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Technical Documentation

Wind Turbine Generator Systems

6.1-158 - 50/60Hz



Calculated Power Curve and Thrust Coefficient

Eng.-Rev:	Rev.5
Leading Edge Protection(LEP):	Without
Apparent Sound Power Level(50Hz):	107dB
Apparent Sound Power Level(60Hz):	107.5dB

Rev. 03 - EN 2022-02-25

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1 Calculated Power Curves

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Wind turbine type: 6.1-158
 Grid standard: 50/60Hz
 Rotor diameter: 158 m

The calculated power curves at an average air density of 1.225 kg/m³ are listed in Table 1. These power curves are consistent with the power curve definition in the IEC 61400-12-1 for hub height wind speed.

Turbulence intensity (TI) ranges are defined in section 3. The method for selecting the appropriate turbulence intensity is provided in section 6.

Wind Speed at Hub Height [m/s]	Electrical Power [kW] with			C _{p,e} Medium TI
	Medium TI Band	Low TI Band	High TI Band	
3.0	91	76	132	0.28
3.5	191	174	238	0.37
4.0	319	300	372	0.41
4.5	478	458	536	0.44
5.0	672	650	738	0.45
5.5	909	882	986	0.45
6.0	1190	1158	1279	0.46
6.5	1521	1485	1622	0.46
7.0	1905	1864	2013	0.46
7.5	2354	2305	2469	0.46
8.0	2842	2799	2938	0.46
8.5	3355	3329	3421	0.45
9.0	3865	3857	3880	0.44
9.5	4348	4351	4345	0.42
10.0	4804	4810	4750	0.40
10.5	5216	5239	5101	0.37
11.0	5568	5614	5330	0.35
11.5	5852	5917	5592	0.32
12.0	6024	6077	5770	0.29
12.5	6089	6100	5908	0.26
13.0	6100	6100	6035	0.23
13.5	6100	6100	6058	0.21
14.0	6100	6100	6094	0.18
14.5	6100	6100	6100	0.17
15.0	6100	6100	6100	0.15
15.5	6100	6100	6100	0.14
16.0	6100	6100	6100	0.12
16.5	6100	6100	6100	0.11
17.0	6100	6100	6079	0.10

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Wind Speed at Hub Height [m/s]	Electrical Power [kW] with			C _{p,e} Medium TI
	Medium TI Band	Low TI Band	High TI Band	
17.5	6080	6100	6039	0.09
18.0	6031	6055	5976	0.09
18.5	5955	5980	5888	0.08
19.0	5847	5874	5771	0.07
19.5	5727	5755	5652	0.06
20.0	5577	5610	5489	0.06
20.5	5397	5433	5308	0.05
21.0	5184	5227	5081	0.05
21.5	4947	4995	4863	0.04
22.0	4686	4729	4620	0.04
22.5	4401	4422	4370	0.03
23.0	4081	4082	4092	0.03
23.5	3832	3791	3899	0.02
24.0	3617	3553	3717	0.02
24.5	3466	3407	3567	0.02
25.0	3391	3349	3500	0.02

Table 1: Calculated power curve table as a function of hub height wind speed for standard air density

2 Power Curves for different Air Densities and Turbulence Intensities

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Following tables show the calculated power curves for different air density values and turbulence intensity classes. The Excel file embedded with this document contains power curves for a larger range of air densities than in the tables below.

Wind Speed at Hub Height [m/s]	Electrical Power [kW]										
	Air density $\rho = 1.02$	Air density $\rho = 1.04$	Air density $\rho = 1.06$	Air density $\rho = 1.08$	Air density $\rho = 1.1$	Air density $\rho = 1.12$	Air density $\rho = 1.14$	Air density $\rho = 1.16$	Air density $\rho = 1.18$	Air density $\rho = 1.2$	Air density $\rho = 1.225$
	kg/m ³	kg/m ³	kg/m ³	kg/m ³	kg/m ³	kg/m ³	kg/m ³	kg/m ³	kg/m ³	kg/m ³	kg/m ³
3.0	66	68	71	73	76	78	81	83	85	88	91
3.5	149	153	157	161	166	170	174	178	182	186	191
4.0	256	262	268	274	280	286	293	299	305	311	319
4.5	388	397	405	414	423	432	440	449	458	467	478
5.0	549	561	573	585	597	609	621	633	645	657	672
5.5	745	761	777	793	809	825	841	857	873	889	909
6.0	978	999	1019	1040	1061	1082	1102	1122	1143	1164	1190
6.5	1254	1280	1306	1332	1358	1384	1411	1437	1463	1489	1521
7.0	1574	1607	1639	1672	1704	1737	1769	1801	1833	1865	1905
7.5	1952	1991	2031	2070	2110	2149	2189	2227	2266	2305	2354
8.0	2371	2419	2466	2512	2559	2606	2652	2698	2743	2787	2842
8.5	2842	2897	2951	3004	3056	3107	3157	3205	3253	3299	3355
9.0	3344	3403	3461	3516	3570	3622	3672	3721	3769	3813	3865
9.5	3877	3934	3989	4042	4092	4139	4184	4226	4266	4304	4348
10.0	4390	4443	4492	4538	4582	4623	4662	4699	4734	4766	4804
10.5	4870	4916	4959	4999	5036	5070	5102	5131	5159	5185	5216
11.0	5294	5331	5366	5398	5427	5454	5479	5503	5525	5545	5568
11.5	5655	5683	5709	5733	5754	5773	5790	5805	5820	5834	5852
12.0	5911	5928	5944	5958	5971	5983	5993	6001	6008	6015	6024
12.5	6049	6056	6062	6067	6071	6074	6077	6080	6083	6086	6089
13.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
13.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
14.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
14.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
15.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
15.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
16.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
16.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
17.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
17.5	6080	6080	6080	6080	6080	6080	6080	6080	6080	6080	6080
18.0	6030	6030	6030	6031	6031	6031	6031	6031	6031	6031	6031
18.5	5954	5954	5954	5955	5955	5955	5955	5955	5956	5956	5955

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19.0	5844	5844	5844	5845	5845	5845	5846	5846	5847	5847	5847
19.5	5723	5724	5724	5724	5724	5724	5724	5725	5725	5725	5727
20.0	5572	5573	5573	5573	5573	5573	5574	5574	5575	5576	5577
20.5	5391	5392	5392	5393	5394	5394	5395	5395	5396	5397	5397
21.0	5175	5176	5176	5177	5178	5179	5180	5180	5180	5181	5184
21.5	4941	4940	4940	4942	4943	4944	4944	4944	4945	4946	4947
22.0	4677	4679	4679	4679	4679	4679	4680	4682	4684	4685	4686
22.5	4387	4388	4388	4389	4390	4392	4394	4395	4395	4397	4401
23.0	4072	4073	4073	4073	4073	4074	4075	4077	4078	4079	4081
23.5	3827	3826	3826	3827	3828	3829	3830	3830	3830	3830	3832
24.0	3612	3612	3612	3613	3614	3614	3614	3614	3615	3616	3617
24.5	3466	3466	3466	3465	3464	3464	3465	3465	3466	3466	3466
25.0	3391	3391	3391	3390	3390	3390	3390	3390	3391	3391	3391

Table 2: Calculated power curve for different values of the air density for medium turbulence intensity

Wind Speed at Hub Height [m/s]	PDF Compressor Free Version										
	Electrical Power [kW]										
	Air density $\rho = 1.02$ kg/m ³	Air density $\rho = 1.04$ kg/m ³	Air density $\rho = 1.06$ kg/m ³	Air density $\rho = 1.08$ kg/m ³	Air density $\rho = 1.1$ kg/m ³	Air density $\rho = 1.12$ kg/m ³	Air density $\rho = 1.14$ kg/m ³	Air density $\rho = 1.16$ kg/m ³	Air density $\rho = 1.18$ kg/m ³	Air density $\rho = 1.2$ kg/m ³	Air density $\rho = 1.225$ kg/m ³
3.0	54	56	58	60	63	65	67	69	71	74	76
3.5	135	139	143	147	151	155	158	162	166	170	174
4.0	240	246	252	258	264	270	276	281	287	293	300
4.5	371	380	388	397	405	413	422	430	439	447	458
5.0	530	542	553	565	577	588	600	612	623	635	650
5.5	723	738	754	769	785	801	816	832	847	863	882
6.0	952	972	992	1012	1032	1052	1073	1093	1113	1133	1158
6.5	1224	1249	1275	1301	1326	1351	1376	1402	1427	1453	1485
7.0	1540	1571	1603	1634	1666	1698	1729	1761	1792	1824	1864
7.5	1908	1947	1985	2024	2063	2102	2141	2179	2218	2257	2305
8.0	2324	2372	2418	2465	2511	2557	2604	2650	2696	2742	2799
8.5	2793	2848	2904	2958	3012	3065	3117	3169	3219	3269	3329
9.0	3306	3368	3428	3487	3544	3600	3653	3705	3754	3801	3857
9.5	3855	3917	3975	4030	4082	4132	4180	4224	4265	4304	4351
10.0	4390	4444	4495	4543	4588	4630	4669	4706	4741	4773	4810
10.5	4888	4934	4977	5017	5054	5089	5122	5153	5181	5208	5239
11.0	5336	5373	5408	5440	5470	5497	5523	5547	5569	5590	5614
11.5	5718	5747	5774	5796	5816	5835	5854	5872	5888	5902	5917
12.0	5985	6001	6015	6026	6037	6047	6056	6063	6068	6072	6077
12.5	6091	6095	6099	6100	6100	6100	6100	6100	6100	6100	6100
13.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
13.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
14.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
14.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
15.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
15.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
16.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
16.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
17.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
17.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
18.0	6055	6055	6055	6055	6055	6055	6055	6055	6055	6055	6055
18.5	5978	5979	5979	5979	5979	5979	5979	5980	5980	5980	5980
19.0	5871	5872	5872	5872	5872	5872	5872	5873	5873	5874	5874
19.5	5750	5751	5751	5752	5752	5752	5752	5753	5753	5754	5755
20.0	5603	5604	5604	5605	5606	5606	5606	5607	5607	5608	5610
20.5	5425	5426	5426	5427	5427	5427	5428	5429	5429	5430	5433
21.0	5217	5218	5218	5219	5220	5221	5221	5222	5222	5224	5227

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21.5	4983 4714	4983 4715	4983 4717	4985 4717	4986 4718	4988	4989	4991	4992	4993	4995
22.0	4405	4407	4407	4408	4409	4411	4413	4415	4417	4419	4422
22.5	4065	4066	4068	4069	4070	4072	4075	4077	4079	4080	4082
23.0	3778	3779	3780	3781	3782	3783	3784	3786	3788	3790	3791
23.5	3546	3546	3546	3546	3547	3548	3549	3551	3551	3552	3553
24.0	3404	3404	3404	3405	3405	3405	3406	3406	3407	3407	3407
24.5	3349	3349	3349	3348	3348	3348	3349	3349	3349	3349	3349

Table 3: Calculated power curve for different values of the air density for low turbulence intensity

Wind Speed at Hub Height [m/s]	PDF Compressor Free Version										
	Electrical Power [kW]										
	Air density $\rho = 1.02$ kg/m ³	Air density $\rho = 1.04$ kg/m ³	Air density $\rho = 1.06$ kg/m ³	Air density $\rho = 1.08$ kg/m ³	Air density $\rho = 1.1$ kg/m ³	Air density $\rho = 1.12$ kg/m ³	Air density $\rho = 1.14$ kg/m ³	Air density $\rho = 1.16$ kg/m ³	Air density $\rho = 1.18$ kg/m ³	Air density $\rho = 1.2$ kg/m ³	Air density $\rho = 1.225$ kg/m ³
3.0	100	103	106	109	112	116	119	122	125	128	132
3.5	189	194	198	203	208	213	218	223	227	232	238
4.0	300	307	314	321	328	335	342	349	356	363	372
4.5	436	446	456	466	475	485	495	505	514	524	536
5.0	603	617	630	643	656	669	682	695	708	721	738
5.5	810	827	844	861	879	896	913	930	947	965	986
6.0	1053	1076	1098	1120	1142	1164	1186	1208	1230	1252	1279
6.5	1340	1368	1396	1424	1451	1479	1506	1534	1561	1588	1622
7.0	1672	1706	1740	1773	1806	1840	1873	1907	1939	1972	2013
7.5	2066	2107	2147	2188	2228	2268	2308	2346	2384	2422	2469
8.0	2493	2540	2586	2631	2676	2720	2764	2806	2848	2889	2938
8.5	2954	3005	3055	3104	3151	3198	3243	3287	3330	3371	3421
9.0	3413	3467	3519	3569	3617	3664	3708	3751	3792	3832	3880
9.5	3917	3970	4020	4067	4112	4155	4196	4234	4270	4304	4345
10.0	4380	4427	4472	4514	4553	4590	4625	4657	4687	4716	4750
10.5	4795	4837	4874	4909	4941	4972	5001	5028	5053	5075	5101
11.0	5103	5135	5164	5191	5216	5239	5259	5278	5296	5312	5330
11.5	5437	5461	5482	5502	5519	5535	5549	5561	5571	5580	5592
12.0	5656	5674	5690	5703	5715	5725	5734	5744	5754	5763	5770
12.5	5827	5839	5851	5862	5871	5879	5886	5892	5897	5902	5908
13.0	5979	5987	5993	5999	6005	6012	6018	6022	6025	6029	6035
13.5	6019	6023	6027	6030	6034	6039	6044	6048	6050	6053	6058
14.0	6074	6078	6080	6082	6084	6086	6087	6089	6091	6092	6094
14.5	6099	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
15.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
15.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
16.0	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
16.5	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
17.0	6078	6077	6077	6078	6078	6078	6079	6079	6080	6080	6079
17.5	6038	6037	6037	6038	6039	6039	6039	6039	6040	6040	6039
18.0	5974	5973	5974	5976	5978	5978	5978	5977	5976	5976	5976
18.5	5888	5887	5887	5889	5890	5890	5889	5889	5888	5888	5888
19.0	5771	5771	5773	5774	5774	5773	5772	5771	5771	5771	5771
19.5	5653	5653	5653	5651	5650	5649	5649	5649	5650	5651	5652
20.0	5495	5494	5494	5492	5491	5490	5489	5488	5487	5488	5489
20.5	5314	5315	5315	5313	5311	5309	5307	5307	5307	5308	5308
21.0	5102	5100	5096	5091	5087	5085	5084	5082	5081	5080	5081

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21.5	4880	4878	4875	4870	4865	4862	4861	4862	4863	4864	4863
22.0	4640	4653	4628	4626	4626	4626	4625	4624	4623	4621	4620
22.5	4387	4383	4380	4379	4378	4377	4376	4377	4378	4376	4370
23.0	4133	4130	4127	4125	4122	4119	4118	4120	4122	4114	4092
23.5	3932	3930	3926	3919	3912	3905	3900	3899	3899	3900	3899
24.0	3747	3746	3745	3744	3742	3739	3733	3727	3720	3716	3717
24.5	3599	3595	3588	3579	3574	3577	3582	3581	3573	3565	3567
25.0	3512	3511	3509	3506	3504	3503	3502	3500	3499	3500	3500

Table 4: Calculated power curve for different values of the air density for high turbulence intensity

3 Applicability **PDF Compressor Free Version**

The power curve information provided in this document applies under the following conditions:

- The mean air density falls inside the range of air densities specified in section 2, including the wider range of air densities in the embedded Excel spreadsheet.
- The measured power curve data shall be density corrected to the nearest 0.01 kg/m³ of the average test period air density. The calculated power curve reference at the same nearest 0.01 kg/m³ density shall be used either directly from the reference power curve tables provided here or interpolated linearly between the provided densities. If the measured average air density during a power performance test falls out of the range of provided densities, data shall be density-corrected to the nearest density provided in Tables 2 through 4 (including the embedded files) by employing air density correction specified by the IEC standard 61400-12-1.
- The site is characterized by one of the following turbulence intensity categories.

TI Band	Lower TI bound	Upper TI bound
Low	$2.5 (0.75V_{hub} + 5.6)/V_{hub}$	$12.5 (0.75V_{hub} + 5.6)/V_{hub}$
Medium	$5 (0.75V_{hub} + 5.6)/V_{hub}$	$15 (0.75V_{hub} + 5.6)/V_{hub}$
High	$10 (0.75V_{hub} + 5.6)/V_{hub}$	$20 (0.75V_{hub} + 5.6)/V_{hub}$

Measured power curve data points for 10-minute average mean turbulence intensities that fall outside the applicable TI band would be filtered out for the purpose of power curve applicability, see Figure 1.

The reference power curve is to be selected from the power curves of the TI class having the largest number of post-filtering data points (upmost coverage). Section 6 of this document gives an example outlining how to determine the TI class with the upmost coverage. The reference power curve is referred to as the calculated power curve in GE’s Technical Documentation Machine Power Performance Test. This document also outlines the data filtering requirements, which have to be met prior to determining the TI class.

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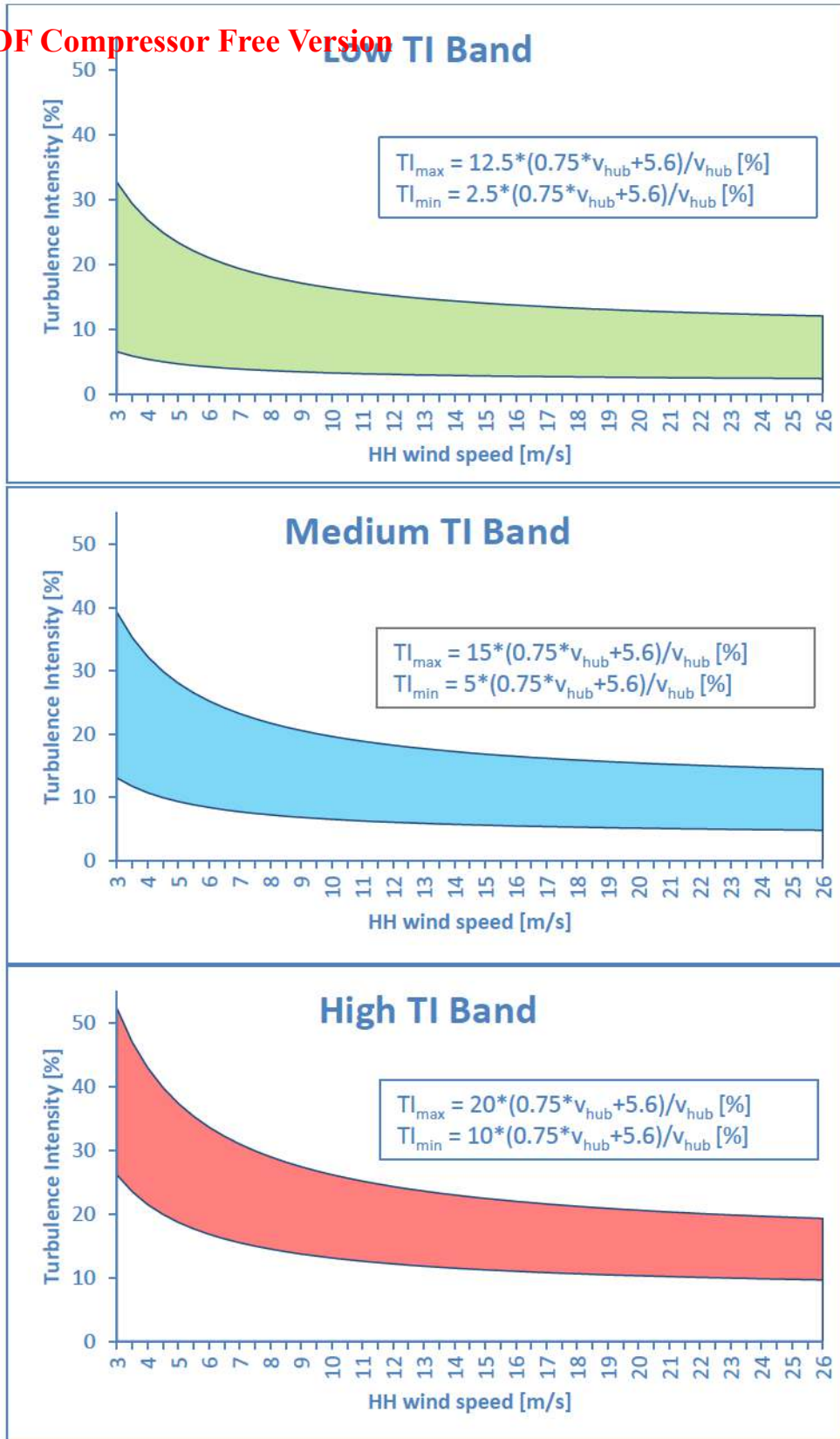


Figure 1: Applicable Turbulence Intensity Range

- Non-degraded and uncontaminated blade surfaces with no icing
- Power shall be measured on the generator side of the transformer unless the net electric power output is referenced otherwise in this document.
- Wind-speed labels are mid-bin values; for example, the 5.0 m/s bin extends from 4.75 to 5.25 m/s.
- Measured wind shear (10-minute average data) such that $-0.1 \leq \text{shear} \leq 0.5$.
- The wind turbine generator system whose power output is not being actively regulated or curtailed for any reason.
- Information on the influence of cold or hot weather and high altitude operation is provided in the documents "Technical Description – Cold Weather Adaptations" and "General Description High Temperature, High Altitude Operation".

4 Cut-Out and Re-Cut-In Wind Speeds

The wind turbine generator system will shut down under the following wind conditions:

- Greater than or equal to 25 m/s over a 600-second duration,
- Greater than or equal to 30 m/s over a 30-second duration,
- Greater than or equal to 34 m/s over a 3-second duration, or
- Greater than 38 m/s instantaneous, sampled every 1 second

The turbine will restart when the wind speed is below 22 m/s over a 5-minute duration post shut down and below 22 m/s over a 10-minute duration (inclusive of pre & post shut down).

A site-specific Mechanical Loads Analysis (MLA) is required to determine the turbine suitability and whether the above-listed cut-out and re-cut-in wind speeds require adjustment to mitigate site-specific loads. If, for example, the MLA concludes that curtailment is needed to reduce loads, the MLA report will state the reduced 600-second cut-out wind speeds and the applicable wind direction sector(s). The remaining cut-out and re-cut-in wind speeds will be reduced by the same amount that the 600-second wind speed is reduced. Any reduction of the wind speeds listed in this section may be turbine location-specific. Refer to the site-specific MLA report for details.

5 Calculated Thrust Coefficient

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Wind Speed at Hub Height [m/s]	Thrust Coefficient [ct]		Wind Speed at Hub Height [m/s]	Thrust Coefficient [ct]
3.0	0.92		14.5	0.21
3.5	0.89		15.0	0.19
4.0	0.86		15.5	0.17
4.5	0.84		16.0	0.16
5.0	0.82		16.5	0.14
5.5	0.81		17.0	0.13
6.0	0.81		17.5	0.12
6.5	0.81		18.0	0.11
7.0	0.80		18.5	0.10
7.5	0.80		19.0	0.09
8.0	0.79		19.5	0.08
8.5	0.75		20.0	0.07
9.0	0.71		20.5	0.07
9.5	0.64		21.0	0.06
10.0	0.58		21.5	0.05
10.5	0.53		22.0	0.05
11.0	0.48		22.5	0.04
11.5	0.43		23.0	0.04
12.0	0.39		23.5	0.03
12.5	0.34		24.0	0.03
13.0	0.30		24.5	0.03
13.5	0.27		25.0	0.03
14.0	0.24			

Table 5: Calculated thrust coefficient table; as a function of hub height wind speed

Calculated using Standard Atmospheric Conditions according to ISO 2533 for geometric altitude of 0.

6 Guidelines for Pre-construction Energy Assessment

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The following guidelines are offered for selecting power curves from this document for measurement purposes or assessment of the energy production of a new wind plant.

The air density should be the annual average air density expected at the site of the new wind plant over the life of the wind turbine.

The reference power curve for warranty purposes shall be chosen for the turbulence intensity range covering the largest fraction of data points from the measured data set of the power curve test. Figure 2 depicts one example to illustrate this guideline. The mean turbulence intensity distribution for the site is plotted over the low, medium, and high turbulence intensity ranges. As shown in Figure 2, the site has a mean turbulence intensity distribution that is most common to the low turbulence intensity range. Accordingly, the low turbulence PCs from Table 3 should be used for this example site.

For site energy assessment purposes the turbulence intensity range between low, medium, and high may also be selected based on comparing the measured 10 min averaged scatter plot in each wind speed bin expected individually to represent the conditions at the site of the new wind plant over the life of the wind turbine.

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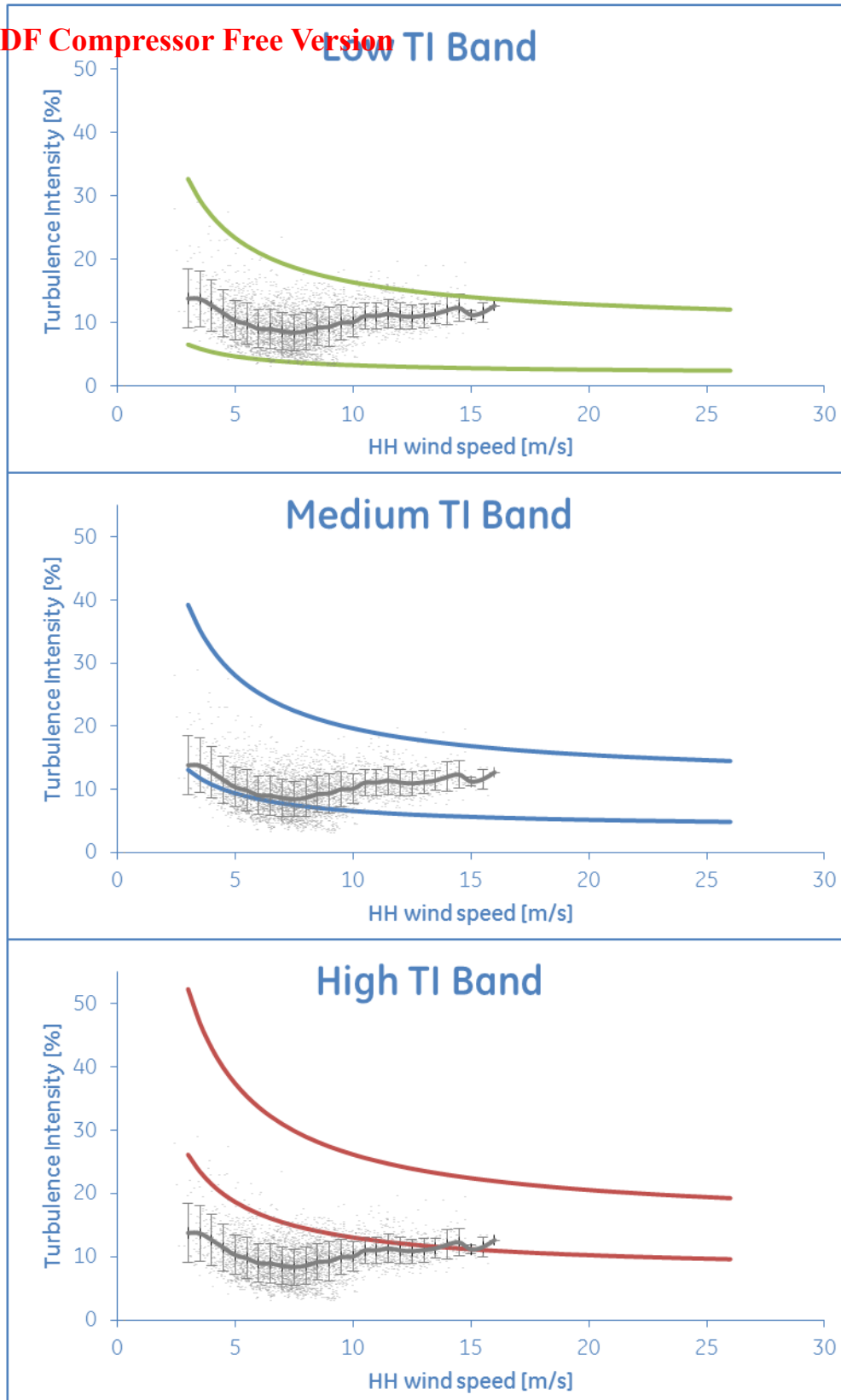


Figure 2: Example of site specific turbulence distribution with mean turbulence data and standard deviation relative to high TI (9%), medium TI (71%) and low TI (98%) band (figures in parenthesis represent the coverage rate)