UpWind

Transmission & Conversion

- Workpackage activities and first findings -

EWEC 2008 Session BW2 “UpWind”

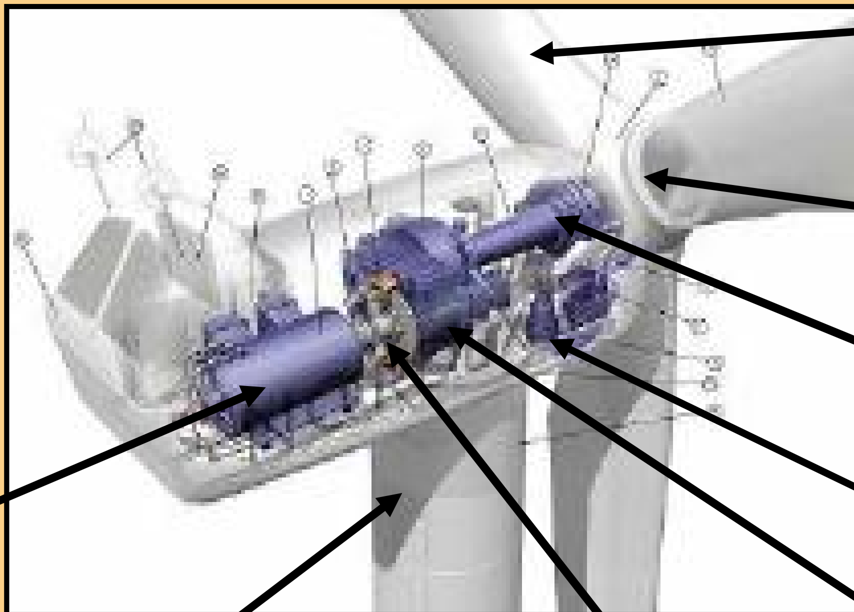
Tuesday 1st April 2008 11:00 - 12:30

Jan Hemmelmann, GE Global Research

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

Global modeling approach for evaluation of “dynamic wind turbine power train loads”



Rotor blades & aero-elasticity:

Blades**:** Beam Elements or Super-Elements & strong aerodynamic coupling using BEM-Theory.

Pitch & control:

Pitch drives: MBS-modelling

Pitch angle: external controller DLL’s

Rotor shaft & main bearings:

Shaft: beam elements

Bearings: specific MBS-approach

Bedplate-main frame:

Super-elements, beams etc..

Tower:

beam elements & aerodynamic interaction (tower shadow)

Disk brake, Slip clutch:

MBS approach:

Generator & control:

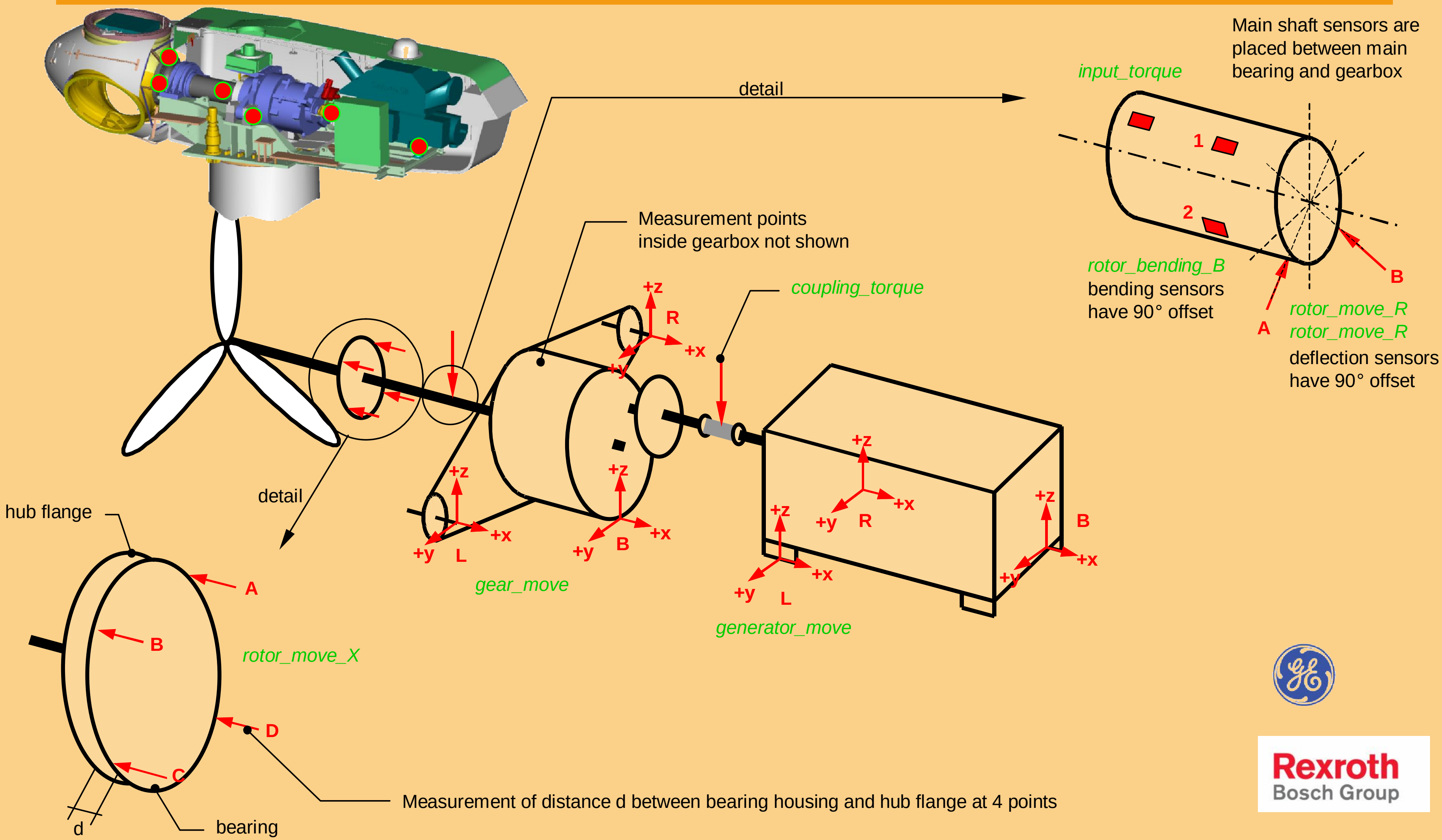
rotor & stator: beam model

generator torque: external controller DLL

Gearbox:

Bearings: non-linear
Gears: flexible non-linear
Shafts: beams
Housing: super-element
Planet carrier: super-element

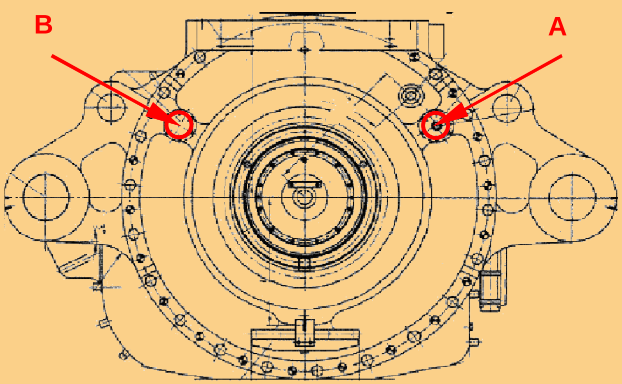
Sensors locations: measurement, simulation

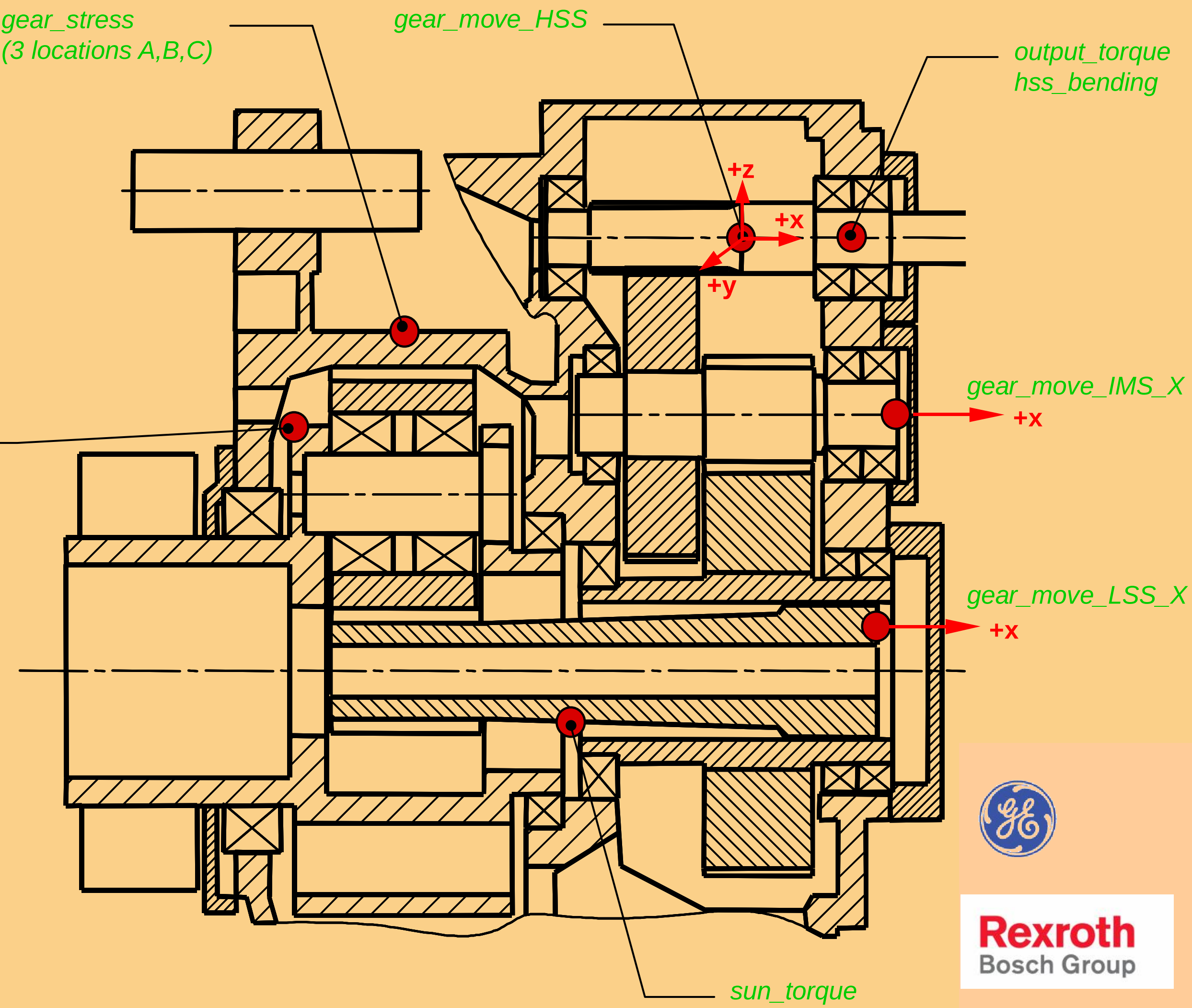


Sensors locations within gearbox

planet carrier movement
measured in axial and
radial direction, sensors
A, B have 120° offset

gear_move_P
(Axial, Radial)

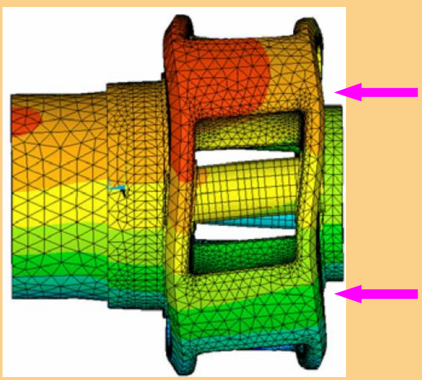




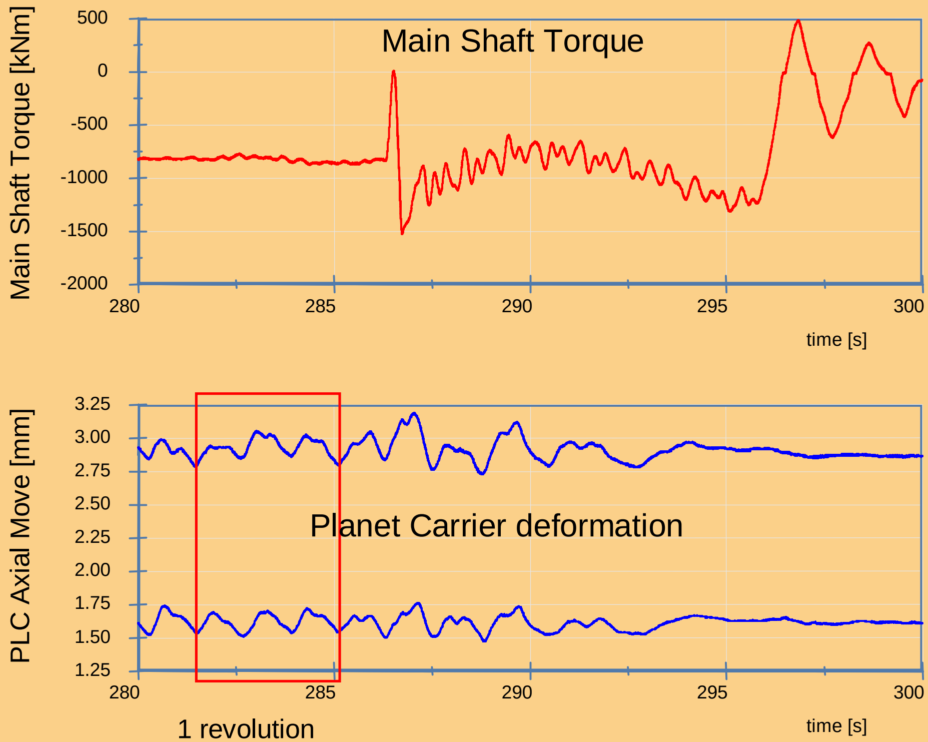
Some interesting findings in measurements

E-Stop Event

Planet Carrier

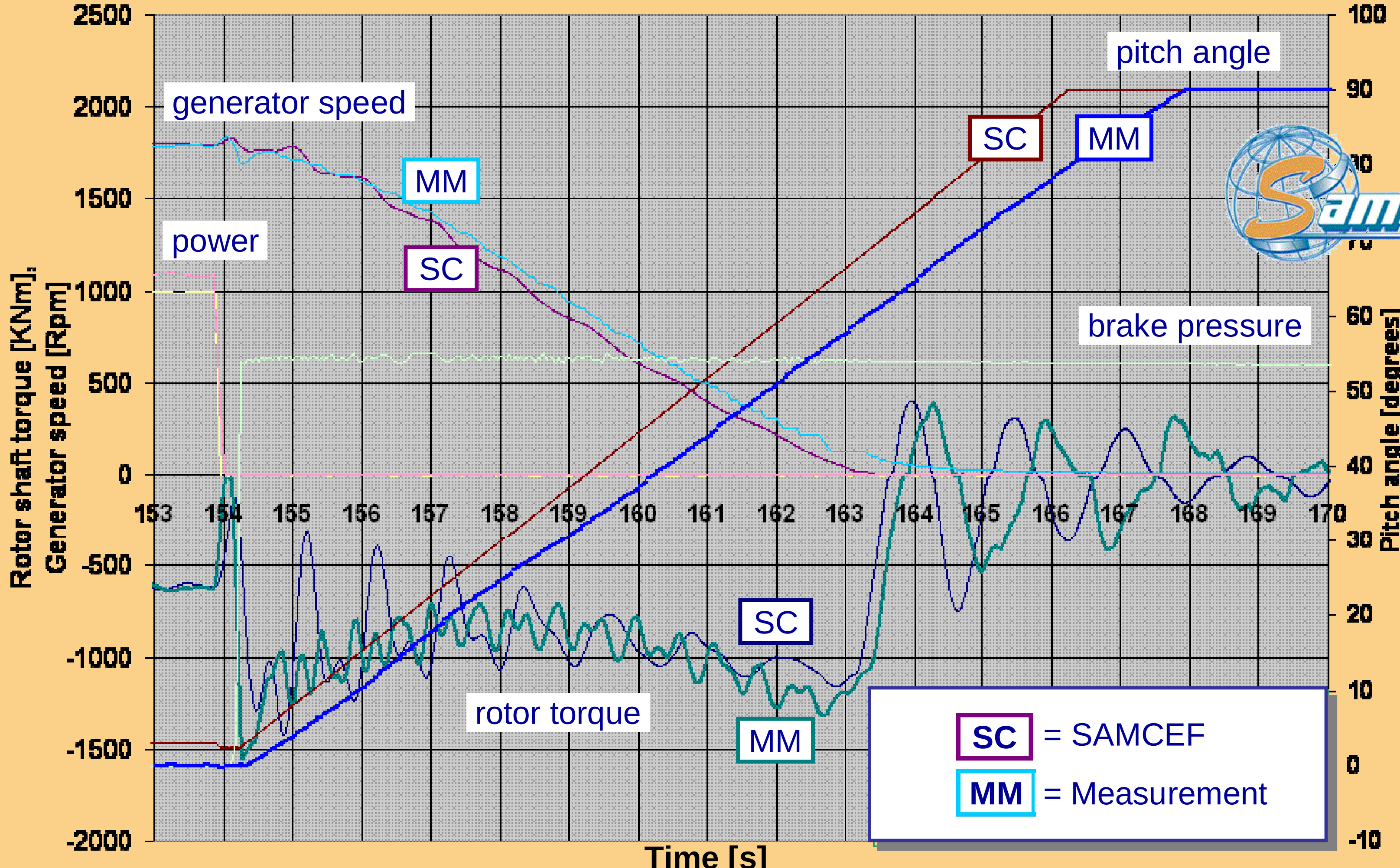


sensor positions 120°



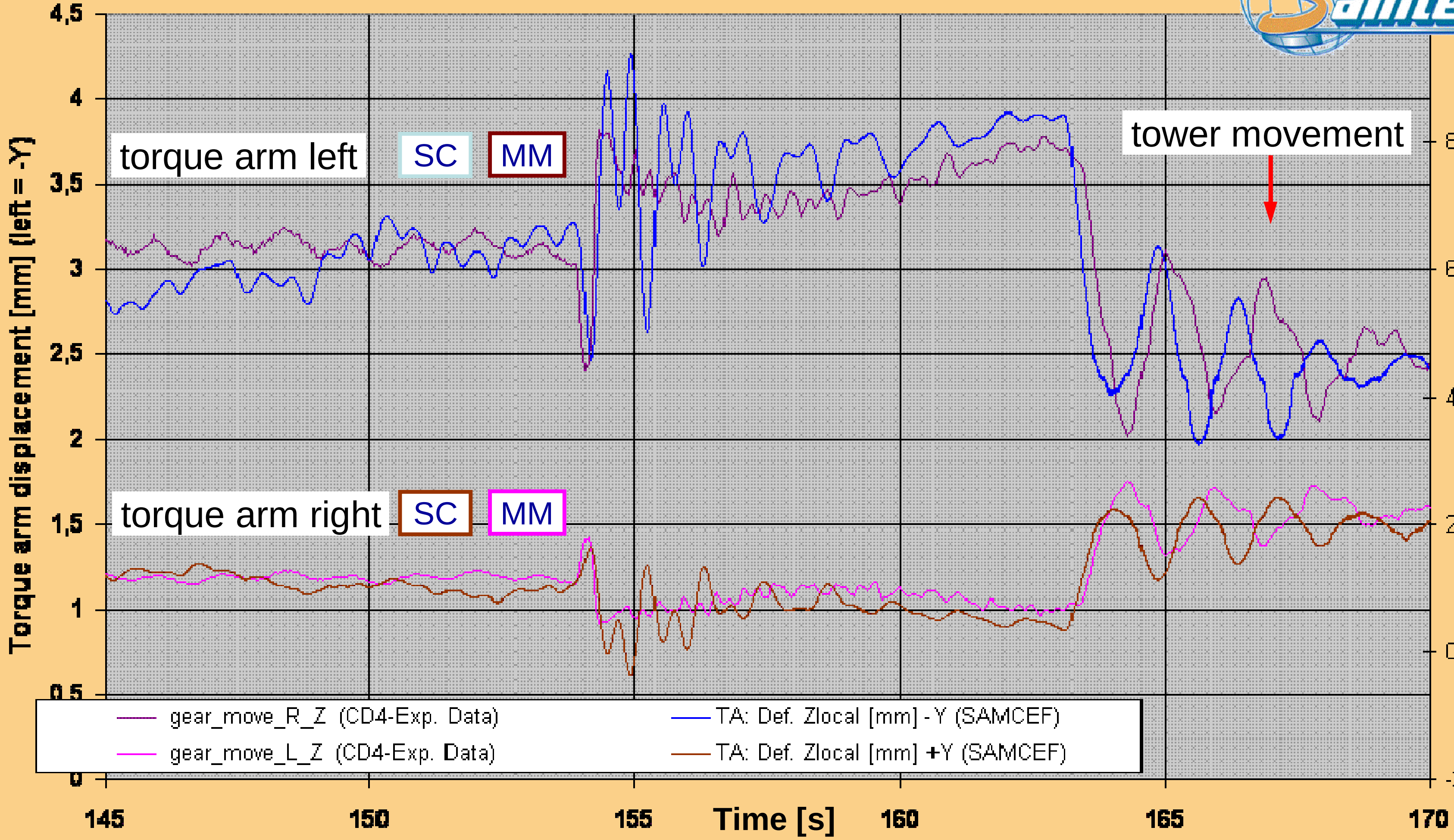
Rotor torque, blade pitch, power, speed

Estop (V_avg = 7.0 m/s) Comparison of experimental data with simulation



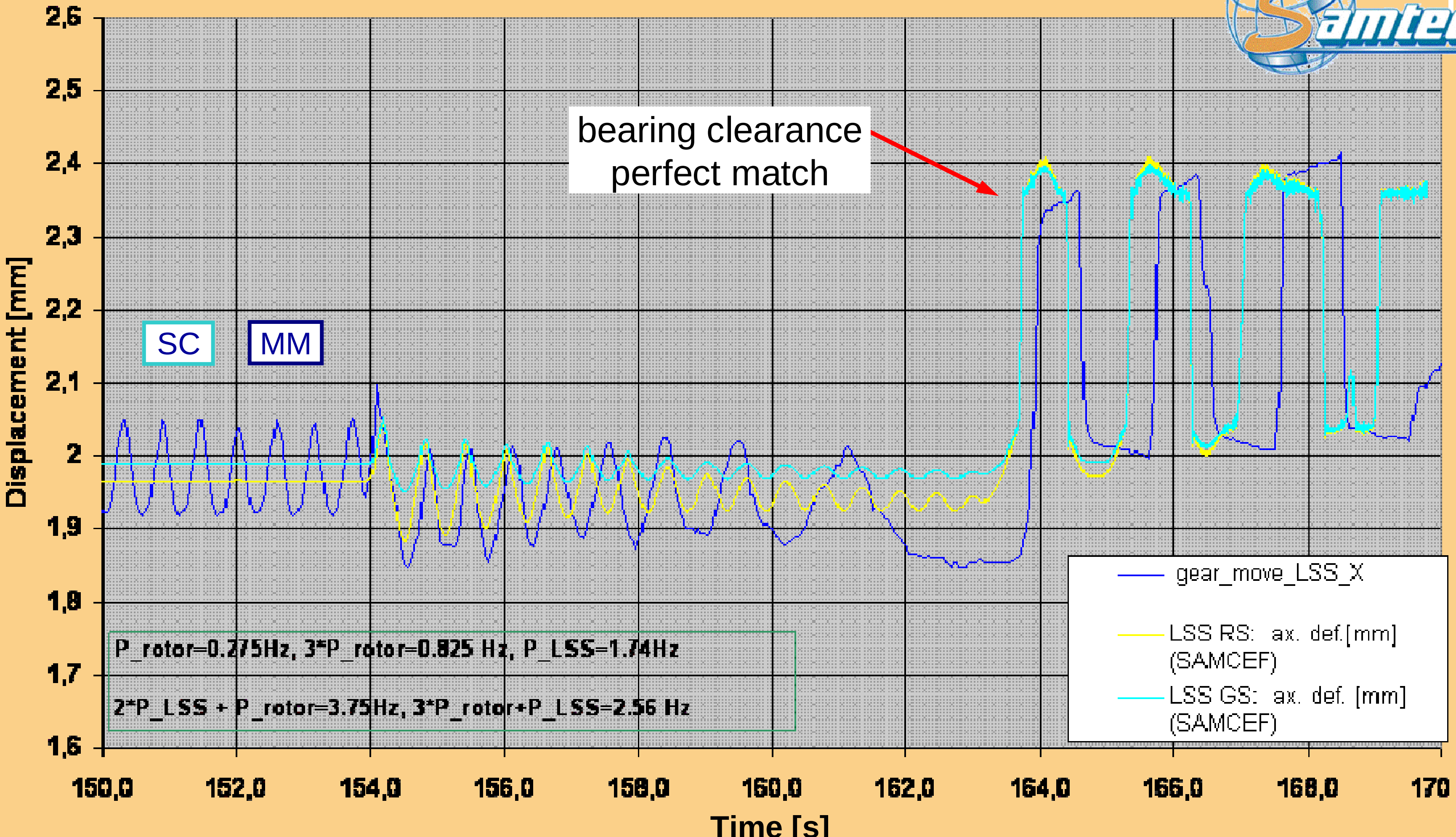
Torque arm displacement - longitudinal

Estop (V_avg = 7.0 m/s)



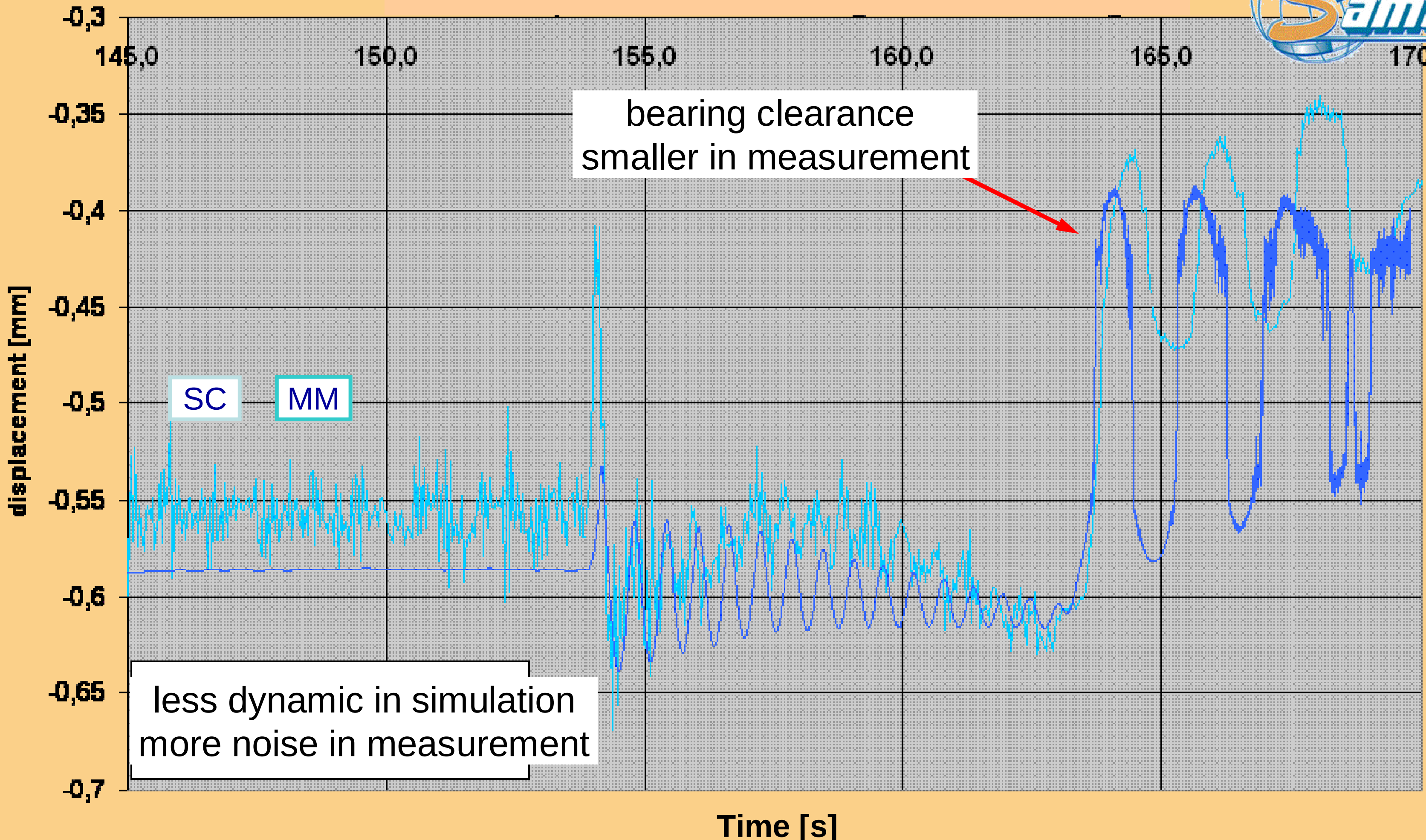
Low speed shaft displacement - axial

Estop (V_avg = 7.0 m/s)



High speed shaft displacement - axial

Estop (V_avg = 7.0 m/s)



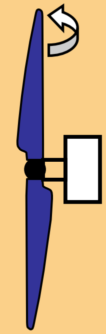
SIXTH FRAMEWORK PROGRAMME

Modeling of defects

Two types of defects are introduced as parameters in the S4WT model:

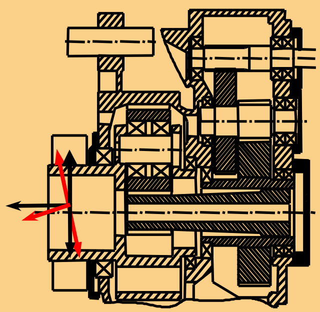
1) Pitch error of 1 blade: 0.1°:

=> excitation of frequency P_rotor



2) Misalignment of rotor shaft and planet carrier:

=> excitation of frequency P_rotor

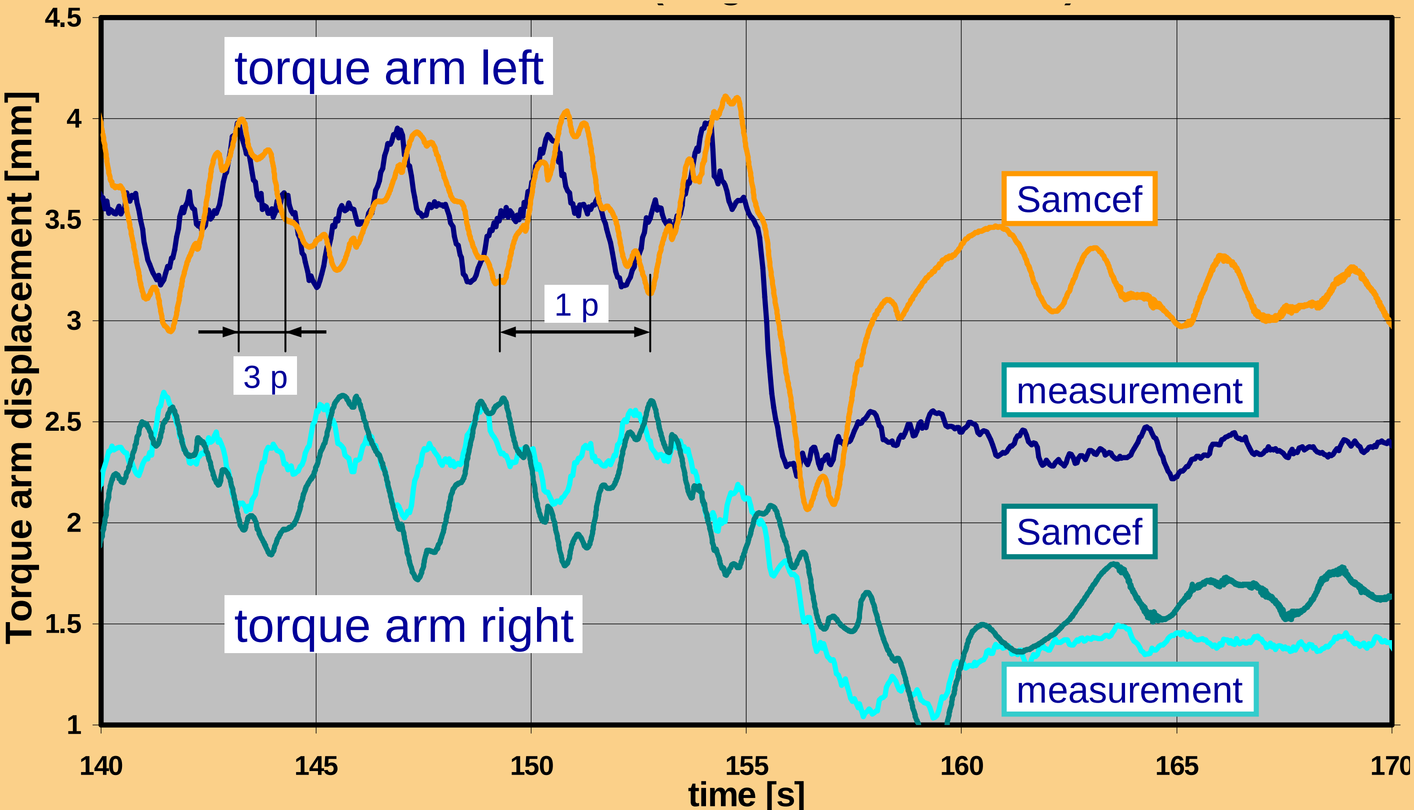


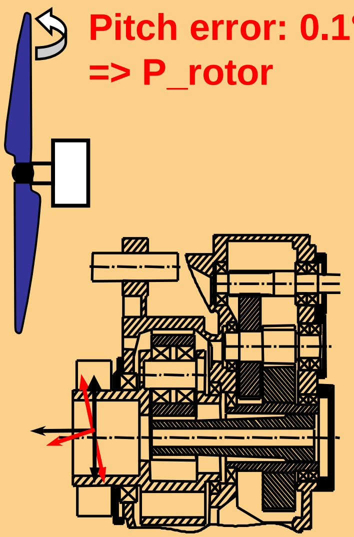
Pitch error & misalignment of main shaft

§ Torque arm displacements show
- 3P_rotor : tower shadow
- 1P_rotor : pitch error

1 P_rotor	= 0.275Hz
3 P_rotor	= 0.825 Hz

Gearbox movement at torque arm bushings (longitudinal – wind direction)



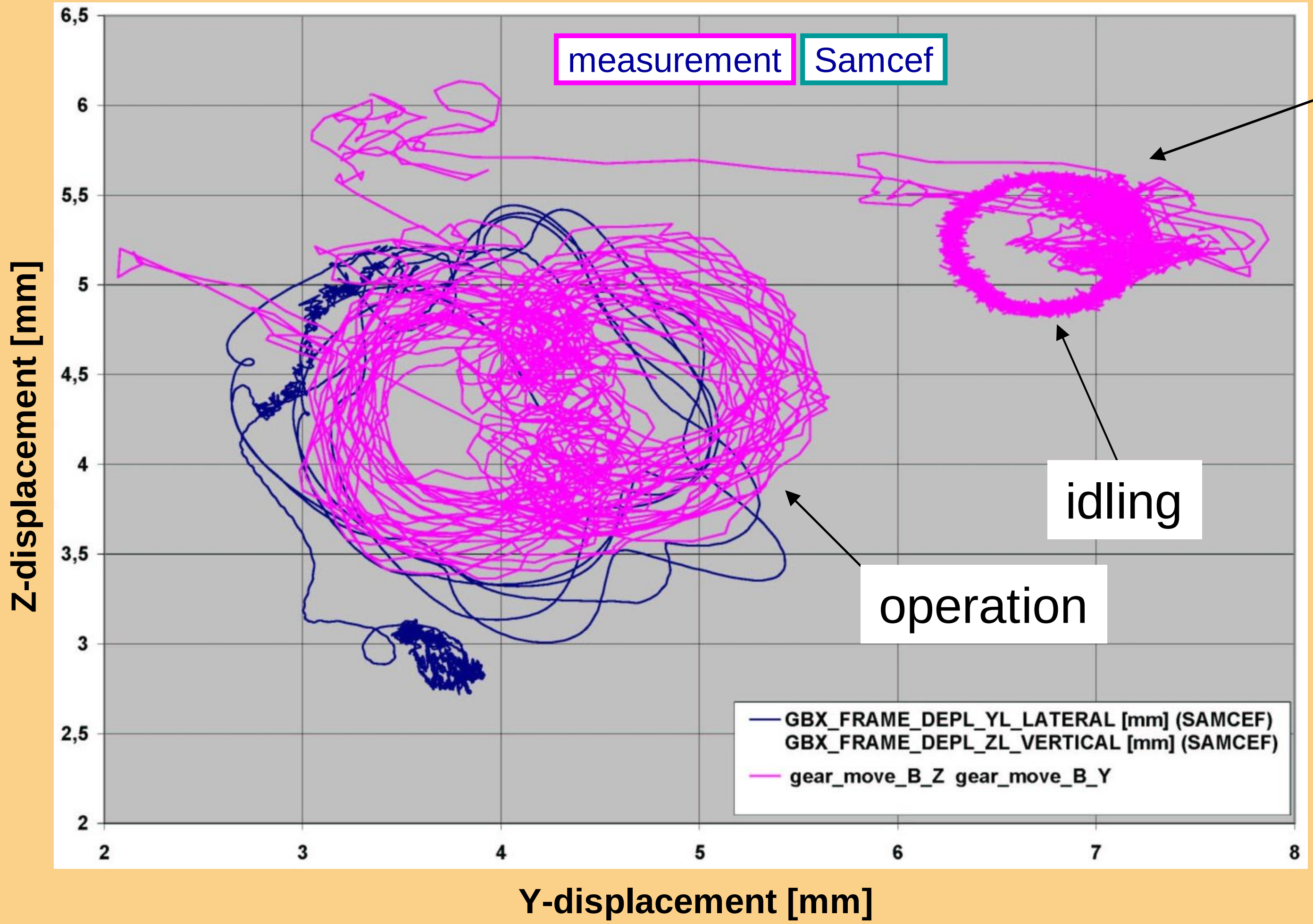


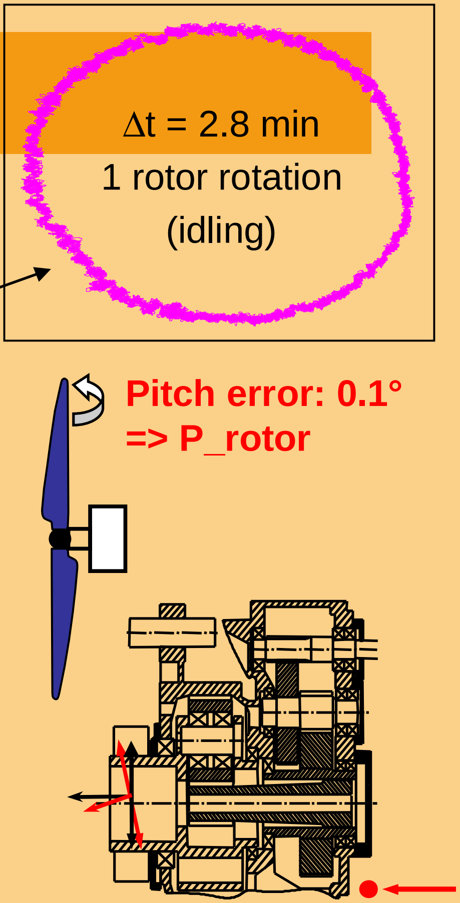
Pitch error: 0.1°
=> P_rotor

Main shaft & planet carrier coupling misalignement:
=> P_rotor

Pitch error and misalignment produces torque arm displacement of frequency P_rotor

Gearbox rear – orbital movement

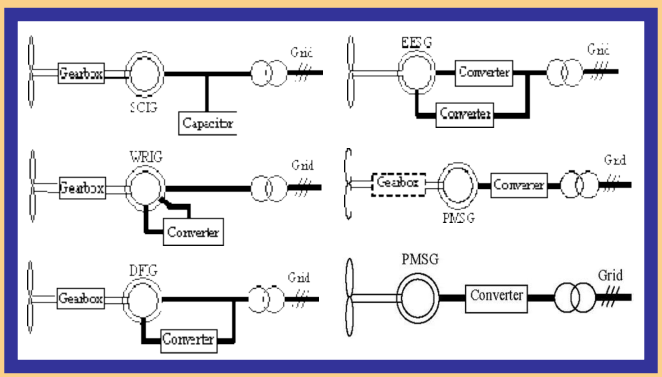


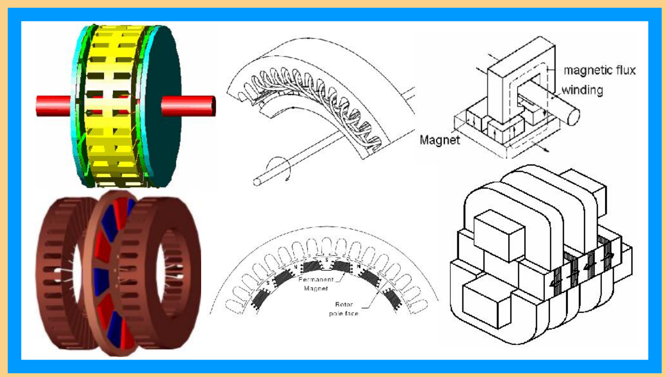


Pitch error and misalignment of main shaft produces gearbox displacement of frequency P_rotor

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

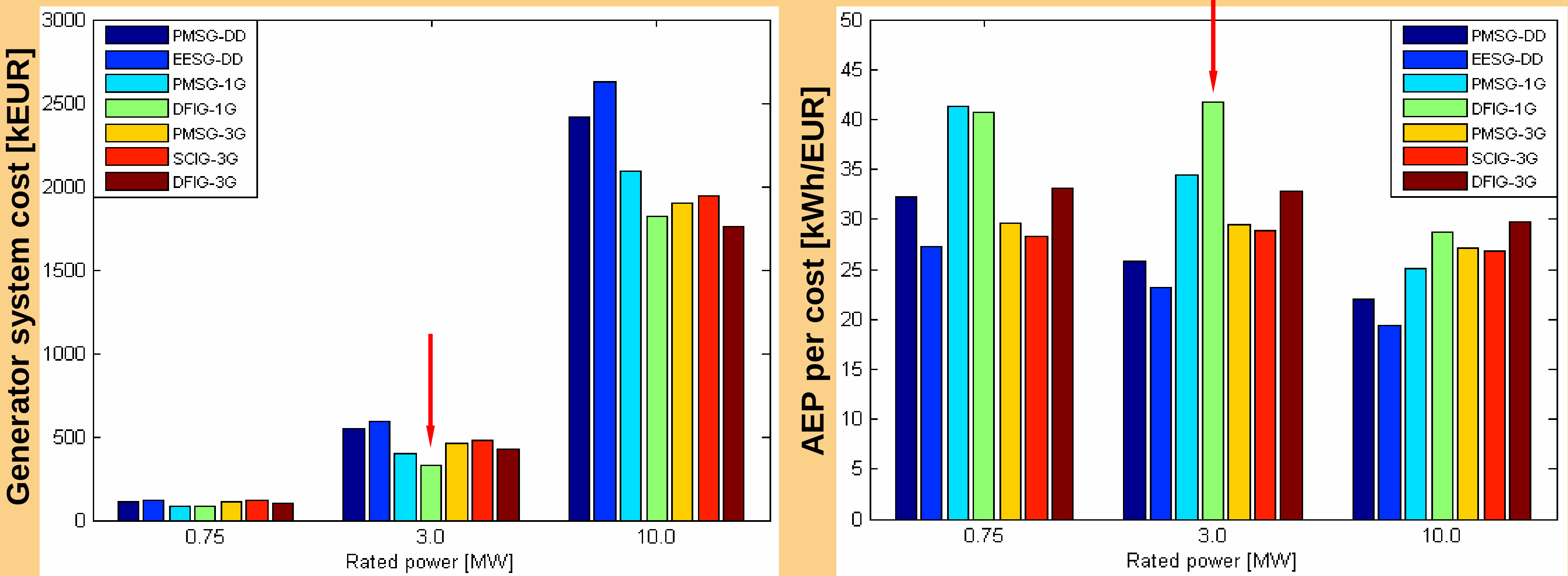




Comparison of generator configurations

- Overview of various wind generator systems
  - Technical features, market situations
- Design models for evaluation of different WTG systems:
  - Drive trains (AEP, gearbox cost, weight, losses)
  - Induction generators and synchronous generators
  - Power electronic converter
- Comparison for the minimum generator system cost
  - Generator system cost includes:
    - active material
    - structural
    - gearbox (if present),
    - power electronic converter
    - other electrical subsystem (transformer, cable, switchgear)

System cost / AEP per cost

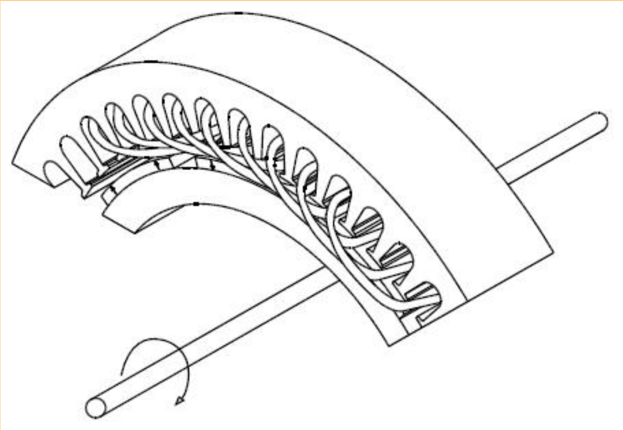


	PMSG_DD	PM synchronous
	EESG_DD	Wound rotor synchronous
	PMSG_1G	PM synchronous single gear stage
	DFIG_1G	Wound rotor induction single gear stage
	PMSG_3G	PM synchronous three gear stages
	DFIG_3G	Wound rotor induction three gear stages
	SCIG_3G	Squirrel cage induction three gear stages

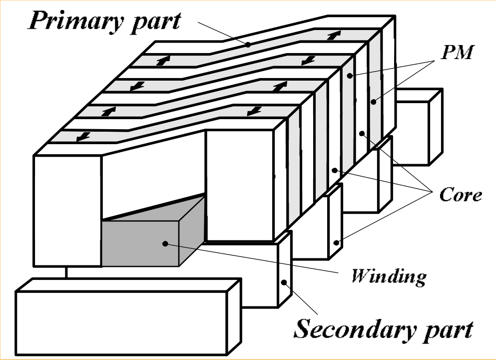
Selection of generator type

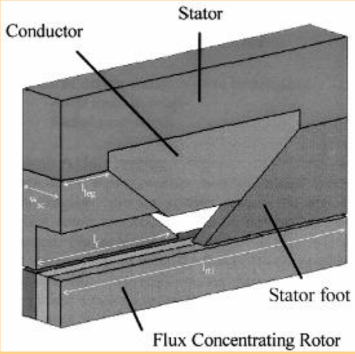
- For active mass reduction:
  Concept with short flux path required

Radial Flux & Axial Flux
PM machine: limited

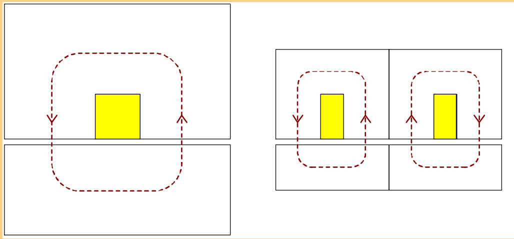


Transversal Flux
PM machine: potential





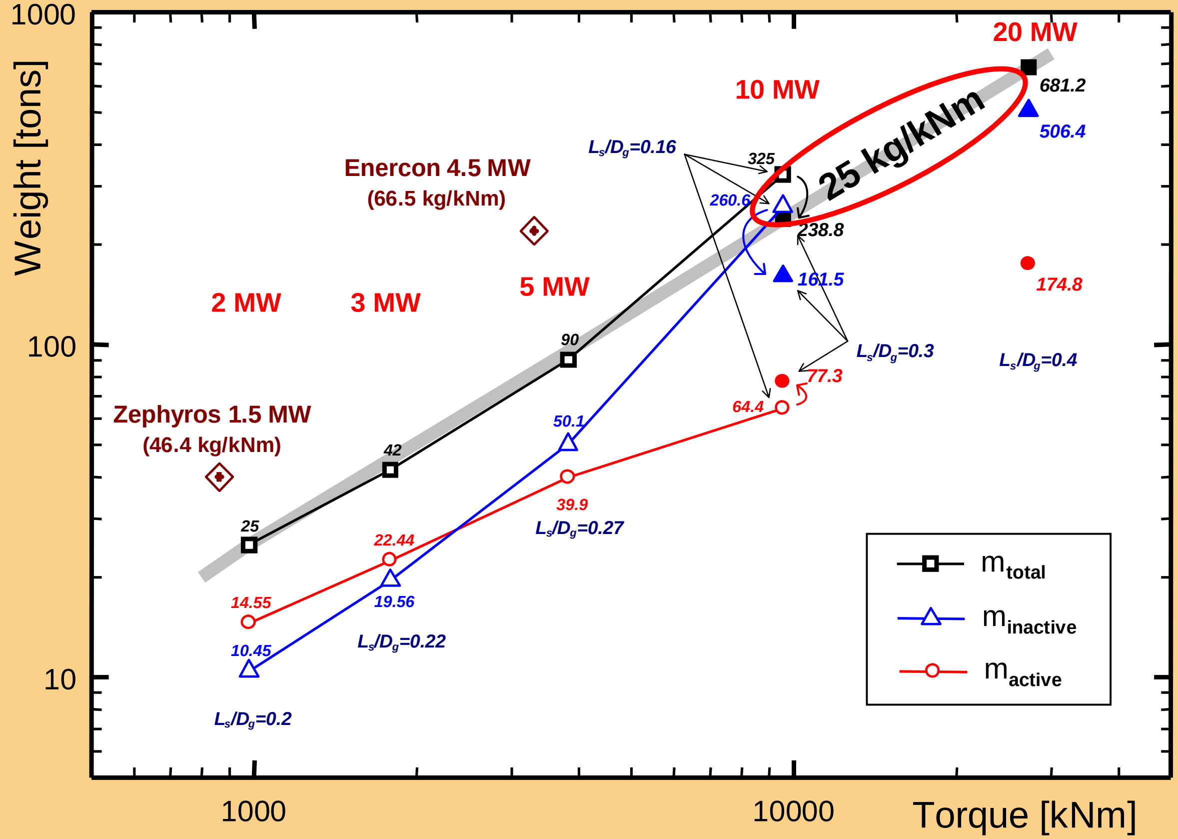
plural module
concept



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

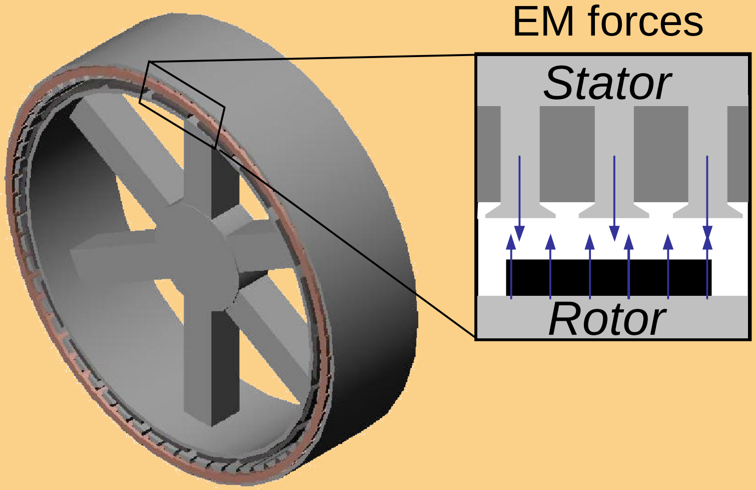


Note: 2, 3, 5 MW : McDonald *et al* (ICEM2006)

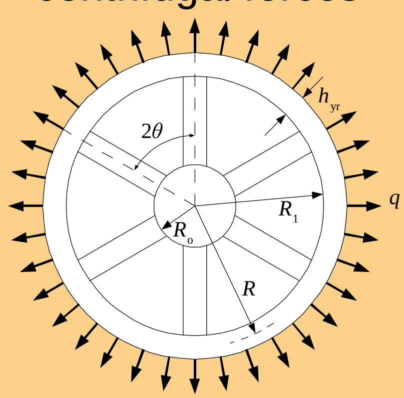
Optimization of the mechanical structure of direct-drive generators

- 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

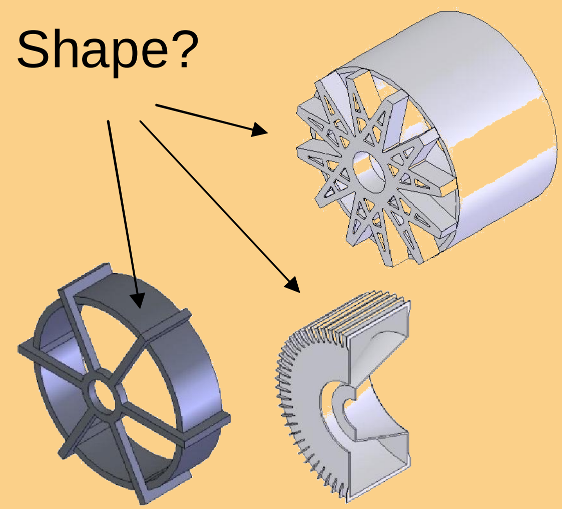
EM forces



centrifugal forces

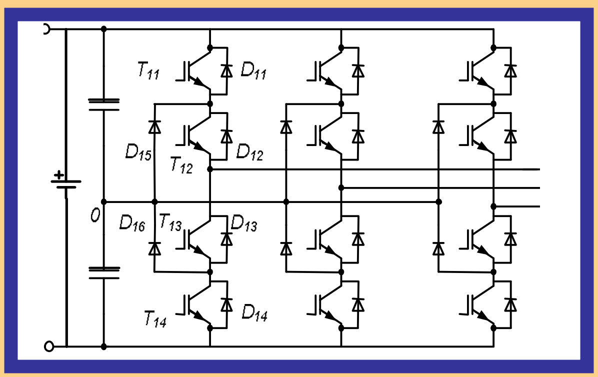


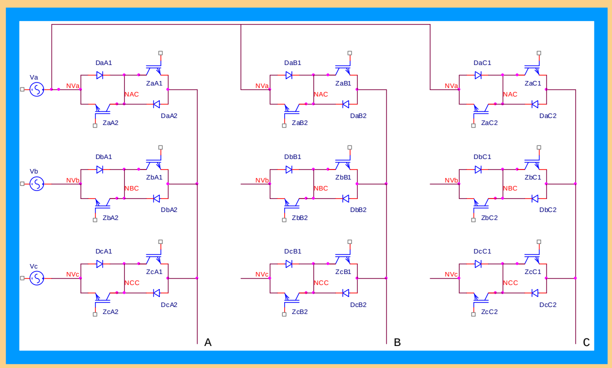
Shape?

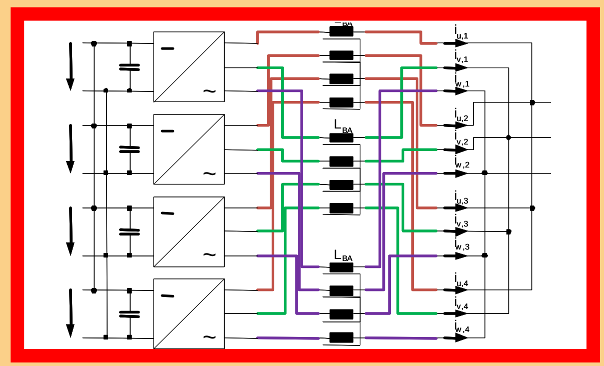


Power Electronics - Converters

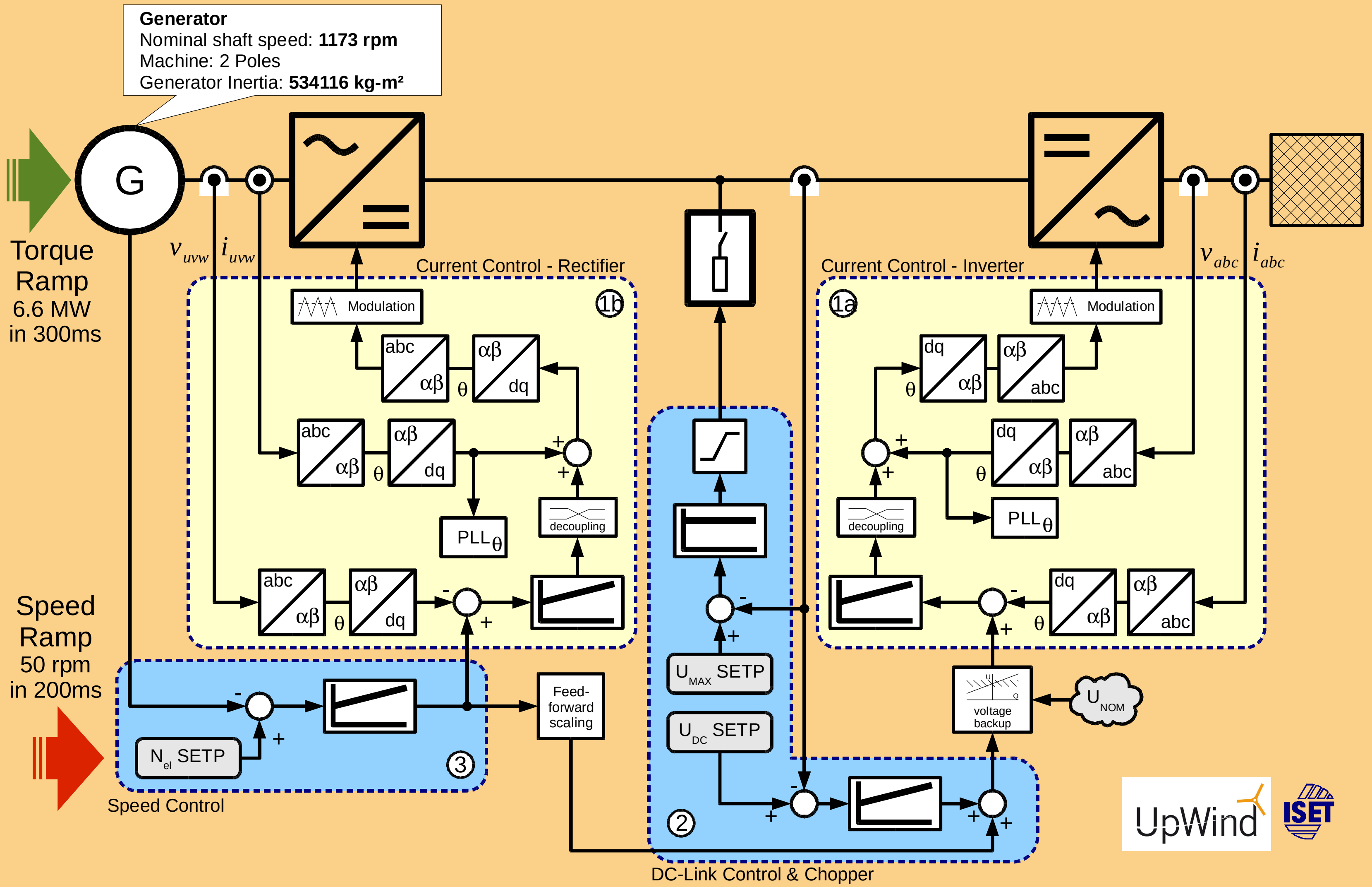
- **ISET:**
  Neutral point clamped converter
- **ROBOTIKER:**
  Matrix converters
- **GE Global Research:**
  Interleaved converter







Neutral point clamped converter (NPC)



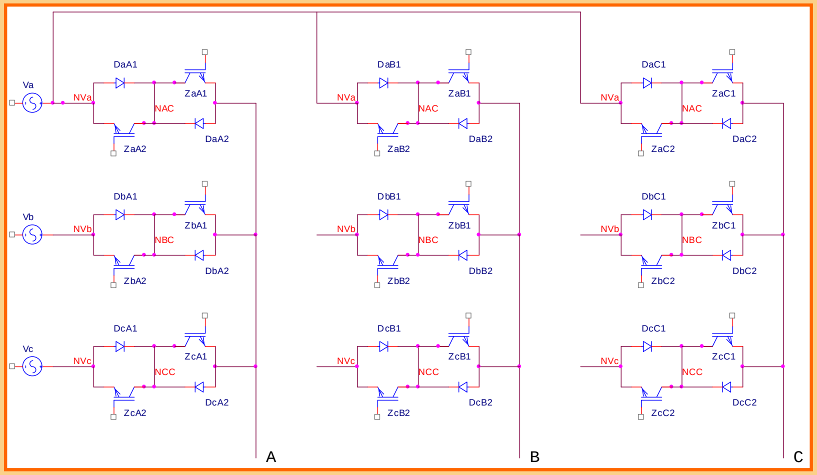
Neutral point clamped converter (NPC)

- Control strategy for NPC converter developed
- Worst case operating conditions were considered
  - Sudden change in input power
  - Sudden change in the shaft speed setpoint
- Forwarding information about scheduled turbine power production may have positive impact on performance

- NPC has little or no redundancy in power electronic devices
- Good robustness against symmetrical and unsymmetrical grid faults to ground
- For prevention of isolation failures to ground a isolation transformer is required

Matrix converter

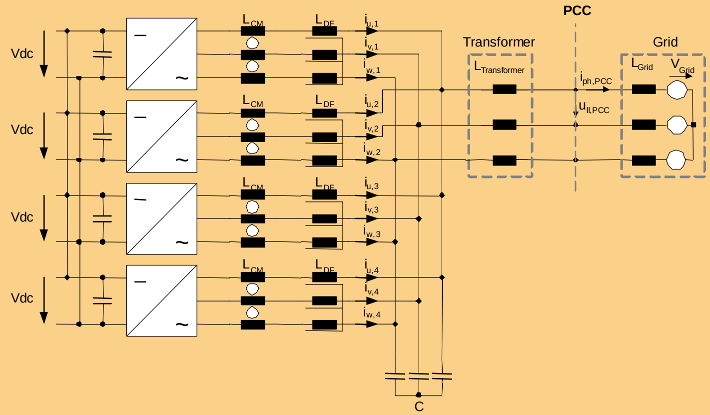
- An “all silicon” AC/AC converter formed by n x m bidirectional switches, without significant reactive elements.
- Promising technology that may contribute to the development of multi-megawatt wind turbines. Further research is needed:
  - Technological barrier: absence of tailor made bidirectional switches → cooperation with semiconductor manufacturers
  - Poor ride through capability against grid disturbances
  - Experimental validation
  - Fault tolerant behaviour

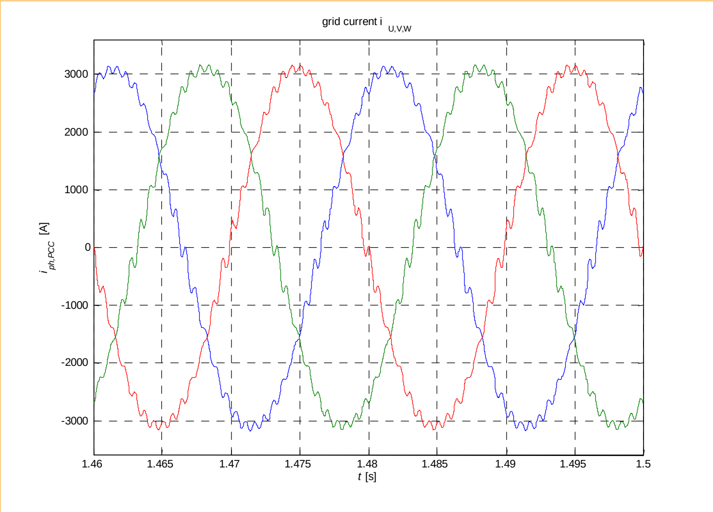


Not a mature technology

Interleaved converter

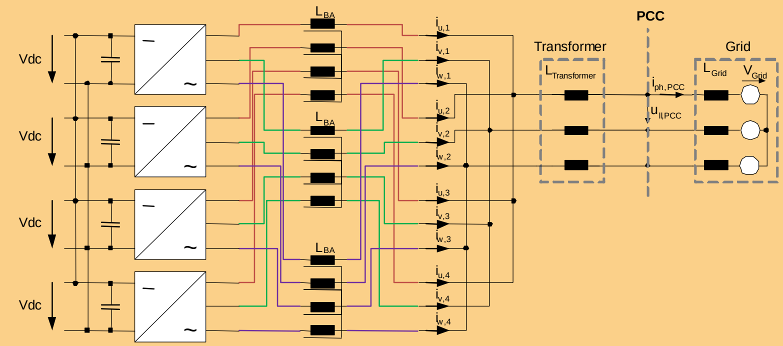
Conventional Design

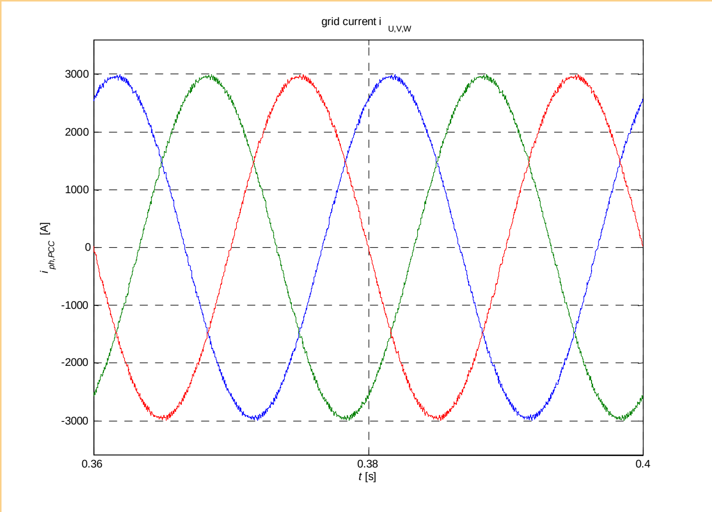




Phase currents at PCC

New Design and Modulation Method





Phase currents at PCC

Interleaved converter

- New modulation and control method for parallel connected inverters is proposed
- Modulation scheme uses a 5-level modulator and a cross current controller instead of 2-level modulation with phase shifted carriers
  - → Better Voltage spectrum
  - → No differential and no common mode choke required
- Disadvantage:
  - → Large voltage differences between converters
  - → Large cross currents
  - → Compensation: a new balancing choke is required

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