - gearbox (if present)
  - converter
  - other electrical subsystem

Selection of generator type

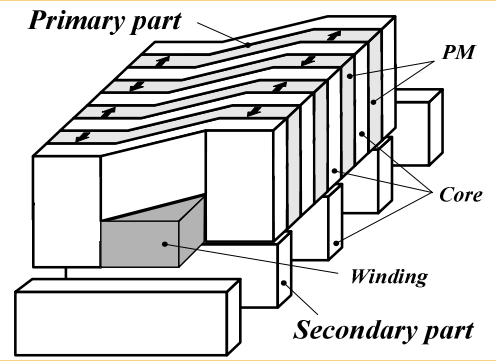
- For active mass reduction:

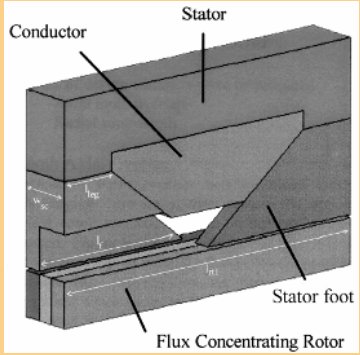
  Concept with short flux path required

Radial Flux & Axial Flux
PM machine: limited

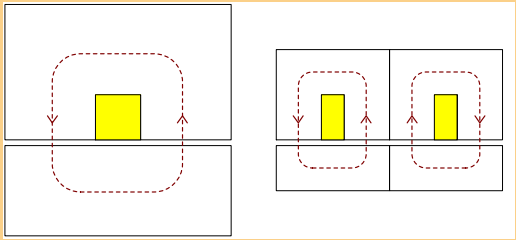


Transversal Flux
PM machine: potential





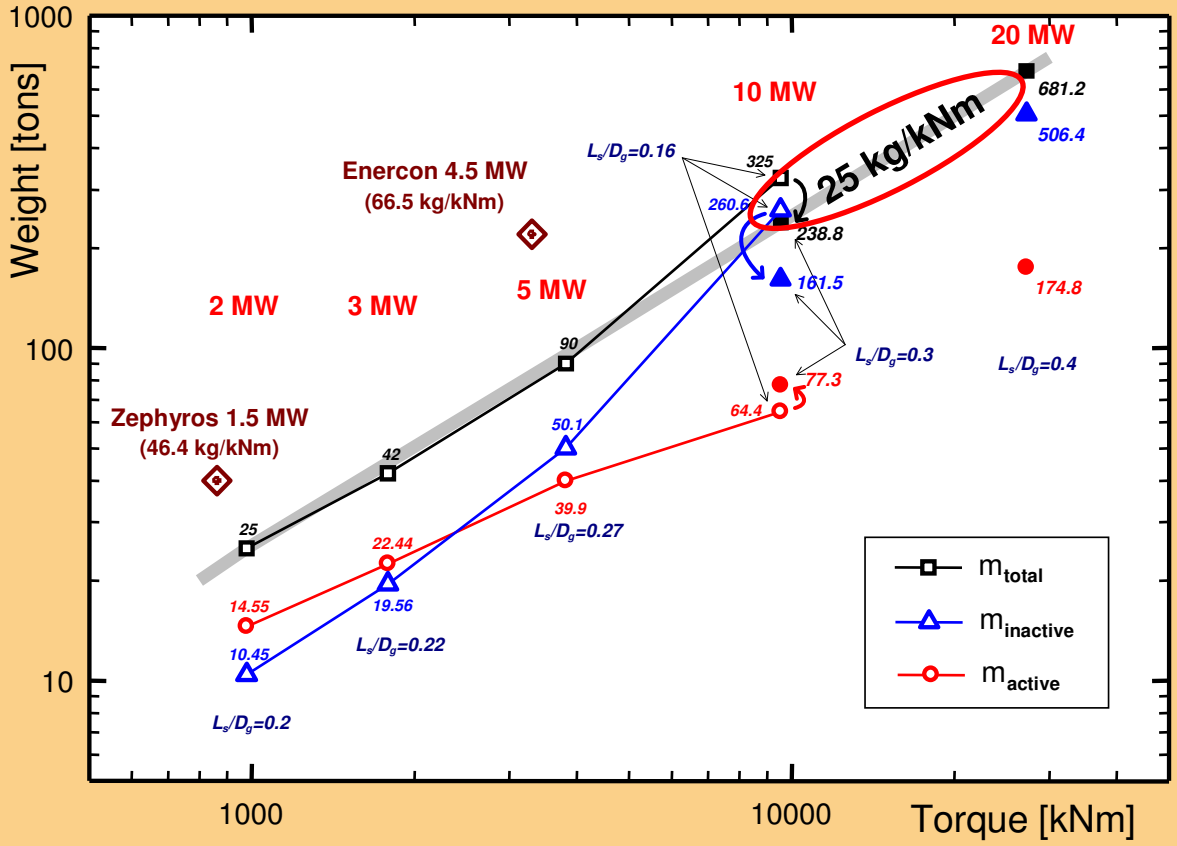
plural module concept



Analytical design procedure developed to assess TFPM machine.

Rough design of 10 & 20 MW direct-drive RFPM generators

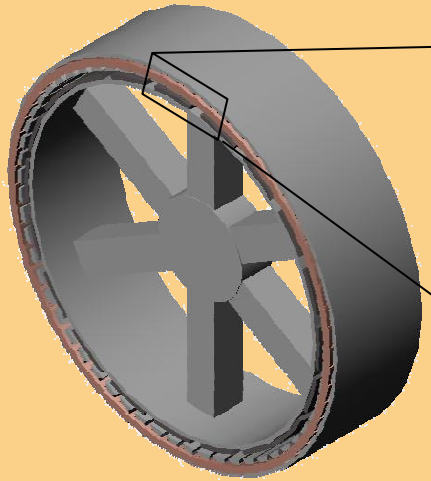
Power (Speed)	**10 MW** (10 rpm)	**20 MW** (7 rpm)
l/D	**0.3** **(2.4/7.96)**	**0.4** **(4.1/10.3)**
Mass [T]	**77.3**	**174.8**
Iron	57.4	127.1
Copper	12.7	27.1
PM	7.2	20.6
Loss [kW]	**655**	**1306**
Iron	54.4	109.4
Copper	300.7	596.9
Converter	300	600



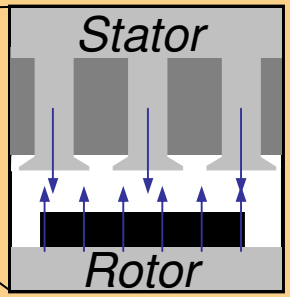
Note: 2, 3, 5 MW : McDonald *et al* (ICEM2006)

Optimization of the mechanical structure of direct-drive generators

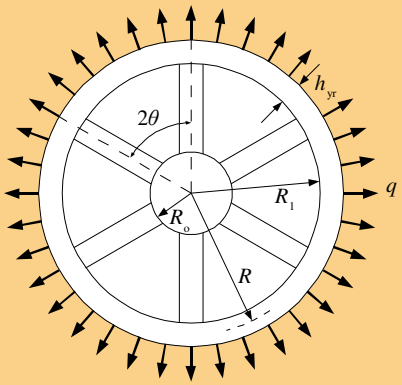
- The concept of ‘structural’ mass
  - Material required to maintain airgap, many forces at work
- The formulation of design tools to estimate the structural material
  - electromagnetically active and structural material must be simultaneously optimized
- The search for optimal shapes for these generators
  - shape optimization to find the ‘best’ mechanical structures



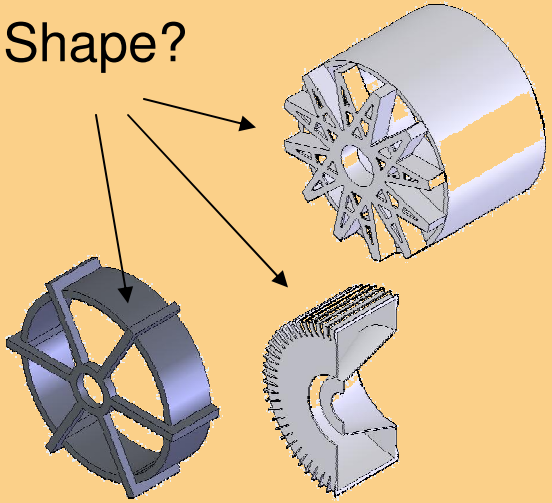
EM forces



centrifugal forces

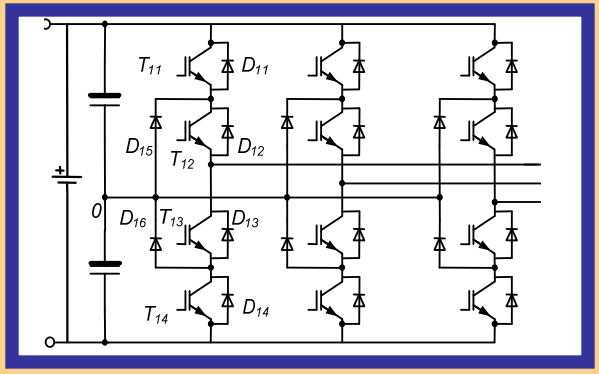


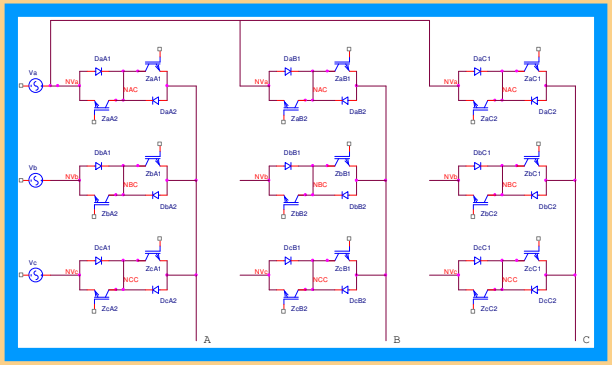
Shape?

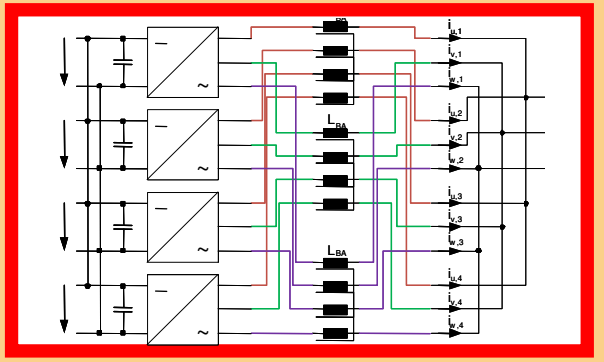


Power Electronics - Converters

- **ISET:**
  Neutral point clamped converter
- **ROBOTIKER:**
  Matrix converters
- **GE Global Research:**
  Interleaved converter







Power Converter Summary

- NPC
  - Industry standard topology
  - Good controllability and good performance under grid-faults
  - Redundancy is required against semiconductor breakdown issues
- Matrix Converter
  - It is not a mature technology yet
  - Poor fault-ride-through capability against grid disturbances
  - Fault tolerant
- Interleaved Converter
  - Fault tolerant (only a power downgrade is required)
  - Good fault-ride-through capability against grid disturbances
  - Good controllability

Conclusions

- Simulation tool for full flexible turbine simulation has been developed and compared against measurements
- First step of comparison is modeling the right effects / defects
- Simulation tool helps to quantify defects

- Generator topologies have been studied, compared and optimized in terms of electromagnetics and mechanics
- Models for multi-parameter optimization have been developed

- Power converter topologies have been compared and optimized
- No barriers for up-scaling in sight, no clear winning technology