METEOROLOGICAL TOWERS
AND
WIND POWER ANALYSIS

General Primer

by

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Introduction

Wind data that is accurately measured, certified, and meticulously analyzed, is valuable information that may be used for project development, facilitate and support the negotiation of both Power Purchase Agreements (PPAs) and Renewable Energy Certificates (RECs), and encourage project financing through equity and or debt funding sources. Each recording meteorological tower is an individual data acquisition point, also known as a "validation point" for wind meso-mapping. Wind maps can be used to identify specific zones within a region having better wind characteristics and more accurate micro-siting of wind turbines can be achieved. Certain land topologies and man-made structures, e.g., ridges, gullies, and mountain gaps, grain elevators covering large areas of land, may cause vertical and or horizontal funneling of wind making certain regions more desirable for turbine placement.

The measurement of wind speed is one of several important metric requirements for estimating energy capture and the corresponding electrical generation one would realize from a given model of wind turbine. Related metrics include temperature, humidity, barometric pressure and direction.

Wind data may be used for projects in the region, within a radius of 2 to 5 miles from the point of validation, provided there is no extraordinary change in surface terrain (topology and ground cover). Larger areas can be mapped using three-dimensional fluid analysis software. Mapping is also advisable when the terrain has changing characteristics.

The kinetic energy in the wind is a cubic function of wind velocity (v^3); therefore, an error of 3% in the recording of wind speed could result in an energy capture projection in error by as much as ± 9.2% of available energy. The importance of having credible wind data, prior to serious consideration for the installation of one or more wind turbines, cannot be overemphasized. Long term measurements of wind data are expensive investments, and most projects do not have a long time table for development. A minimum one year of recorded wind data is required and should be evaluated against historical long term data that is purchased for the region. Site specific short term data is reviewed with long term historical data using the "measure, correlate and predict (MCP)" technique.

There are many meteorological systems that may be purchased; the systems range in cost from $5,000 to $30,000 for equipment, plus installation, and insurance. Telemetry fees may also be a consideration should the system be remotely located and generally cost in the neighborhood of $500-$650 per year. Telemetry is typically recommended for meteorological tower sites in distant locations not readily accessible.

Meteorological tower installation costs are in the range of $6,500 to $8,500 depending on tower assembly requirements, and cost of travel and labor for the tower construction crew. Through experience, we have determined that the mean installation time generally falls between 135-160 man-hrs (labor) for the correct and safe installation of a 60m tower.

Untrained individuals, with no experience in tower construction, should not attempt the installation of any tower exceeding 30 m (98.4ft). Towers that fall are usually severely damaged, will require repair, or section and component replacement, and will need to be erected again.

Importance of Meteorological Measurement Height

Wind speed is a function of height, topology and ground cover. Generally speaking, a better picture of the wind resource is gained from towers closest to the height of the turbine that is being contemplated for the installation. A small variation in wind speed has a significant impact on energy capture.

Unfortunately, many 30 m towers have been installed without proper technical guidance. This has occurred in regions that have high wind shear and complex terrain which requires the use of higher tower measurement of the wind. Hence, data collected does not have meaningful value for energy capture calculations, using wind turbines that are 70 m (229 ft) to the center of the turbine's rotor.

Data needs to be collected at a minimum of two levels (three levels are preferred) to determine the turbulence and shear within the wind. This is accomplished by having more than one anemometer mounted to the tower at prescribed intervals. Dual anemometers are recommended at the highest metering point. Anemometers are placed at various levels to determine the wind shear and the magnitude of wind turbulence which may fatigue the rotor blades over time.

Wind speed has a functional relationship to elevation. As a general rule, the higher a turbine rotor is placed above ground, the greater the velocity and power of the wind. Turbine generators placed on higher towers will produce more electrical energy. Wind speed over the first 500 meters above ground tends to increase with an exponential factor (a friction coefficient derived for ground cover resistance) in proportion with the height. For every 20 meter increase in elevation, the velocity of the wind increases 5% to 15% depending on type of ground cover.

The type of ground cover in the region tends to offer a certain degree of resistance to the movement of wind as ground level is approached. The opposition that ground cover offers to wind can be given a value, known as the "coefficient of friction", that may be used in projecting wind speed at higher altitudes when the speed of the wind is known at a certain height above ground level.

Friction Coefficient of Various Terrain

Terrain Type	Friction Coefficient (α)
Lake, ocean and smooth hard ground	0.10
Foot high grass on level ground	0.15
Tall crops, hedges, and shrubs	0.20
Wooded country with many trees	0.25
Small town with some trees and shrubs	0.30
City area with tall buildings	0.40

Source: Wind and Solar Power Systems, 1999, Dr. M. Patel

Wind speed at some projected turbine height may be calculated with reasonable accuracy when the speed at a reference height, obtained from an anemometer, and ground cover are known. By incorporating speed and terrain friction coefficients into the following formula, we can arrive at an estimated speed.

$$v_2 = v_1 \times \left[\frac{h_2}{h_1} \right]^{\alpha}$$

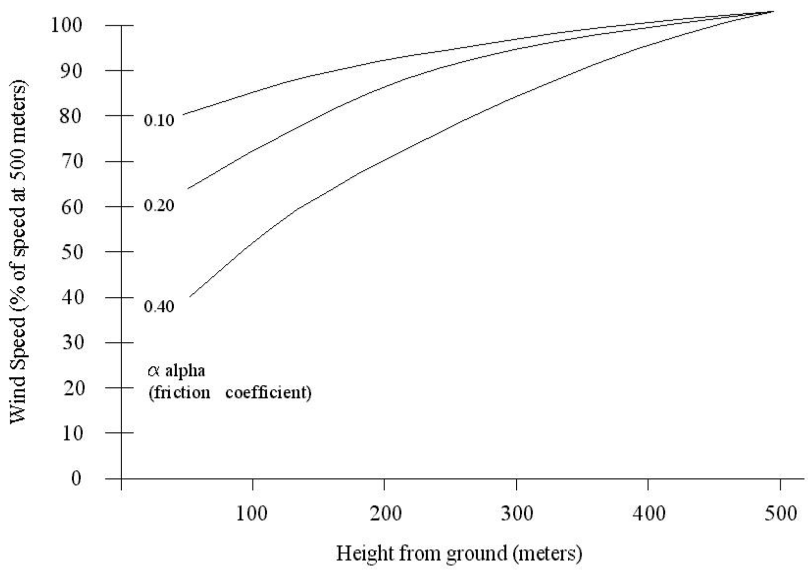
Where α is the coefficient of resistance for ground cover,
h_2 is the height at the rotor hub,
h_1 is the height of the meteorological tower.
v_2 is the wind speed at the rotor hub, and
v_1 is the wind speed at the meteorological tower.

The following graph illustrates the fact that wind speed at a turbine height will be closer to the 500 meter speed percentage-wise when ground cover has the lower coefficient of friction and the tower has greater height.

Anemometer

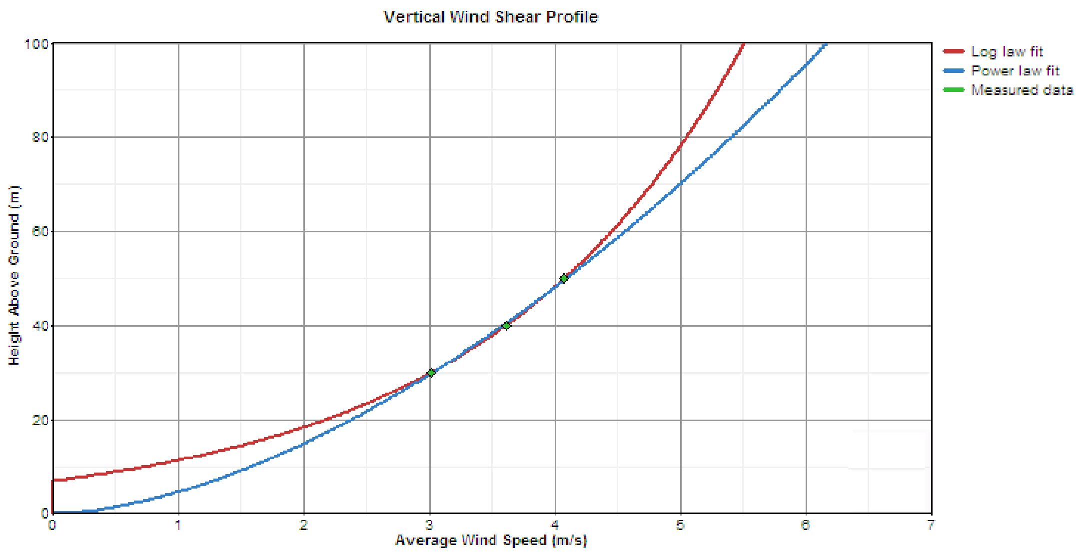
Wind Vane

Wind Speed with Respect to Ground Cover and Height



Source: Wind and Solar Power Systems, 1999, Dr. M. Patel

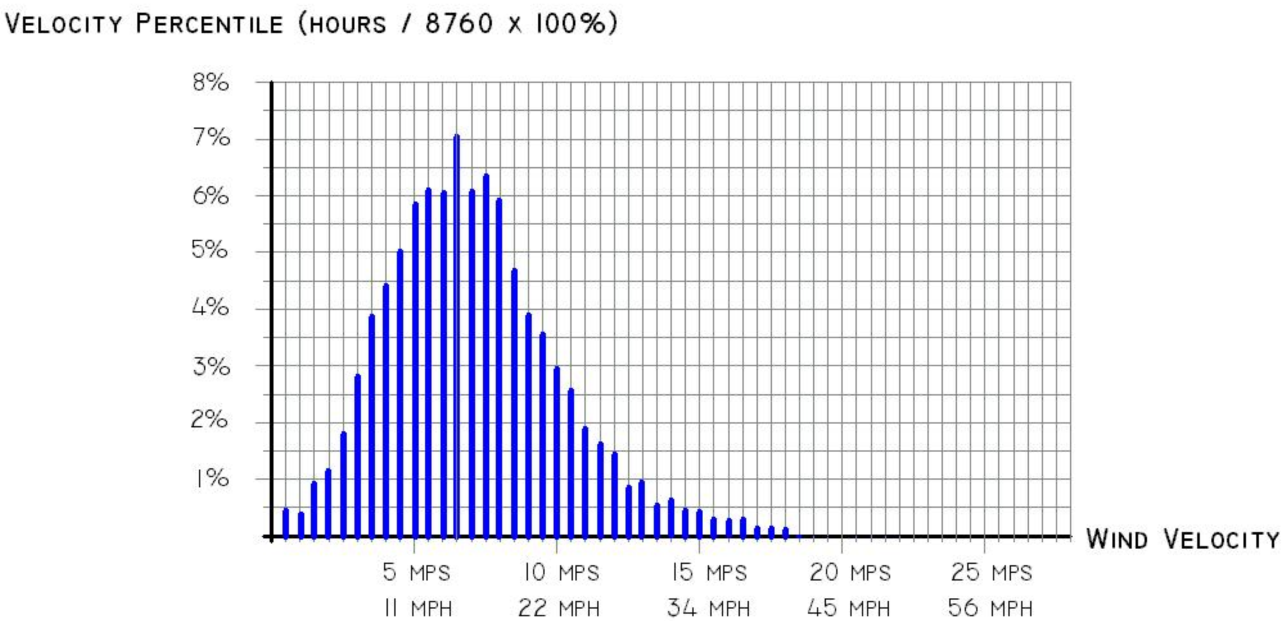
Geographic areas having good wind may have higher costs associated with the long term maintenance of the turbine gearbox and experience long term rotor blade fatigue if located in turbulent wind zones. Turbulence is one factor that is used in determining life-span of the turbine system and project feasibility (20 years or more).



The measured data points (green diamonds) are used to establish reference points for one of two curves, e.g., Logarithmic and Power Laws. The curves are fitted to the data points for wind speed projections at higher elevations which have not been metered.

The following distribution curve gives a graphic picture of the wind speed data presented on the previous page. From this data and graph a determination of mean-, mode-, and rms-wind speed is made. The shape of the curve also gives important information as to the amount of energy that is available for the wind turbine.

TYPICAL WIND SPEED FREQUENCY DISTRIBUTION CURVE



The evaluation and analysis of wind data uses what is known as Weibull statistical analyses with focus on two important parameters, the shape factor of the wind speed frequency distribution curve and the scale parameters. Although there are wind sites that have higher wind velocities, v > 25 mps (56 mph), these sites are generally not suitable for wind turbines. Wind turbines are programmed to stall at high wind speeds, to protect the rotor and tower structure. Stalling the rotor is accomplished by turning the blade pitch into the wind at cut-out speed or may also be achieved by using what are referred to as “tip-breaks”.

When evaluating wind data, simply knowing that a site has a high average wind speed is not sufficient information to warrant the investment in a wind turbine facility. The pattern for the distribution of wind speed and frequency are equally important factors.

In the US and Canada, wind speed and power density is categorized within seven classifications, Class I through VII, Class I being the weakest and Class VII the strongest of the categories. Europe uses a different classification system.

Wind Speed Classification Chart

Class	30 meter height Wind Speed	30 meter height Power (W/m2)	50 meter height Wind Speed	50 meter height Power (W/m2)
I	0 – 5.1 m/s	0 – 160	0 – 5.6 m/s	0 – 200
II	5.1 – 5.9 m/s	160 – 240	5.6 – 6.4 m/s	200 – 300
III	5.9 – 6.5 m/s	240 – 320	6.4 – 7.0 m/s	300 – 400
IV	6.5 – 7.0 m/s	320 – 400	7.0 – 7.5 m/s	400 – 500
V	7.0 – 7.4 m/s	400 – 480	7.5 – 8.0 m/s	500 – 600
VI	7.4 – 8.2 m/s	480 – 640	8.0 – 8.8 m/s	600 – 800
VII	8.2 – 11.0 m/s	640 – 1,600	8.8 – 11.0 m/s	800 – 2,000

Class IV and Class V wind zones, an industry consensus, are generally most feasible for use with fixed speed wind turbine design and direct connection to the electrical grid. Lower wind classifications are generally better suited for variable speed turbines with energy storage[1]. Class II and Class III regions may be better served with variable speed wind turbine generators. Class I may be suitable for specially designed low speed wind turbines. This will be best determined by a comprehensive wind analysis and wind turbine energy capture study.

Wind turbines capture the kinetic energy of the wind as it passes through the rotor, which has two or more blades that are mechanically linked to an electric generator. The actual power that will be extracted from the wind will be the difference between the upstream (before the rotor) and downstream (after the rotor) wind power.

A practical formula for estimating the available power that a turbine might be capable of generating is:

$$P_{avail} = 0.25\ \rho\ A\ v^3$$

where ρ is the density of air,
A is the swept area of the turbine rotor in square meters (m^2), and
v is the velocity of the air in meters per second (m/s)

Note (1): Currently battery storage has been a popular storage method. The opinion of the writer is that compressed-air storage systems have better storage scalability and are very compatible with larger wind systems. New energy recovery technologies are being developed for compressed air storage. It is presumed that the newer technology will have greater efficiencies of operation compared to systems available today.

Once wind data is gathered, the metric is compiled to determine the amount of time the wind is moving at a given incremental velocity (beginning with 0 m/s to 50 m/s with increments of 0.5 m/s). Contrary to popular belief, while Class VI and Class VII wind regimes have exceptional wind power densities, turbines are cut-out of operation for much longer time periods during high winds, result - lower energy capacity factors are generally realized.

A simple frequency distribution curve can then be generated detailing shape factor, average, mean and root mean cubic speeds. This provides a thumbnail sketch of the wind resource, and upon further analysis, an informed decision about a region's actual wind characteristic and its potential for use in generating electricity can be made.

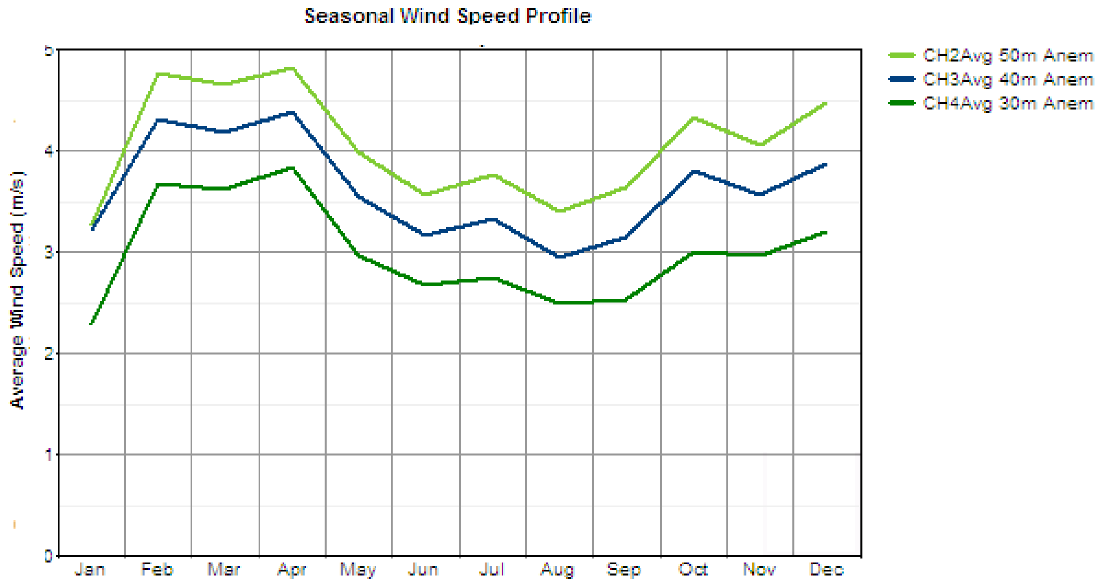
Shape factor (k) is very important for determining energy capture. For example, three sites may be chosen having the exact same average annual wind speed. Correspondingly, each site will have energy capture that may vary by as much as 25% or more, based on the fact that the frequency distribution favored different areas under the frequency distribution curve. Shape factors typically range from k = 1.45 to k = 2.5 with most wind sites having shape factors of k = 1.9 to k = 2.0.

Meteorological Towers

Towers can be installed so they are permanent fixtures or capable of being dismantled.
Manufacturers provide a wide selection of tower designs: tilt-up and telescoping are among the most common. This tower is being assembled at the top of a high hill in a municipal composting site.

Top end of a typical 50m sectional tower

Accurate monitoring of wind velocity over the course of the study period allows the project proponent to see variations in wind speed with elevation and time of day, these measurements are referred to as diurnal patterns.



A 50 m tower weighs as much as 2,200 lbs. Towers will typically require a steel base plate that is constructed for lifting the mast and then serving as the base for the period of time that the tower is in place. Depending on soil conditions, the base may need to be supplemented with either a wood or concrete footing.

Placement of the base and anchors is important and must be done accurately (tolerance requirements vary between ± 1ft to ± 5ft depending on manufacturer) so the tower does not have a tendency to tilt or lean in any one direction. Tilting compounds problems with stress on the guy wires under icing and high-wind conditions.

Manufacturers provide engineered survival wind speed charts for tower loading under high wind and icing conditions. The proper installation of the tower better insures survival under adverse weather conditions. Heavier gage steel is recommended for areas where icing and high wind may be expected. The survival speed for a meteorological tower must be known along with the typical weather for the installation site. We recommend +15% wind velocity tolerance for this consideration.

The physical anchoring of the tower is accomplished with long rod soil-screws, arrowhead anchors, cemented eye-bolts, etc. Anchors must be properly set and tested to insure mechanical integrity of the tower.

Monitoring

Real-time data measurements are converted into digital pulses for anemometers and analog signals for wind vanes, temperature and other metrics.

Data is fed down from the tower to an interface board which connects with a simple microprocessor. Systems that are on the market typically measure data once every ten seconds. The data is averaged over a period of several minutes and then saved to a file for the day's record. The method of storage on many systems is a memory card.

The data is read and printed using software that is generally provided by the manufacturer.

Data may also be relayed using cellular or satellite phone technology. Systems that are adjacent to building can often be directly wired to a LAN line. Unless the tower is in a remote location, it is not cost effective to have telemetry. Also, manufacturers do not provide meaningful technical support for proving software protocols between the telephony carrier, both cellular and satellite, and the Internet Service Provider (ISP).

The processor is enclosed in a weather-tight plastic or metal enclosure and has provisions to secure the equipment. Solar power is generally the source of energy for the system.

Installation Requirements

1) A 60 meter tower that is supported with guys will require a footprint that is no less than 200 ft square on each side.

2) Labor requirements: 75 to 135 man-hrs (Average 86 man-hr)

Task	Estimate Time
Siting and Installation of Anchors	30-80 man-hr (Average 45 man-hr)
Tower Assembly and Instrumentation	24-40 man-hr (Average 34 man-hr)
Lifting Tower and Tensioning Adjustments	45-85 man-hr (Average 62 man-hr)

Notes to Siting and Anchor Installation: The amount of time for anchor installation can be estimated closely if several feet of soil is removed prior to the anchor installation (recommended when there is no knowledge of ground composition). This may be done by digging up the ground or by driving a test rod or steel pipe having at least a 1" trade-size prior to deciding on the appropriate anchoring technique. Incorrect anchor selection and installation are subject to failure during wind conditions that typically occur with thunderstorms and other volatile weather conditions. There are at least six different soil type classifications, each having a different holding capability when force is applied to the anchor being used. Understanding the soil, the type of anchor, and the proper application of the anchor, as well as the depth the anchor is installed, are all very important issues for a good tower installation.

3) Level land with less than a 25 degree slope. Higher slopes may require unique anchoring and rigging for lifting the tower and securing it properly. We have experience with rigging meteorological towers on sand dunes and forest areas.

4) No tree or branch overhang within the guy wire working envelope area, or in the direction that the tower will be laid during construction (for a length equal to or greater than the actual height of the tower).

5) A minimum 10,000 lb. winch for lifting the tower.

6) Labor recommendations: 4-man crew for 30m and 40m towers; a 5-man crew for 50 m and 60 m towers.

Additional Points for Consideration

The tower can be purchased outright and remain on-location should the wind be judged suitable for energy production. The existing tower would be used to provide velocity and directional back-up for monitoring equipment on the turbine.

The tower can be purchased and then re-sold to another party, thus minimizing the investment risk for the institution.

Towers used by Alternate Energy Solutions, Inc. may be leased on an annual basis to clients interested in evaluating their wind resource, provided that they are available. Please contact us for more information.

We also have access to Doppler technology to measure wind velocities and vertical wind shear at elevations exceeding 100 m.

Comments and questions on this white paper are welcome and may be directed to:

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