RESOURCE & TECH

NOVEMBER 14–15 | AUSTIN, TX

Gennaro H. Crescenti
Pattern Energy

Pattern

Are 60-m Meteorological Towers Obsolete for Wind Resource Assessment?

BACKGROUND

Wind turbine hub heights and blade diameters have been steadily increasing over the last four decades. An analysis of data in the U.S. Wind Turbine Database[1] (USWTB) from 1983 through 2022 shows an approximate linear increase in average turbine hub height and blade diameter of 1.9 and 3.1 m/year, respectively. Average blade area shows near-exponential growth. Average hub height and blade diameter in 1983 was 23 and 15 m, respectively, while the average hub height and blade diameter in 2022 was 94 and 133 m, respectively. Average blade area was 184 and 13,967 m^2 in 1983 and 2022, respectively. The highest hub height reported in the USWTDB is 137 m!

OBJECTIVE

60-m meteorological towers are the primary platform of choice for acquiring on-site wind data. This is due to a variety of factors including cost, ease of installation and no requirement for Federal Aviation Administration (FAA) permits. Taller towers (≥ 80 m) and ground-based remote sensors are being more utilized for on-site observations. However, many projects rely mostly on 60-m towers. Thus, extrapolation distances continue to increase between mast height and hub height, which increases the potential for overprediction of hub height wind speed. The objective is to show the potential for overestimation of hub height wind speed using 60-m and taller tower data where the power law breaks down.

METHODS

The potential overestimation of hub height wind speed from 60-m towers is quantified based on observations from taller towers and lidars in a semi-complex, near coastal site.

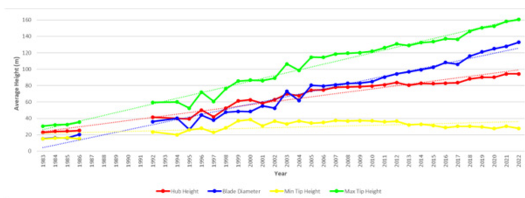
Proposed hub height: 113 m

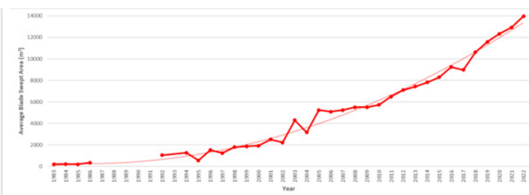
Wind speeds acquired at 15 sites:

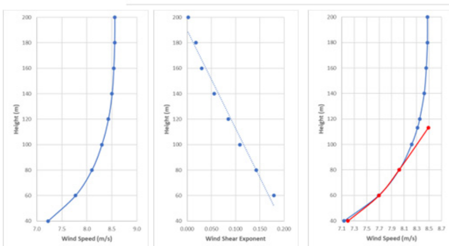
- Seven (7) 60-m towers
- Five (5) 80-m towers
- Two (2) 100-m towers
- One (1) 120-m tower
- Two (2) lidar sites

RESULTS

Over last 20 years, extrapolation distances have increased 1.2 m per year between 60 m measurements and average hub height. As of 2022, the average extrapolation distance was 34 m!





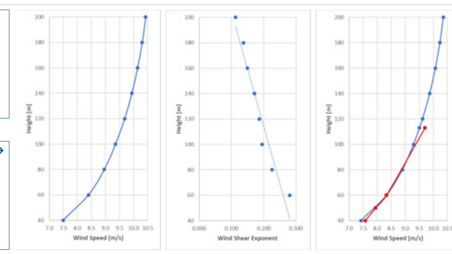


← ← ←

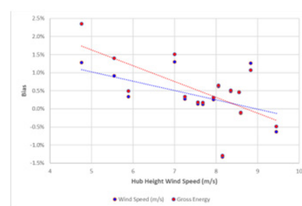
Average wind speed profile (left) and wind shear exponent profile (center, ~ -0.015 / 10 m) from lidar deployed at Tower 06, and fully concurrent data (right) from the lidar (blue) and tower (red). The hub height predicted wind speed based on tower data overestimates the wind speed by 0.18 m/s relative to the bias-corrected lidar wind speed profile.

→ → →

Average wind speed profile (left) and wind shear exponent profile (center, ~ -0.013 / 10 m) from lidar deployed at Tower 15, and fully concurrent data (right) from the lidar (blue) and tower (red). The hub height predicted wind speed based on tower data overestimates the wind speed by 0.19 m/s relative to the bias-corrected lidar wind speed profile.



Tower	01 80 m	02 80 m	03 100 m	04 60 m	05 80 m	06 80 m	07 60 m	08 60 m	09 60 m	10 120 m	11 100 m	12 60 m	13 80 m	14 60 m	15 60 m
Upper Height (m)	79	79	100	60	80	80	60	60	60	120	100	60	80	60	60
Middle Height (m)	61	61	80	50	60	60	50	50	50	100	80	50	60	50	50
Lower Height (m)	40	40	60	40	40	40	40	40	40	80	60	40	40	40	40
Δz U/L (m)	39	39	40	20	40	40	20	20	20	40	40	20	40	10	10
Δz U/M (m)	18	18	20	10	20	20	10	10	10	20	20	10	20	10	10
Δz M/L (m)	21	21	20	10	20	20	10	10	10	20	20	10	20	10	10
α U/L	0.166	0.205	0.223	0.263	0.241	0.166	0.260	0.215	0.187	0.202	0.249	0.270	0.267	0.220	0.251
α U/M	0.130	0.189	0.203	0.245	0.215	0.159	0.238	0.208	0.177	0.183	0.225	0.280	0.263	0.218	0.271
α M/L	0.201	0.220	0.242	0.280	0.267	0.173	0.281	0.221	0.196	0.221	0.272	0.260	0.271	0.221	0.231
α U/M – α U/L	-0.036	-0.016	-0.020	-0.018	-0.026	-0.007	-0.022	-0.007	-0.010	-0.019	-0.024	0.010	-0.004	-0.002	0.020
Δα (%)	-22	-8	-9	-7	-11	-4	-8	-3	-5	-9	-10	4	-1	-1	8
Mast Wind Speed (m/s)	8.32	7.76	5.73	4.03	5.10	6.85	5.94	7.46	7.16	8.70	7.70	7.97	6.90	6.68	6.95
U/L Hub WS (m/s)	8.83	8.35	5.89	4.76	5.54	7.25	7.00	8.55	8.06	8.59	7.94	9.45	7.56	7.68	8.15
U/M Hub WS (m/s)	8.72	8.31	5.87	4.70	5.49	7.23	6.91	8.51	8.01	8.60	7.92	9.51	7.55	7.67	8.26
ΔWind Speed (m/s)	0.11	0.05	0.01	0.05	0.05	0.02	0.09	0.04	0.05	-0.01	0.02	-0.06	0.01	0.01	-0.10
ΔWind Speed (%)	1.26	0.48	0.34	1.28	0.91	0.28	1.30	0.47	0.62	-0.12	0.25	-0.63	0.13	0.13	-1.33
ΔMWh / ΔWS	0.85	1.06	4.45	1.84	1.54	1.21	1.16	0.97	1.04	0.90	1.21	0.77	1.37	1.34	0.97
ΔEnergy (%)	1.07	0.51	0.49	2.35	1.40	0.34	1.51	0.45	0.65	-0.10	0.31	-0.49	0.18	0.17	1.29



For this site, the wind shear exponent decreases with height for most towers. Hub height predicted wind speeds (blue dots, above) are biased by up to 1.3% using the upper/lower wind shear exponent versus the upper/middle value. The sensitivity (ratio of change in gross energy to change in wind speed) is also inversely proportional to wind speed, with values less than unity at wind speeds greater than 8 m/s, and exceeding 1.4 at wind speeds less than 6 m/s. Gross energy (red dots) is also biased high and is inversely proportional to wind speed. On average, the potential overprediction of gross energy ranges from 0.5 to 1.0%, with values exceeding 1.5 to 2.0% at low wind speeds.

CONCLUSIONS & RECOMMENDATIONS

So, are 60-m meteorological towers obsolete for wind resource assessment? The answer depends on several factors, including site and wind resource complexity, average wind speed, wind speed frequency distribution, and power curve. The logarithm wind speed profile tends to breakdown in complex topographic sites and where winds are thermally driven. In some extreme cases, maximum wind speeds are observed at heights of 80 to 120 m above ground and then quickly decrease with height. Overprediction of hub height wind speed is generally low for high wind speed sites whereas can be quite significant at lower wind speeds. Depending on the derived sensitivity ratio (which is a function of the wind speed frequency distribution and power curve), the potential for over prediction of gross energy can be significant, especially at lower wind speeds.

60-m towers are the "workhorse" platform used to acquire on-site wind resource data and will continue to do so in the foreseeable future. However, on-site measurement platforms must evolve as turbine hub heights and blade diameters continue to grow. This is already occurring in the wind energy industry. Consideration should be given to increase the ratio of taller (≥ 80 m) towers to 60-m towers at project sites and continued deployment of ground-based remote sensors such as lidars to help further quantify the wind speed profiles. For taller towers, consideration should be given to increasing the number measurement heights (from three to at least four) of wind speed which can further help quantify trends of wind shear exponent with height.

This study is a simple reminder to understand the meteorology at a project site and to very carefully examine trends in wind shear exponents from 60-m tower towers when trying to predict hub height wind speeds that have considerable extrapolation distances, and especially when there are few or no available tall towers and/or lidars to help reduce the potential overprediction of hub height wind speed.

ACKNOWLEDGEMENTS

The author would like to acknowledge the Pattern Energy Meteorology team for their comments and suggestions. Pattern Energy's approach begins and ends with establishing trust, accountability, and transparency. We aim to sustainably develop, construct, and operate clean, renewable energy projects in a safe and responsible manner and with respect for communities and cultures where we have a presence.

REFERENCES

[1]United States Wind Turbine Database (USWTDB)
https://eerscmap.usgs.gov/uswtdb/

CONTACT INFORMATION

Gennaro H. Crescenti
Pattern Energy
888 Westheimer Road, Suite 350
Houston, TX 77006

Mobile: 941-304-6377
Email: Jerry.Crescenti@patternenergy.com