DTU Wind Energy
Department of Wind Energy

Variation of Extreme and Fatigue Design Loads on the Main Bearing of a Front Mounted Direct Drive System

Asger Bech Abrahamsen and Anand Natarajan

Technical University of Denmark, Department of Wind Energy, Frederiksborgvej 399, 4000 Roskilde, Denmark

The drivetrain of a 10 MW wind turbine has been designed as a direct drive transmission with a superconducting generator mounted in front of the hub and connected to the main frame through a King-pin stiff assembly. It is found that the initial generator weight of 363 tons must be reduced by 25% in order not to result in higher extreme loads on main and yaw bearing than the 10 MW geared reference drive train. A weight reduction of 50% is needed in order to maintain main bearing fatigue damage equivalent to the reference drive train. Thus a target mass of superconducting direct drive generators is found to be between 183-272 tons.

Front mounted 10 MW superconducting generators

- Superconducting generators can provide high shear forces
- A 10 MW generator design based on MgB_2 as start (m = 363 t)
- Length scaled to obtain the 10 MW light weight design of GE based on the NbTi low temperature superconductor (m = 142 t, table A2)
- King-Pin nacelle configuration with two main bearings (10-20 MW)
- 10 MW INNWIND.EU onshore reference turbine (table A1)
- Design Load Cases (DLC): 1.3 Normal operation under extreme turbulence and 2.3 Gust + Grid loss

Results & Discussion

- Extreme loads of DLC 2.3 on main and yaw bearing are shown for m = 40, 50, 75 and 100% of initial generator mass as well as reference medium speed drive train in fig 2 and 3. A reduction to 75 % mass gives equal main bearing extreme. Yaw bearing extreme are high, but within the design envelope.
- Fatigue loads of DLC 1.2 on yaw and main bearing are shown in figure 4. A reduction to 50 % is needed to obtain main bearing fatigue similar to the reference medium speed drive train.

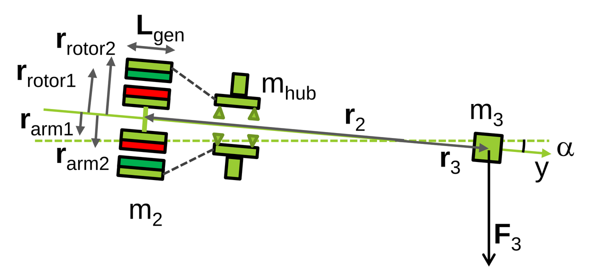


Table A1. Properties of INNWIND.EU 10 MW reference nacelle as represented in the aeroelastic model as well as the King-pin nacelle adapted to hold a 10 MW MgB_2 generator.

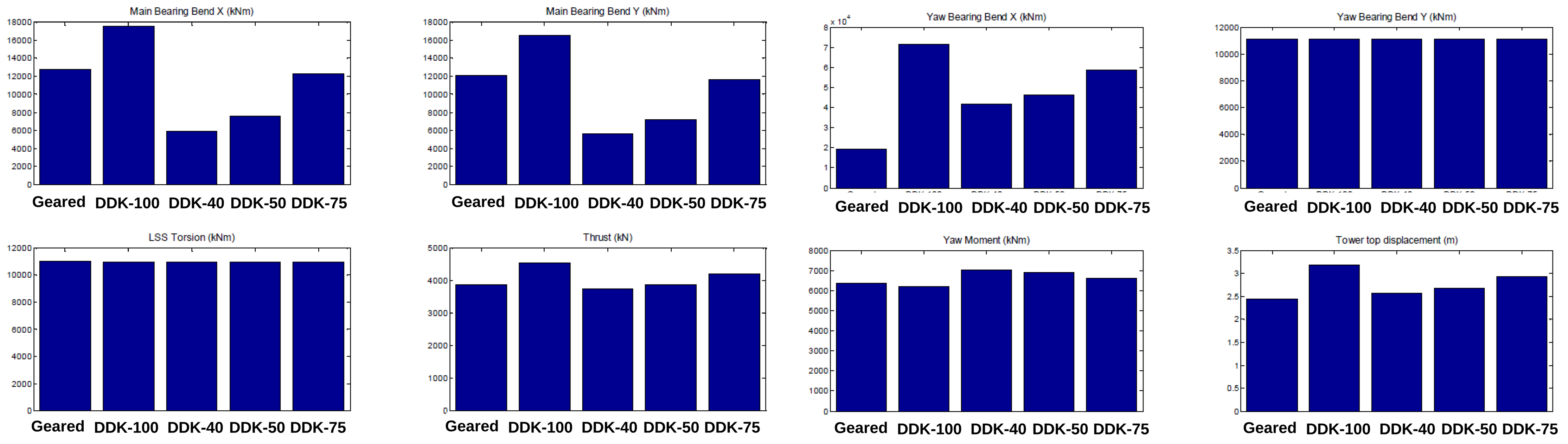
Nacelle properties	DTU 10 MW	SCDD 10 MW
Distance along Shaft from Hub Center to Yaw Axis (m)	7,07	6,09
Distance along Shaft from Hub Center to Main Bearing (m)	2,7	2,1
Hub Mass (kg)	105520	163669
Hub Inertia about Low-Speed Shaft (kg m^2)	3,26E+05	1,40E+06
Nacelle Mass (kg)	446036	140813
Nacelle Inertia about Yaw Axis (kg m^2)	7,33E+06	2,87E+06
Nacelle Inertia about rotation axis vertical (kg m^2)		3,60E+06
Nacelle Inertia about rotation axis horizontally (kg m^2)		1,14E+06
Nacelle CM Location Downwind of Yaw Axis (m)	2,68	3,31
Nacelle CM Location above Yaw Bearing (m)	2,45	2,34
Tilt of shaft, α (degrees)	5	5
DRIVE TRAIN		
Rated Rotor Speed (rpm)	9,6	9,6
Rated Generator Speed (rpm)	480	9,6
Gearbox Ratio	50:1	None
Electrical Generator Efficiency (%)	94	94
Generator Inertia About Medium-Speed Shaft (kg m^2)	1501	1,15E+06
Fully-Deployed Medium-Speed Shaft Brake Torque (N-m)	52254	None
Medium-Speed Shaft Brake Time Constant (sec)	0,74	None

Table A2. Mass and moment of inertia properties of 10 MW MgB_2 superconducting direct drive generator which is reduced in mass by reducing the length down to 40% of the initial design in order to approach the generator weigh proposed by the 10 MW NbTi machine of GE [9].

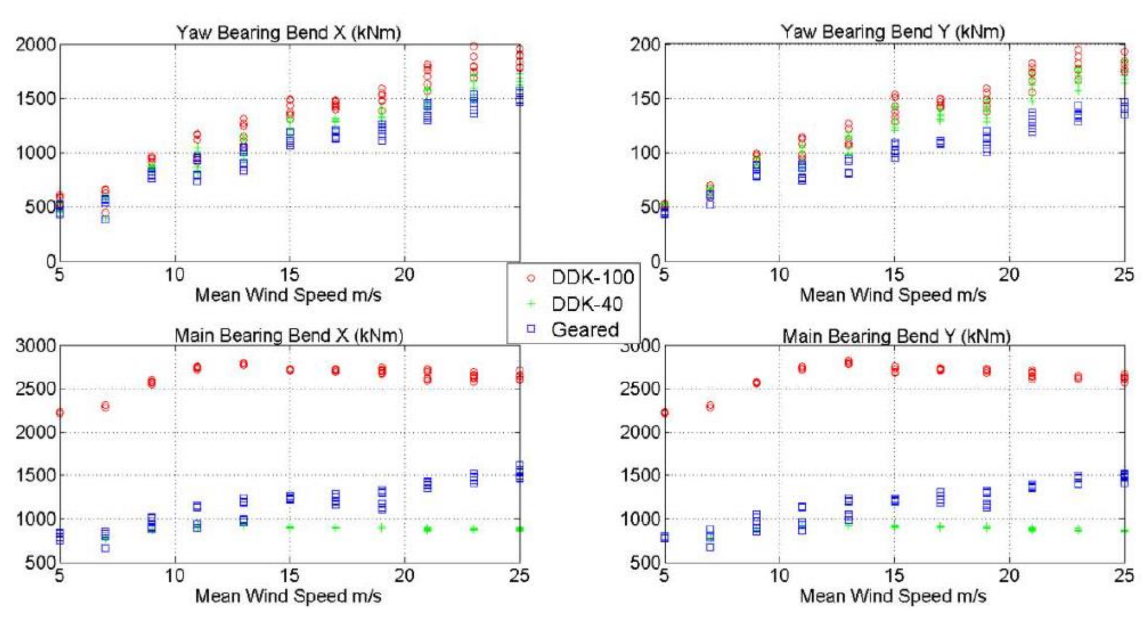
Generator rotor	SCDD MgB_2 10MW	SCDD 75 % Lgen	SCDD 50 % Lgen	SCDD 40%Lgen	GE NbTi 10 MW
Length [m]	2,44	1,83	1,22	0,98	1,88
$Radius_{outer}$ [m]	3,264	3,264	3,264	3,264	2,415
$Radius_{mid}$ [m]	3,146	3,146	3,146	3,146	2,291
$Radius_{inner}$ [m]	3,006	3,006	3,006	3,006	2,164
$Density_{outer}$ [kg/m^3]	7200	7200	7200	7200	7750
$Density_{inner}$ [kg/m^3]	7200	7200	7200	7200	6865
Fill $factor_{out}$	1,00	1,00	1,00	1,00	1,00
Fill $factor_{in}$	0,59	0,59	0,59	0,59	1,00
$Mass_{outer}$ [kg]	4,17E+04	3,13E+04	2,09E+04	1,67E+04	2,67E+04
$Mass_{inner}$ [kg]	2,80E+04	2,10E+04	1,40E+04	1,12E+04	2,29E+04
$Mass_{active\ total}$ [kg]	6,98E+04	5,23E+04	3,49E+04	2,79E+04	4,96E+04
$Mass_{suport}$ [kg]	7,00E+04	5,25E+04	3,50E+04	2,80E+04	
$Mass_{total}$ [kg]	1,40E+05	1,05E+05	6,99E+04	5,59E+04	4,96E+04
I_{outer} [kg m^2]	4,29E+05	3,22E+05	2,14E+05	1,71E+05	1,48E+05
I_{inner} [kg m^2]	2,65E+05	1,99E+05	1,33E+05	1,06E+05	1,14E+05
$I_{activetotal}$ [kg m^2]	6,94E+05	5,21E+05	3,47E+05	2,78E+05	2,62E+05
$I_{rotor\ support}$ [kg m^2]	4,58E+05	3,44E+05	2,29E+05	1,83E+05	
$I_{rotor\ total}$ [kg m^2]	1,15E+06	8,64E+05	5,76E+05	4,61E+05	2,62E+05
Generator stator					
$Mass_{stator\ active}$ [kg]	8,32E+04	6,24E+04	4,16E+04	3,33E+04	1,73E+04
$Mass_{stator\ support}$ [kg]	7,00E+04	5,25E+04	3,50E+04	2,80E+04	3,81E+04
$Mass_{stator\ total}$ [kg]	153284	114963	76642	61314	55319
Gen active mat					
$Mass_{rotor\ active}$ [kg]	6,98E+04	5,23E+04	3,49E+04	2,79E+04	4,96E+04
$Mass_{stator\ active}$ [kg]	8,32E+04	6,24E+04	4,16E+04	3,33E+04	1,73E+04
$Mass_{active\ total}$ [kg]	153000	114750	76500	61200	66886
Gen support mat					
$Mass_{rotor\ support}$ [kg]	1,40E+05	1,05E+05	6,99E+04	5,59E+04	3,81E+04
$Mass_{stator\ support}$ [kg]	7,00E+04	5,25E+04	3,50E+04	2,80E+04	3,81E+04
$Mass_{support\ total}$ [kg]	2,10E+05	1,57E+05	1,05E+05	8,39E+04	7,61E+04
$Mass_{generator\ total}$ [kg]	362836	272127	181418	145134	143000
Position[a] [m]	10,74	10,44	10,13	10,01	10,46

[a]Generator center of mass position along y-axis with respect to yaw axis.

Extreme DLC 2.3



Fatigue DLC 1.2



Conclusion

The mass of the front mounted superconducting generator should be reduced to 75% to provide equal extreme loads, whereas the fatigue load on the yaw bearing indicate a reduction to 50 %. Thus aero-elastic simulation indicate a target mass of 183-272 tons.

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