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Design of a 10MW Drivetrain Architecture

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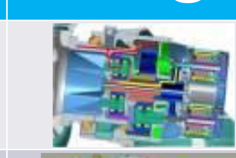
Abstract

Drivetrain architecture still plays an important role in overall system reliability and energy efficiency. The known reliability issues with conventional gearboxes is leading to investigation and implementation of alternative configurations, such as two-stage gearboxes with a medium speed (100 - 400 rpm) generator, single stage gearboxes with a low speed (~90 rpm) generator, as well as direct drive. The premise of the study was to determine that most optimal drivetrain architecture for a hypothetical 10MW offshore turbine through architecture benchmarking and conceptual design.

Approach

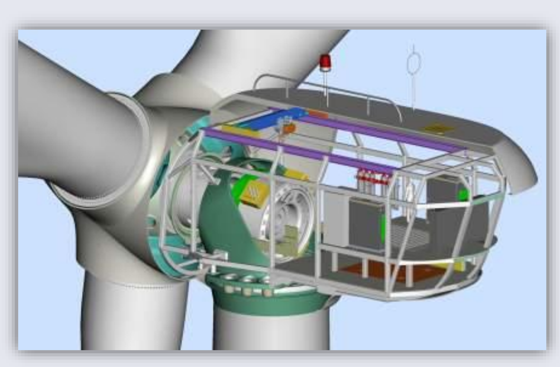
The study began with an evaluation of the technology and patent landscape in order to determine how technology evolved and what comprises the current state of the art. Next, 5 design alternatives were chosen based on currently commercially available technology and then CAD models and associated FEAs were completed to model the 5 concepts. Sensitivity studies for each concept were undertaken to determine the optimum around CapEx and weight, with adjustment of air gap diameter, torque, bearing type and gearbox architecture.

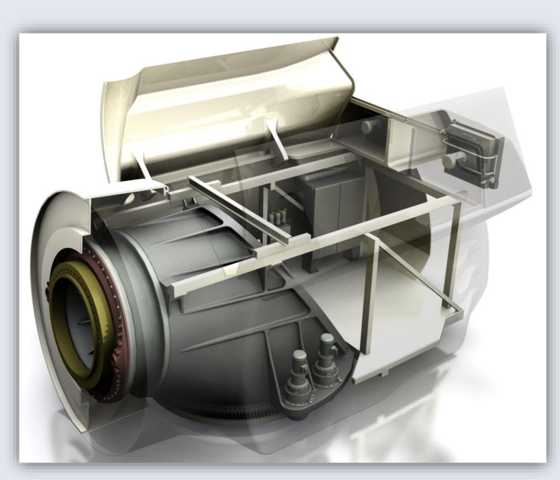
Benchmarking / Evaluation

Architecture		Generator		Drivetrain / System				
Type	Image	Rating	Speed	Head Mass	Part Count	Efficiency	CapEx	CoE
3 Stage, High		10.4MW	2275rpm	498,000kg	900	87.1%	€3,136,899	€132/MWh
2 Stage, Med		10.4MW	230rpm	498,000kg	849	88.9%	€3,136,899	€132/MWh
1 Stage, Low		10.4MW	92rpm	493,800kg	883	90.6%	€3,131,773	€132/MWh
DD – Radial		10.4MW	11.5rpm	570,200kg	1,057	90.9%	€5,192,401	€136/MWh
DD – Axial		10.4MW	11.5rpm	577,900kg	2,197	92.1%	€5,511,181	€142/MWh

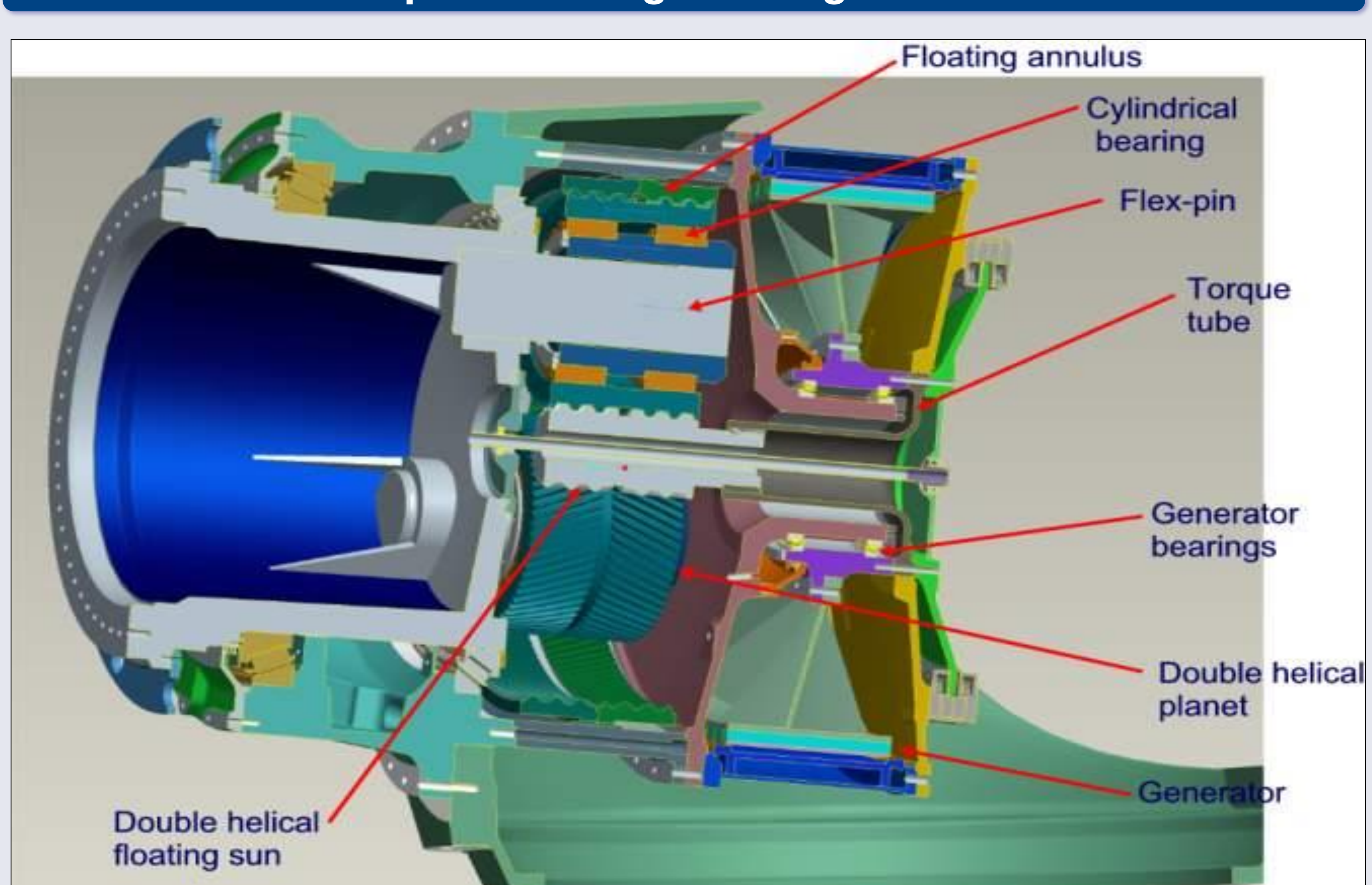
Design Drivers

- Lower cost of energy
  - High overall system efficiency
  - Minimal commodities impact
- Simplified design
  - Increased reliability through reduced part count
  - Sub-system redundancy
- Ease of operations and maintenance
  - Condition monitoring supported
  - Predictive maintenance enabled





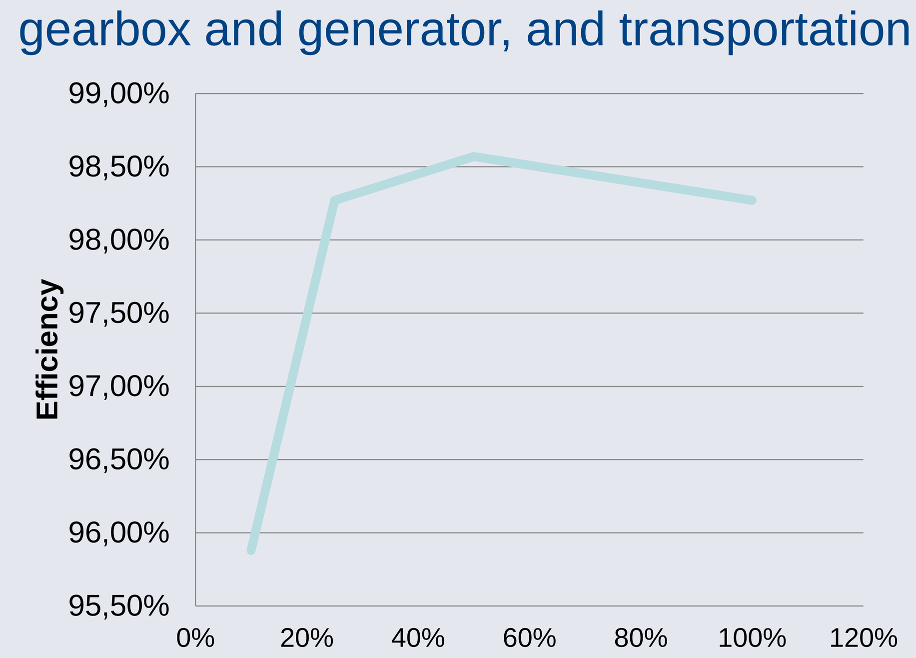
Optimal Design Configuration

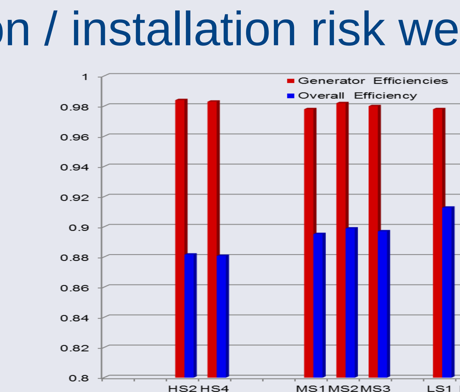


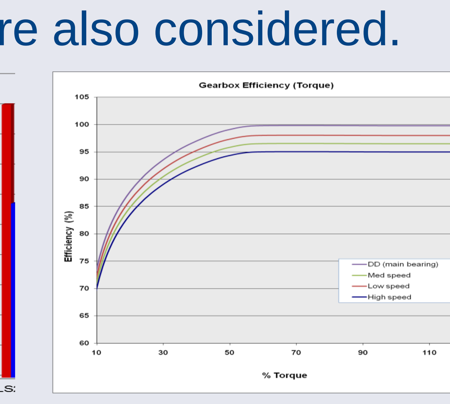
Floating annulus, ring gear
- Three planet
- 7.696:1 gear ratio
- Planets supported on self-aligning bearings

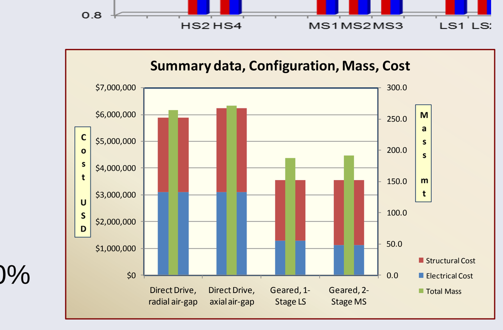
Evaluation Method

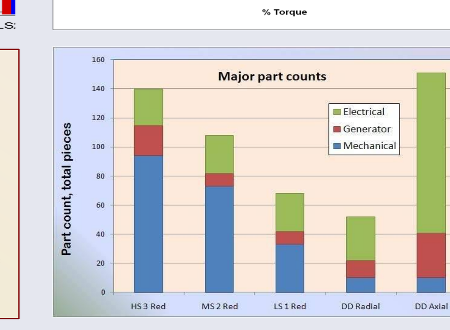
Overall system efficiency, torque rating, part count, reliability, sub-component cost, manufacturing and operating costs were evaluated for each of the designs. Ancillary factors, such as cooling, yaw system demand, tower load, up-tower serviceability of gearbox and generator, and transportation / installation risk were also considered.











Design Type	Rated Power	75% Rated	50% Rated	25% Rated	10% rated
High Speed	420 kVA	360 kVA	320 kVA	160 kVA	140 kVA
Medium Speed	360 kVA	320 kVA	260 kVA	120 kVA	120 kVA
Low Speed	320 kVA	280 kVA	240 kVA	100 kVA	100 kVA
Direct Drive	240 kVA	200 kVA	160 kVA	95 kVA	95 kVA

Total power losses for each major configuration were assessed.

Mass and cost of the optimal design was calculated.

Component	Sub-component	Mass	Total Cost
Gearbox / Structure	Ductile Iron	83,584 kg	€ 625,212
	Precision Machined Components	74,509 kg	€ 1,401,853
Generator / Electrical	Magnets	1,802 kg	€ 108,467
	Copper Windings	2,497 kg	€ 62,629
	Electrical Back-iron	3,365 kg	€ 33,760
	Rotor Ductile Iron	22,400 kg	€ 252,824
	Precision Machined Components	600 kg	€ 17,033
	Ancillary Electrical Equipment	Nominal	€ 655,767
	TOTAL	188,757 kg	€ 3,131,773

Conclusions

From the study results it is clear that from the standpoint of lowest Cost of Energy, lowest Tower Head Mass, acceptable overall system efficiency, as well as ease of service, the single-stage, low-speed concept appears to be the most viable option. The passive, self-aligning mesh is insensitive to system deflections which accounts for the high reliability in the system. To date, this type of single-stage design has seen very limited commercial introduction so far, but wider adoption is anticipated.