

Exemplar Wind Turbines

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Theme X Workshop

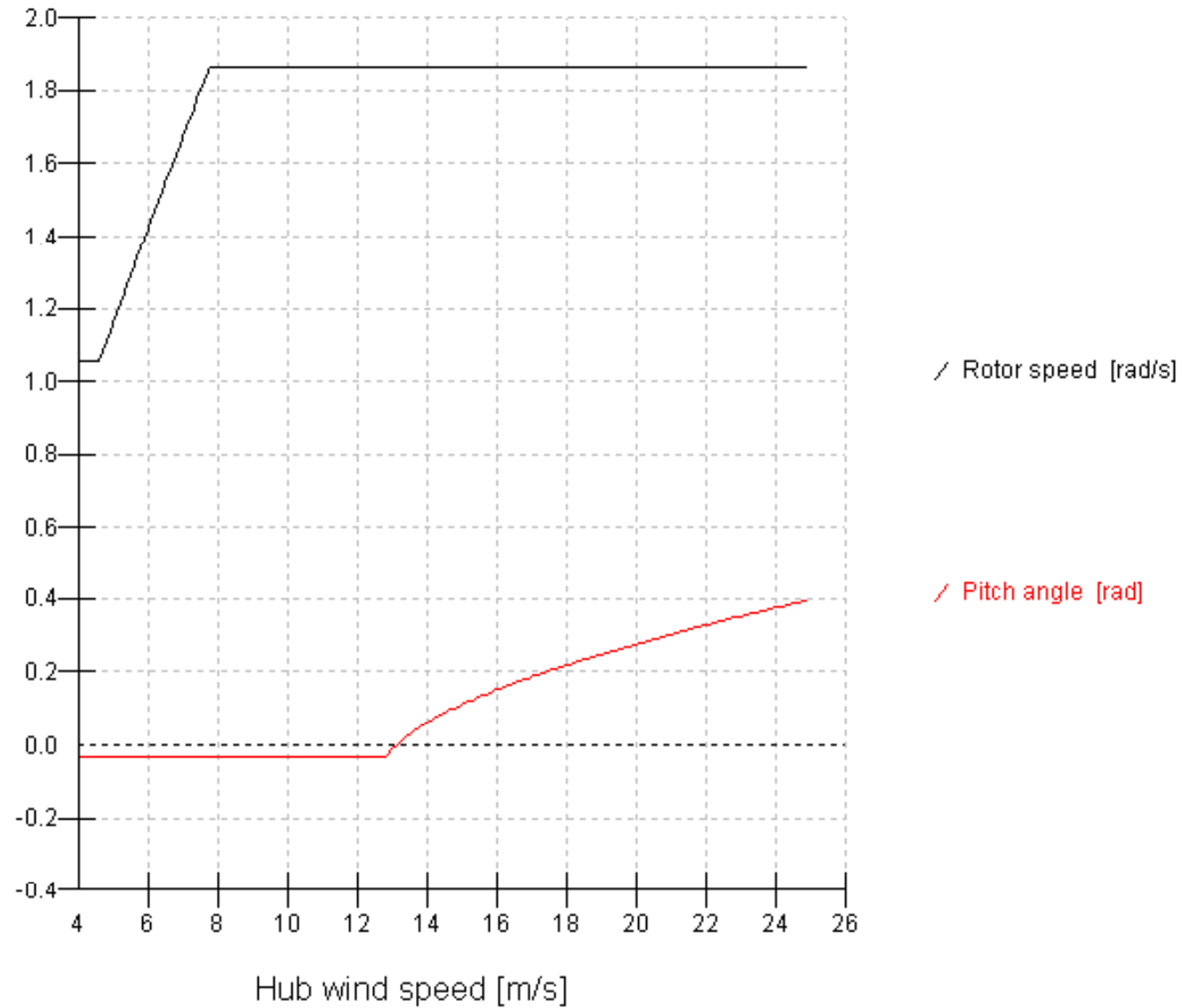
Durham 2nd July 2007

2 MW Exemplar Wind Turbines

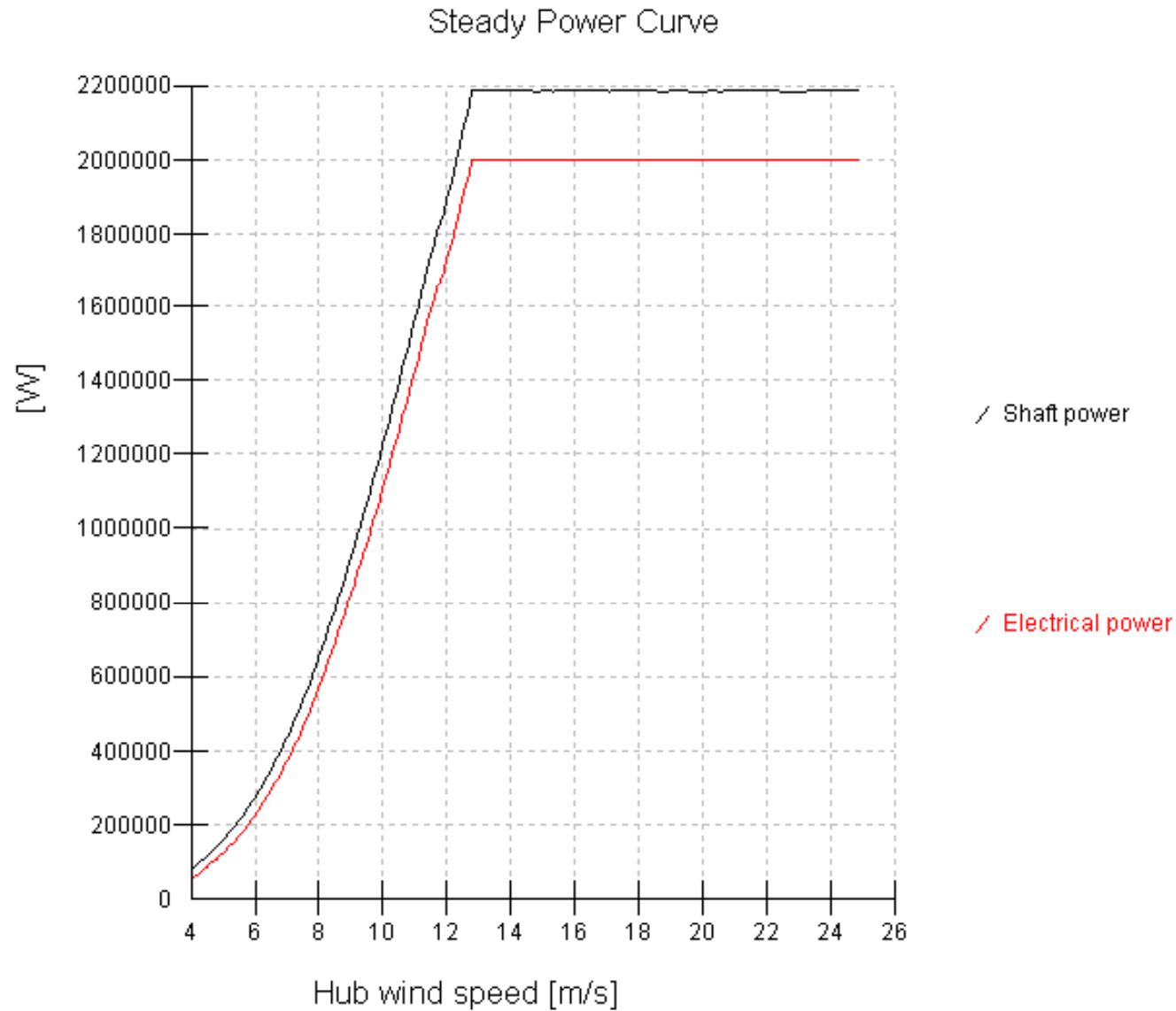
Configuration

- off-shore
- 3-bladed upwind
- pitch regulated variable speed
- drive-train
 - gearbox
 - generator
 - brake on high-speed shaft

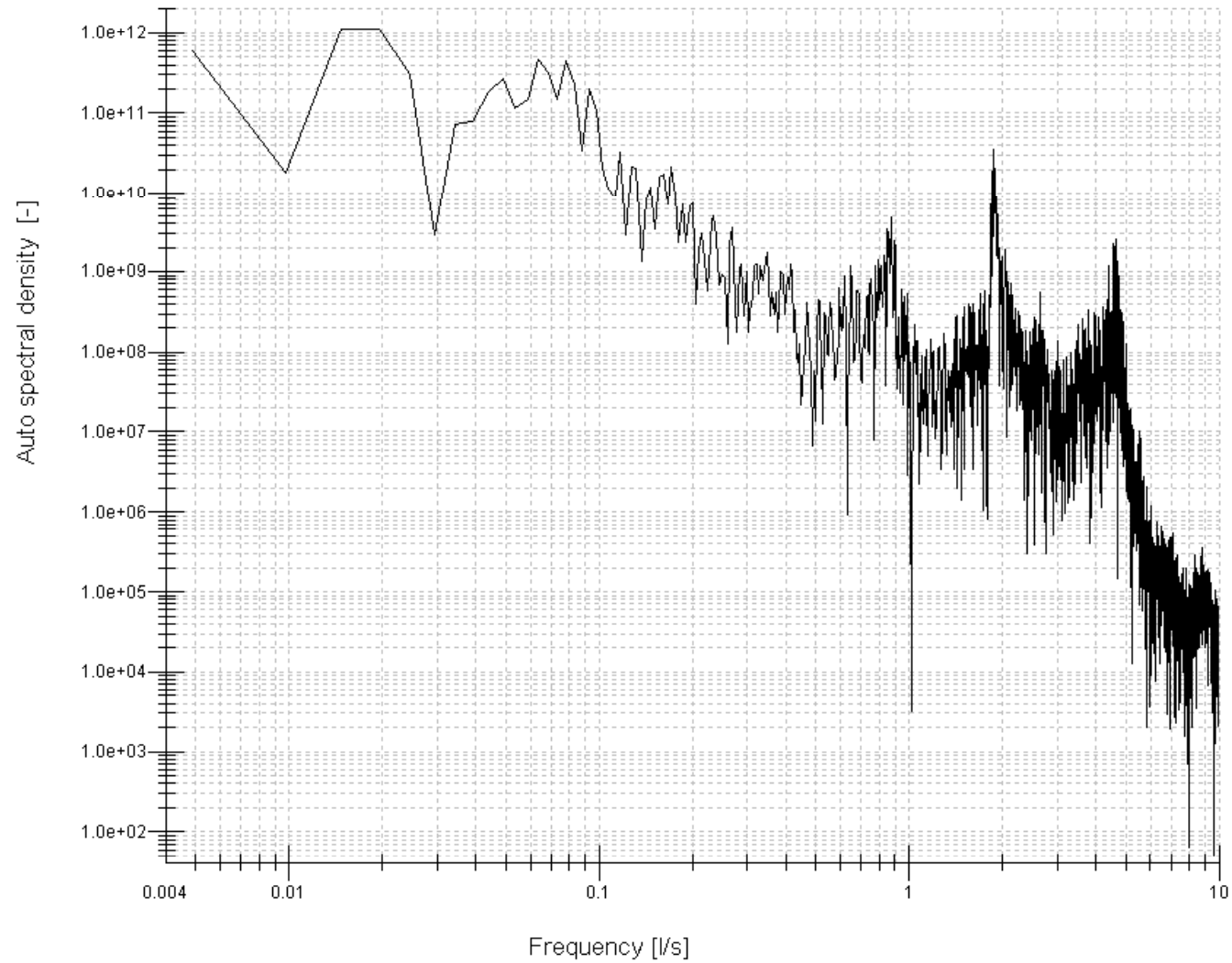
2MW Exemplar Wind Turbine



2MW Exemplar Wind Turbine



2MW Exemplar Wind Turbine



2MW Exemplar Wind Turbine

- Dimensions
 - rotor diameter 75 m
 - tower height 63.125 m
 - hub height 65 m
- Operation
 - rated wind speed 12.8 m/s
 - cut-in wind speed 4 m/s
 - cut-out wind speed 25 m/s
 - rated power 2 MW
 - rated speed 1.867 rad/s
 - minimum speed 1.058 rad/s
 - maximum speed 2.400 rad/s

2MW Exemplar Wind Turbine

Hub

- mass 17,000 kg
- inertia 12,000 kgm²

Rotor

- mass 33,640 kgm
- inertia 4.269e+6 kgm²
- tilt angle 4 deg
- rotor overhang 4.3 m
- spinner diameter 2.5 m
- root length 1.9m

2MW Exemplar Wind Turbine

Actuator

- bandwidth 6.283 rad/s
- damping ratio 0.8
- minimum pitch angle -2 deg
- maximum pitch angle 90 deg
- maximum pitch rate 8 deg/sec

2MW Exemplar Wind Turbine

Blade

- mass 5320.2 kg
- Inertia (about shaft) $1.419e+6 \text{ kgm}^2$

Distance (m)	Centre of mass (%)	Mass (kg/m)	Flap Stiffness (Nm ²)	Edge Stiffness (Nm ²)
0	50	949	5.72e+9	5.72e+9
1.07	50	324	1.86e+9	2.0e+9
3.22	38	243	1.08e+9	1.6e+9
5.37	29	205	6.39e+8	1.09e+9
11.81	29	173	2.66e+8	6.79e+8
18.26	29	129	8.38e+7	2.79e+8
24.7	29	91	2.26e+7	9.32e+7
29.54	29	60	7.19e+6	3.99e+7
33.3	29	49	1.73e+6	1.86e+7
34.37	29	47	5.06e+5	1.25e+7
35.77	29	36	8.72e+4	3.46e+6
36.25	29	22	2,400	6,260

2MW Exemplar Wind Turbine

Blade

- Flap frequency 6.14 rad/s (stiffened 6.65 rad/s)
- Edge frequency 9.66rad/s (stiffened 9.94 rad/s)

Distance (m)	Chord (m)	Twist (deg)	Thickness (%)	Pitch axis (%)	Twist axis (%)
0	1.93	13	100	50	25
1.07	1.93	13	100	50	25
3.22	2.58	13	64	38	25
5.37	3.22	13	40	29	25
11.81	2.9	9.5	25	29	25
18.26	2.15	6.2	19	29	25
24.7	1.72	3.3	15	29	25
29.54	1.4	1.5	12	29	25
33.3	1.07	0.3	11.5	29	25
34.37	0.97	0	11	29	25
35.77	0.64	2.75	11	29	25
36.25	0.03	4	11	29	25

2MW Exemplar Wind Turbine

Nacelle

- mass 65,000 kg
- inertia about tower axis 215,000 kgm²
- centre of mass height above tower 1.3 m
- centre of mass height in front tower axis -0.6 m

Total tower-head mass

97,961 kg

Total yaw inertia

2.959e+6 kgm²

2MW Exemplar Wind Turbine

Tower

- mass (steel) 376,132 kg
- frequency 2.54 rad/s

	Height (m)	Diameter (m)	Mass (kg/m)	Stiffness (Nm ²)	Thickness (mm)
	63.125	2.6	884.56	1.978e+10	13.869
	50	2.995	1568.03	4.637e+10	21.382
	40	3.296	2185.15	7.809e+10	27.105
	30	3.597	2885.62	1.226e+11	32.829
	20	3.898	3669.45	1.828e+11	38.553
	10	4.199	4536.63	2.619e+11	44.276
	5	4.135	5001.49	3.096e+11	47.138
	2.5	4.425	5241.74	3.357e+11	48.569
Sea level	0	4.5	5487.17	3.634e+11	50
Sea bed	-20	4.5	5487.17	3.634e+11	50
	-35	4.5	5487.17	3.634e+11	50

2MW Exemplar Wind Turbine

Drive-train

- gearbox ratio 84.15
- low-speed shaft stiffness 2.4e+8 Nm/rad

Generator (DFIG)

- inertia 130 kgm²
- maximum torque 14,400Nm
- no. of pole-pairs 3
- efficiency 95%

Mechanical losses

Low-speed shaft torque (kNm)	0	960	1260
Loss torque (kNm)	23	37	49

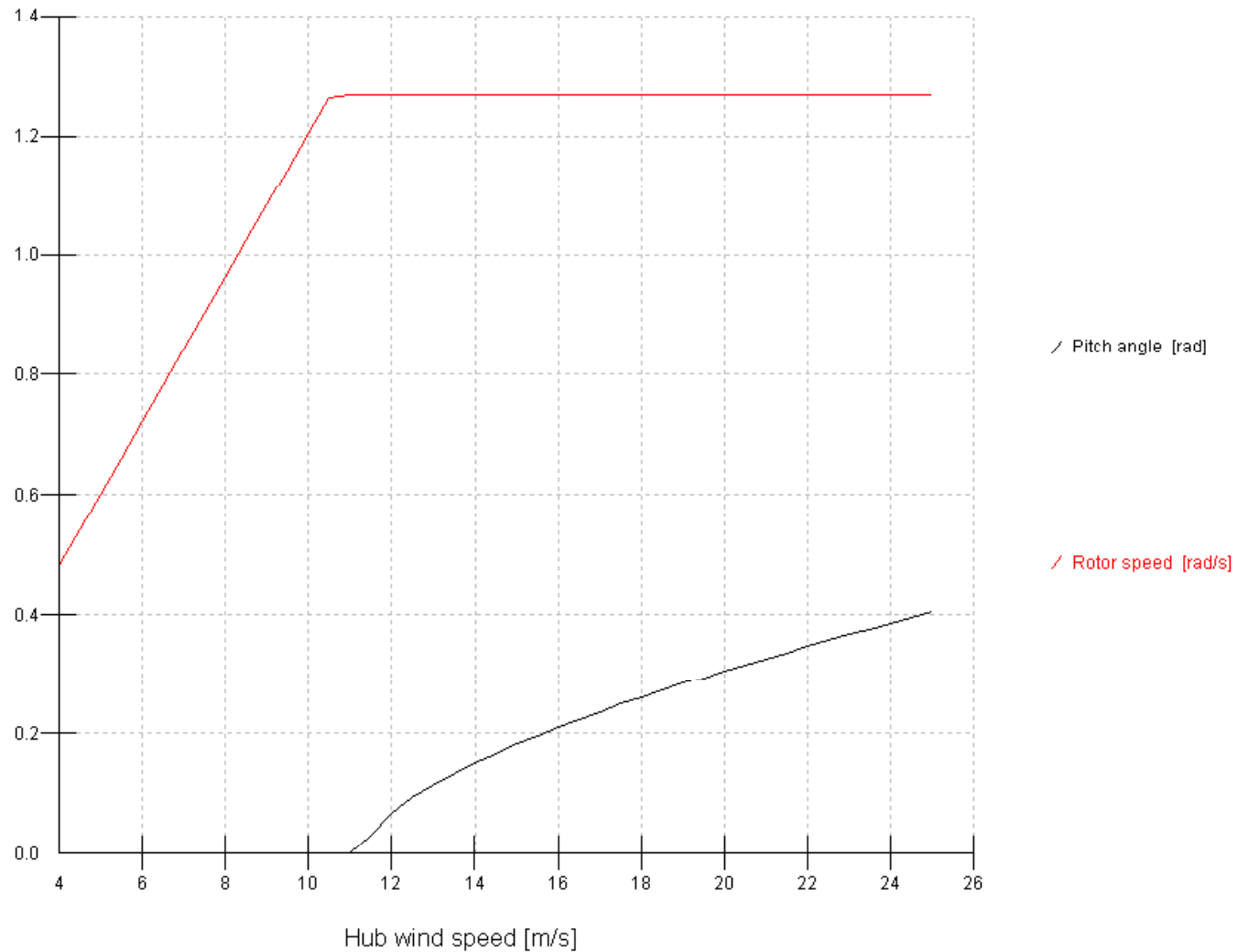
5MW Exemplar Wind Turbine

Configuration

- off-shore
- 3-bladed upwind
- pitch regulated variable speed
- drive-train
 - gearbox
 - generator
 - brake on high-speed shaft

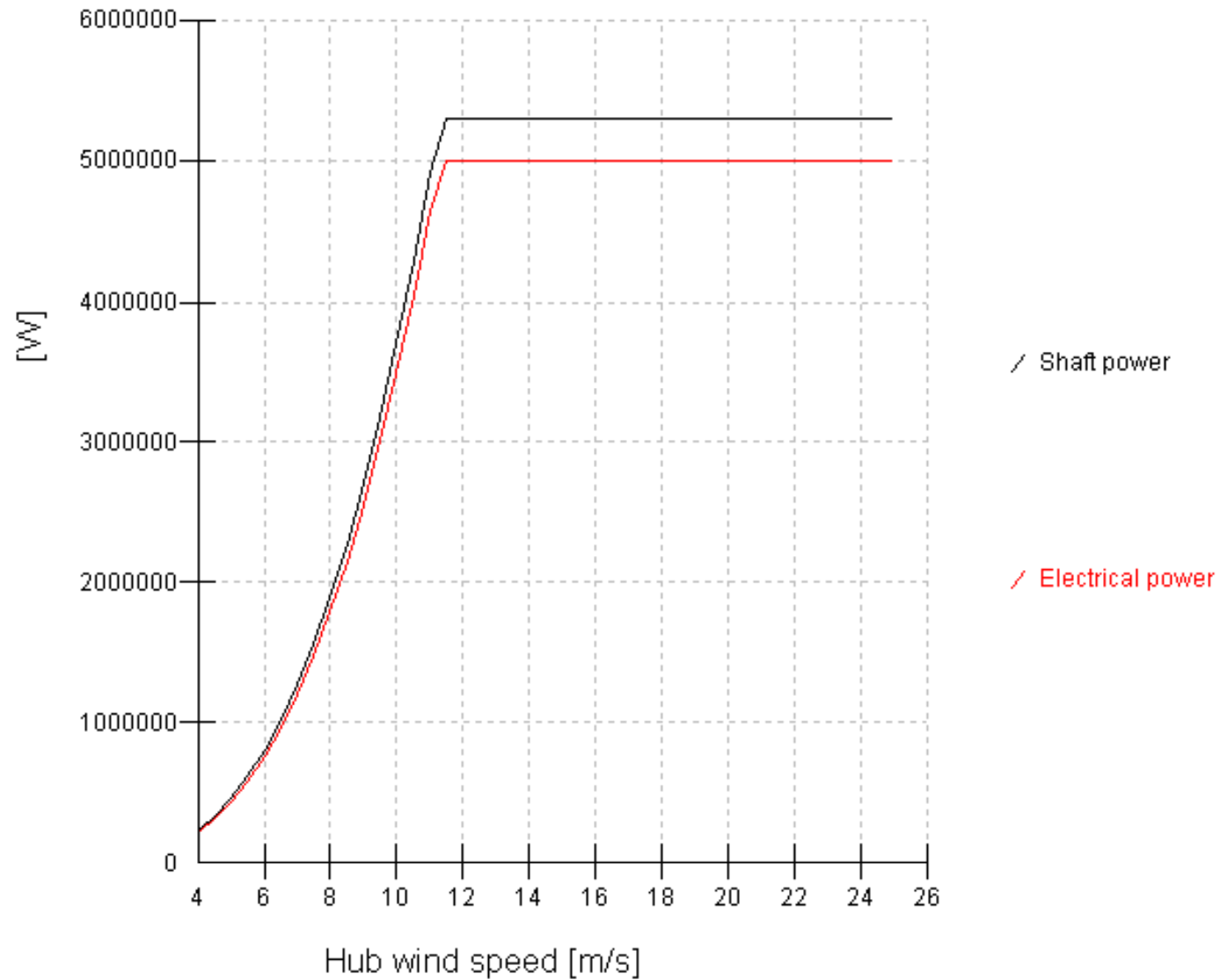
5MW Exemplar Wind Turbine

Steady power curve - 5MW

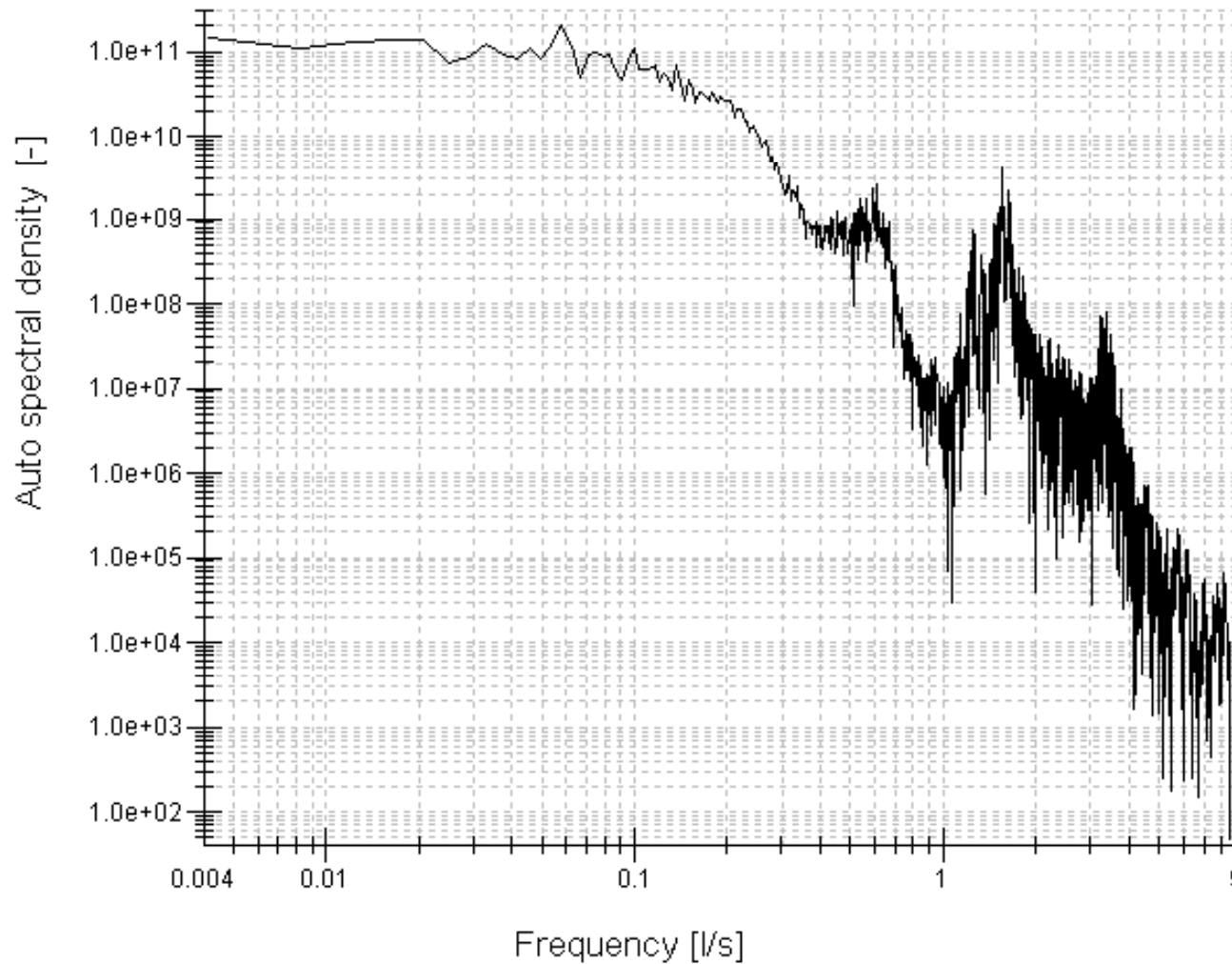


5MW Exemplar Wind Turbine

Steady Power Curve - 5MW



5MW Exemplar Wind Turbine



5MW Exemplar Wind Turbine

- Dimensions
 - rotor diameter 126 m
 - tower height 87.6 m
 - hub height 90 m
- Operation
 - rated wind speed 11.5 m/s
 - cut-in wind speed 4 m/s
 - cut-out wind speed 25m/s
 - rated power 5 MW
 - rated speed 1.267 rad/s
 - minimum speed 0 rad/s
 - maximum speed not specified

5MW Exemplar Wind Turbine

Hub

- mass 56,780 kg
- inertia 115,926 kgm²

Rotor

- mass 110,004 kgm
- inertia 3.878e+7 kgm²
- tilt angle 5 deg
- rotor overhang 5 m
- spinner diameter 3 m
- root length 1.5m
- Cone angle -2.5deg

5MW Exemplar Wind Turbine

Actuator

- bandwidth unspecified
- minimum pitch angle 0 deg
- minimum pitch angle 90 deg
- maximum pitch rate 8 deg/s

5MW Exemplar Wind Turbine

Blade

- mass 17741.2 kg
- Inertia (about shaft) $1.29e+7 \text{ kgm}^2$

Distance (m)	Centre of mass (%)	Mass (kg/m)	Flap Stiffness (Nm ²)	Edge Stiffness (Nm ²)
0	49.98	713.8	1.81e+10	1.81e+10
1.37	51.87	807.4	1.91e+10	1.96e+10
6.83	41.85	430.3	5.82e+9	8.46e+9
14.35	23.57	370.4	2.54e+9	5.03e+9
22.55	30.17	337.0	1.55e+9	3.95e+9
30.75	36.73	273.9	6.41e+8	2.69e+9
38.95	34.01	202.4	2.15e+8	1.49e+9
47.15	27.33	141.4	8.40e+7	7.56e+8
54.67	27.08	91.3	3.72e+7	3.76e+8
57.4	34.64	71.3	2.55e+7	2.74e+8
60.13	42.78	48.6	7.89e+6	8.73e+7
61.5	44.82	10.8	1.70e+5	5.01e+6

5MW Exemplar Wind Turbine

Blade

- Flap frequency 4.24 rad/s (stiffened 4.57 rad/s)
- Edge frequency 6.83 rad/s (stiffened 7.00 rad/s)

Distance (m)	Chord (m)	Twist (deg)	Thickness (%)	Pitch axis (%)	Twist axis (%)
0	3.50	13.3	99	25	25
1.37	3.54	13.3	99	25.1	25
6.83	4.17	13.3	99	31.2	25
14.35	4.65	11.5	99	37.5	25
22.55	4.25	9.0	99	37.5	25
30.75	3.75	6.5	99	37.5	25
38.95	3.26	4.2	99	37.5	25
47.15	2.76	2.3	99	37.5	25
54.67	2.31	0.9	99	37.5	25
57.4	2.09	0.4	99	37.5	25
60.13	1.42	0.1	99	37.5	25
61.5	0.2	0	99	37.5	25

5MW Exemplar Wind Turbine

Nacelle

- mass 240,000 kg
- inertia about tower axis $2.61e+6 \text{ kgm}^2$
- centre of mass height above tower 1.75 m
- centre of mass height in front tower axis -1.9 m

Total tower-head mass

350,004 kg

Total yaw inertia

$2.475e+7 \text{ kgm}^2$

5MW Exemplar Wind Turbine

Tower

- mass (steel) 522,614 kg
- frequency 1.76 rad/s

	Height (m)	Diameter (m)	Mass (kg/m)	Stiffness (Nm ²)
	87.6	3.87	1953.87	8.949e+10
	79.84	4.08	2148.34	1.095e+11
	72.08	4.30	2351.87	1.328e+11
	64.32	4.50	2564.46	1.595e+11
	56.56	4.72	2786.13	1.901e+11
	48.80	4.94	3016.86	2.248e+11
	41.04	5.15	3256.66	2.641e+11
	33.28	5.36	3505.52	3.083e+11
	25.52	5.57	3763.45	3.578e+11
	17.76	5.79	4030.44	4.131e+11
Sea level	10	6	4306.51	4.745e+12
	0	6	9517.14	1.037e+12
Sea bed	-20	6	9517.14	1.037e+12

5MW Exemplar Wind Turbine

Drive-train

- gearbox ratio 97
- low-speed shaft stiffness 8.676e+8 Nm/rad

Generator

- inertia 534.1 kgm²
- maximum torque 100,000 Nm
- no. of pole-pairs 3
- efficiency 94.4%

Mechanical losses

- not specified