

Fortis wind turbine load calculations per IEC 61400 Part 2: Design Requirements for Small Wind Turbines (rev. 2008.06.29, ajw)

		Espada		Passaat		Montana		Alizé		Comments
Number of blades	B	2		3		3		3		Fortis Netherlands measurement
Rotor diameter (m, ft)	D	2.2	7.2	3.1	10.2	5.0	16.4	7.0	23.0	Fortis Netherlands measurement
Rotor radius (m, ft)	R	1.1	3.6	1.6	5.1	2.5	8.2	3.5	11.5	Fortis Netherlands measurement
Swept area of rotor (m ² , ft ²)	A	3.8	40.9	7.6	82.3	19.6	211.3	38.5	414.2	Fortis Netherlands measurement
Rotor center to yaw axis (tower center) distance (m, ft)	L(rt)	0.25	0.82	0.26	0.85	0.51	1.67	0.65	2.13	Fortis Netherlands measurement
Rotor center to first bearing distance (m, ft)	L(rb)	0.050	0.16	0.067	0.22	0.118	0.39	0.118	0.39	Fortis Netherlands measurement
Mass of blade (kg, lb)	m(b)	2.6	5.7	2.6	5.7	9.0	19.8	20.0	44.1	Fortis Netherlands measurement
Mass of rotor (kg, lb)	m(r)	8.3	18.3	11.8	26.0	30	66.1	70	154.3	Fortis Netherlands measurement
Moment of inertia of blade (kg*m ² , lb*ft ²)	I(b)	1.05		2.11		18.75		81.67		for thin rod rotating about ⊥ axis at one end
Rated power (W)	P(design)	600		1400		5000		13000		The manufacturer's "rated" values are equated with IEC "design" values, rather than imposing a set of design parameter values corresponding to standard IEC SWT "classes" to each of the Fortis turbines. The "rated" values given are Fortis Netherlands measurements.
Wind speed @ rated power (m/s, mph)	V(design)	12	26.8	14	31.3	17	38.0	15	33.6	
Rotor speed @ rated power (rpm)	n(design)	680		500		430		280		
Tip speed (angular velocity) of rotor @ rated power (rad/s)	ω(design)	71.2		52.4		45.0		29.3		
Tip speed (linear velocity) at rated power (m/s, mph)	v(design)	78	175	82	183	113	252	103	230	
Tip speed ratio (TSR) @ rated power	λ	6.5		5.8		6.6		6.8		
Rotor torque @ rated power = P(R)/ω (N*m, ft*lb)	Q(design)	8.43	6.21	26.7	19.7	111.0	81.9	443.4	327.0	
IEC Ave. wind speed @ hub height = V(design)/1.4 (m/s, mph)	V(ave)	8.6	19.2	10.0	22.4	12.1	27.2	10.7	24.0	These values imply IEC Class II for Espada, IEC Class I for Passaat and Alizé, and (perhaps) IEC Class "S" for Montana. Fortis America calculation per IEC.
IEC "Reference" wind speed = 5*V(ave) (m/s, mph)	V(ref)	42.9	95.9	50.0	111.8	60.7	135.8	53.6	119.8	
IEC 50-year max wind speed (3s ave.) = 1.4*V(ref) (m/s, mph)	V(e50)	60.0	134.2	70.0	156.6	85.0	190.1	75.0	167.8	
IEC 50-year max tip speed ratio	λ(e50)	1.9		1.8		1.4		1.7		
Maximum rotor speed - with load (rpm)	n(max,load)	1000		775		450		350		measured by Fortis Netherlands?
Maximum rotor speed - with load (rad/s)	ω(max,load)	104.7		81.2		47.1		36.7		
Maximum rotor speed - no load (rpm)	n(max,noload)	1133		1250		758		700		measured by Fortis Netherlands?
Maximum rotor speed - no load (rad/s)	ω(max,noload)	118.6		130.9		79.4		73.3		
IEC Max yaw rate (rad/s)	ω (yaw,max)	2.98		2.94		2.82		2.64		Fortis America calculation per IEC
Rotor center to blade center-of-gravity distance (m, ft)	R(cog)	0.52	1.71	0.60	1.97	1.00	3.28	1.40	4.59	Fortis Netherlands measurement
Blade area in projection (m ² , ft ²)	A(proj,b)	0.090	0.969	0.095	1.023	0.336	3.617	0.620	6.674	Fortis Netherlands measurement
Generator area in projection (m ² , ft ²)	A(proj,g)	0.036	0.388	0.046	0.495	0.133	1.432	0.130	1.399	Fortis Netherlands measurement
Tail area in projection (m ² , ft ²)	A(proj,t)	0.250	2.691	0.250	2.691	0.500	5.382	0.750	8.073	estimates - actual values TBD
Drag coefficient of blade	Cd(b)	1.5		1.5		1.5		1.5		per Fortis Netherlands
Drag coefficient of generator	Cd(g)	1.3		1.3		1.3		1.3		per Fortis Netherlands
Drag coefficient of tail assembly	Cd(t)	1.5		1.5		1.5		1.5		per IEC Table 3
Acceleration due to gravity (m/s ² , ft/s ²)	g	9.81				32.19				
Air density @ sea level, 25°C (kg/m ³ , lb/ft ³)	ρ	1.225				0.076				

Power Production: Normal operation (Load Case A) - fatigue loads for operation @ rated power

Blade loads - provided by Fortis Netherlands										
Force (centrifugal loading, along blade toward tip) (N, lb)	$F(zB)$	6849	1540	4272	960	18230	4098	24049	5406	Fortis Netherlands calculation
Moment (acting in rotational direction of blade) (N*m, ft*lb)	$M(xB)$	30.71	22.65	37.58	27.72	203.06	149.77	662.54	488.66	Fortis Netherlands calculation
Moment (bending blade tip backward) (N*m, ft*lb)	$M(yB)$	18.33	13.52	45.83	33.80	176.47	130.16	972.22	717.07	Fortis Netherlands calculation
Shaft loads - provided by Fortis Netherlands										
Force (along rotor axis) (N, lb)	$F(x)$	50	11	137.5	31	642	144	1392	313	Fortis Netherlands calculation
Force (along rotor axis) (N, lb) x 10 safety factor	$F(x) * 10$	500	112	1375	309	6420	1443	13920	3129	see letter from J. Kuikman, Fortis Netherlands
Moment (around rotor axis) = Rotor torque (N*m, ft*lb)	$M(x)$	8.43	6.22	21.02	15.50	79.99	59.00	341.22	251.67	Fortis Netherlands calculation
Moment (around y-axis) (N*m, ft*lb)	$M(y)$	8.13	6.00	15.38	11.34	69.38	51.17			Fortis Netherlands calculation
Blade loads (calculated from IEC equations)										
Centrifugal loading (acting along blade toward tip) (N, lb)	$\Delta F(zB)$	13711	3082	8554	1923	36498	8205	48146	10824	Fortis America calculation per IEC
Bending moment (acting in rotational direction of blade) (N*m, ft*lb)	$\Delta M(xB)$	30.7	22.7	39.5	29.1	214	158	697	514	Fortis America calculation per IEC
Bending moment (bending blade tip backward) (N*m, ft*lb)	$\Delta M(yB)$	27.5	20.3	52.0	38.4	245	181	1011	746	Fortis America calculation per IEC
Shaft loads (calculated from IEC equations)										
Thrust loading (force along rotor axis) (N, lb)	$\Delta F(x-shaft)$	75.0	16.9	150.0	33.7	441	99	1300	292	Fortis America calculation per IEC
Thrust loading (force along rotor axis) (N, lb) x 10 safety factor	$\Delta F(x-shaft) * 10$	750	169	1500	337	4412	992	13000	2923	see letter from J. Kuikman, Fortis Netherlands
Torsion moment (torque around rotor axis) (N*m, ft*lb)	$\Delta M(x-shaft)$	9.3	6.9	28.5	21.1	118	87	467	345	Fortis America calculation per IEC
Bending moment (N*m, ft*lb)	$\Delta M(shaft)$	9.9	7.3	22.8	16.8	119	88	435	321	Fortis America calculation per IEC

Power Production: Yawing (Load Case B) - loads imposed @ max yaw rate

Blade loads - provided by Fortis Netherlands										
Moment (bending blade tip backward) (N*m, ft*lb)	$M(yB)$	14961	11035	20451	15084	169234	124820	478676	353053	Fortis Netherlands calculation, DOUBTFUL.
Shaft loads - provided by Fortis Netherlands										
Bending moment (N*m, ft*lb)	$M(b-max)$	149.27	110.10	306.15	225.80	2531.63	1867.23	7180.13	5295.78	Fortis Netherlands calculation
Blade loads (calculated from IEC equations)										
Bending moment (bending blade tip backward) (N*m, ft*lb)	$M(yB)$	458	337	680	501	4927	3634	13252	9774	Fortis America calculation per IEC
Shaft loads (calculated from IEC equations)										
Bending moment (N*m, ft*lb)	$M(shaft)$	909	670	1022	754	7371	5436	19770	14581	Fortis America calculation per IEC

Power Production: Yaw Error (Load Case C) - assumes 30° max yaw error

Blade loads (calculated from IEC equations)										
Bending moment (bending blade tip backward) (N*m, ft*lb)	$M(yB)$	228	168	381	281	3991	2943	8513	6279	Fortis America calculation per IEC

Power Production: Maximum Thrust (Load Case D) - calculated @ $V(ave) = V(design)/1.4$

Shaft loads (calculated from IEC equations)										
Thrust loading (force along rotor axis) (N, lb)	$F(x-shaft)$	535	120	1463	329	5542	1246	8456	1901	Fortis America calculation per IEC

Power Production + Fault: Maximum Rotational Speed (Load Case E) - loss of electrical load (freewheeling)

Blade loads (calculated from IEC equations)											
Centrifugal loading (acting along blade toward tip) (N, lb)	F(zB)	19032	4279	26730	6009	56707	12748	150457	33824	Fortis America calculation per IEC	
Shaft loads (calculated from IEC equations)											
Bending moment (N*m, ft*lb)	M(shaft)	36.2	26.7	112.6	83.0	314	231	858	633	Fortis America calculation per IEC	

Power Production + Fault: Short at Load Connection (Load Case F) - electrically shorted generator

Blade loads (calculated from IEC equations)										
Bending moment (acting in rotational direction of blade) (N*m, ft*lb)	M(xB)	8.4	6.2	17.8	13.1	74	55	296	218	Fortis America calculation per IEC
Shaft loads (calculated from IEC equations)										
Torsion moment (torque around rotor axis) (N*m, ft*lb)	M(x-shaft)	16.9	12.4	53.5	39.4	222	164	887	654	Fortis America calculation per IEC

Shutdown: Shutdown (braking) (Load Case G) - NOT APPLICABLE - no braking system in turbine drive train

Blade loads (calculated from IEC equations)										
Bending moment (acting in rotational direction of blade) (N*m, ft*lb)	M(xB)									
Shaft loads (calculated from IEC equations)										
Torsion moment (torque around rotor axis) (N*m, ft*lb)	M(x-shaft)									

Parked: Parked Wind Loading (Load Case H) - assumes rotor is allowed to spin (under load) when "parked" = furled

Blade loads (calculated from IEC equations)										
Bending moment (bending blade tip backward) (N*m, ft*lb)	M(yB)	146	107	297	219	2478	1828	4984	3676	Fortis America calculation per IEC
Shaft loads (calculated from IEC equations)										
Thrust loading (force along rotor axis) (N, lb)	F(x-shaft)	497	112	951	214	2913	655	6374	1433	Fortis America calculation per IEC

Parked: Parked Wind Loading, Maximum Exposure (Load Case I) - assumes failure of yaw mechanism

Force acting perpendicular to blades (N, lb)	F(blades)	304	68	655	147	3414	767	4904	1103	Fortis America calculation per IEC
Force acting perpendicular to generator (N, lb)	F(generator)	53	12	92	21	390	88	297	67	Fortis America calculation per IEC
Force acting perpendicular to tail plane (N, lb)	F(tail)	422	95	574	129	1693	381	1978	445	Fortis America calculation per IEC
Sum of above forces (N, lb)	F(total)	778	175	1320	297	5498	1236	7179	1614	Fortis America calculation per IEC

Transport, Assembly, Maintenance + Repair: (Load Case J) - To Be Determined