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A Measurement Program to Characterize the Wind at a Potential WECS Site

by
M. Gary Verholek

March 1978

**Pacific Northwest Laboratory
Richland, Washington 99352
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SUMMARY

Having identified a potential wind turbine installation site, the installation decision process involves two options: a) determining if the site is suitable for the intended machine design, or b) determining an appropriate machine for the intended site. Either option requires that onsite wind characteristics be compared to machine characteristics to determine the proper site-machine match.

This paper describes an onsite meteorological measurement program to characterize the wind at a potential wind turbine installation site. The basic informational requirements have been postulated, the analysis described, and an appropriate measurement program has been devised. This phase of siting measurements provides the information for the final installation decision process -- which WECS to put at which site.

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A MEASUREMENT PROGRAM TO CHARACTERIZE THE WIND AT A POTENTIAL WECS SITE

M. Gary Verholek

1. INTRODUCTION

The objective of this paper is to describe an onsite measurement program to characterize the wind at a potential wind energy conversion system (WECS) site. Having identified and selected a potential WECS location, there are two options: a) determining if the site is appropriate for a given machine, or b) determining an appropriate machine for the potential site. This program will enable an investigator to evaluate the feasibility of installing one or more wind turbines on a site.

This paper will first identify the basic wind descriptions required in the siting process, and then describe a measurement program for acquiring the necessary wind data. The evaluation process requires that we determine the relevant wind characteristics at each site, compare them to the characteristics of the particular WECS machine(s), and then balance the economic and technical requirements. To make such an evaluation, detailed wind characteristics must be determined from data for each site. Site measurement programs for single units and multiunit "farms" differ in magnitude and scope; however, similar wind characteristics need to be determined and, therefore, similar data must be obtained.

2. WIND CHARACTERISTICS FOR SITING

The description of the wind characteristics at a site should include:

- a) joint frequency distribution of speed and direction;
- b) seasonal and diurnal variability of speed;
- c) persistence duration;
- d) turbulence and shear characteristics.

2.1 JOINT FREQUENCY DISTRIBUTION OF WIND SPEED AND DIRECTION

The joint frequency distribution (JFD) can be used for many purposes. It gives an indication of the predominant wind direction(s) and the frequency distribution of speed. Analyzed in relation to the local topography, surface roughness and thermal processes, the JFD gives an indication of the effect such features have on the nature of wind flow over the site and the frequency of occurrences. Such information can be useful for deducing the general flow pattern in the site area and for inferring enhanced and/or sheltered areas in the local flow-field. It is also useful for determining the frequency of occurrence of various turbulent intensities and high shears with respect to local influences. (The topic of turbulence measurements will be discussed later.)

The joint frequency distribution can also be summed over all directions to yield the frequency distribution of speed which is generally used to estimate wind power.

2.2 WIND POWER ESTIMATES FROM WIND SPEED DISTRIBUTIONS

An evaluation of a potential WECS site must also provide a quantitative estimate of the potential power at the site. The available power is the equivalent of the rate of change of kinetic energy in the moving mass of air, and is given by:

$$P(v) = 1/2 \cdot \rho \cdot A \cdot v^3 \quad (2.2-1)$$

where

$P(v)$ = power available from the wind
 ρ = air density at the site
 A = area swept out by the blades
 v = wind speed at the machine hub height.

Then the average potential power available at the site is

$$\bar{P} = \int_0^{\infty} P(v) \cdot p(v) \cdot dv \quad (2.2-2)$$

where

$\bar{P}$ = the average available potential power
 $P(v)$ = potential power available at wind speed v
 $p(v)$ = frequency distribution of wind speed v .

We have the expression for $P(v)$, and so we need only to determine the frequency distribution of the wind speed.

The available power is useful for depicting the relative potential of sites as part of the selection process. However, for an economic analysis, it is important to estimate the extractable power. The extractable power is the power that can be produced by a given WECS, and is a function of the machine characteristics, as well as of the wind characteristics. Each machine has design-operating characteristics, such as cut-in, rated, and cut-out speeds. According to Cliff^[1], an estimate of the turbine's expected average power output may be computed from:

$$\bar{T}_p = \int_0^{\infty} T_p(v) \cdot p(v) \cdot dv \quad (2.2-3)$$

where

$$\begin{aligned}\bar{T}_p &= \text{the average extractable power for the turbine} \\ T_p(v) &= \text{specified turbine output as a function of} \\ &\quad \text{wind speed} \\ p(v) &= \text{frequency distribution of the wind speed} \\ v &= \text{wind speed at hub height.}\end{aligned}$$

Figure 2.2-1 illustrates the processes involved in Equation 2.2-3. Figure 2.2-1(A) depicts a typical wind turbine performance curve. At a cut-in wind speed, A, the turbine begins to produce power and produces more power as the wind speed increases, until it reaches the rated wind speed, B. Above this wind speed the turbine's power output stays constant until the cut-out speed, C, is reached. At wind speeds greater than the cut-out speed, the turbine does not produce power. The turbine's blades are usually feathered or are designed to stall above the cut-out speed to prevent damage to the machine.

Figure 2.2-1(B) depicts a typical wind speed frequency distribution. Only a small percentage of time is spent at either the extreme low or high ends of the distribution. The convolution of the curves in Figs. 2.2-1(A) and (B), $T_p(v) \times p(v)$, yields the power frequency distribution of the turbine's output as a function of wind speed, Fig. 2.2-1(C). The integral of this curve (Eq. 2.2-3) then yields the average expected power output of the wind turbine, $\bar{T}_p$. Since the turbine only produces power when the wind speed is between the cut-in and the cut-out specifications, Eq. 2.2-3 needs to be integrated only over these limits, rather than from 0 to ∞ .

The frequency distributions are generated from discrete or averaged observations and are depicted as histograms of the number of observations in each speed interval. The speed

Figure 2.2-1. Interaction of Wind Turbine Characteristics and Wind Statistics to Produce the Wind Turbine Power Frequency Distribution

histogram can be either used directly or fitted with a distribution function for integration in closed form. The method of analysis used will depend on the spacing of the intervals selected. Speed intervals 0.5 m/sec are generally adequate for direct application in Eq. 2.2-2 and Eq. 2.2-3.

The result of Eq. 2.2-3 should provide a reasonable estimate of the average power produced by a specific wind turbine operating in an environment described by $p(v)$. Nevertheless, the actual power output of the turbine may differ from this estimate since the complete machine transfer function and some meteorological factors (i.e., vertical profile of the horizontal component of wind velocity, the wind direction variability, and turbulence) are not considered in Eq. 2.2-3.

2.3 SEASONAL AND DIURNAL VARIATIONS

The usability of the power from WECS depends, in some cases, on matching the availability of power with the demand. This is especially true in direct applications without storage and where the WECS is expected to supply a significant portion of the power base. In any case, usability will be enhanced where supply matches demand. This is not trivial and should be examined as part of the installation decision process.

Data in the Wind Energy Mission Analysis Reports of Lockheed^[2] and General Electric^[3] illustrate the variability of both power demand and the supply of available wind energy. An examination of these documents reveals variations in the available wind energy which include:

- a) seasonal variations that differ with location;
- b) diurnal variations that differ with location; and
- c) diurnal variations that differ with the seasons at different locations.

These reports show variations in power demand that are directly related to the application and/or primary consumer. Clearly, generalized cyclical variations in power demand are not adequate input for siting decisions. In general, a user's load demand warrants complete examination. Localized available power estimates, produced on a monthly and diurnal basis, need to be compared to specific load demands.

2.4 TURBULENCE

Turbulence is of interest for two reasons. First, it causes differential loading on the blade and, secondly, as a characteristic of the airflow into the blade, it affects the smoothness of power output.

Fluctuations of fluid flow are often described statistically in terms of turbulence intensity, mathematically expressed as:

$$I_t = \frac{\sigma_v}{\bar{v}} \quad ,$$

where σ_v is the standard deviation of wind speed and $\bar{v}$ is the mean speed for the same period. The specification of the turbulent intensity requires statistical analysis of the data for wind speeds above cut-in.

Turbulence is not a feature of fluids but of fluid flow. The airflow over a site varies with the influence on that flow by terrain and vegetation. Therefore, turbulence intensity has to be specified as a function of wind direction and speed. Examining the relation of turbulence versus speed and direction with respect to the joint frequency distribution of speed and direction will reveal the frequency of various turbulence intensities at a site. Such information can then be used to decide how important turbulence may be to the proper site-machine match.

2.5 SHEAR

Wind velocity generally varies with height both in magnitude and direction. This change in velocity with height is called shear. At sites where pronounced shear frequently occurs, differential loading and fatigue may lead to failure of a turbine blade. Studies of shear at a potential site become increasingly important as larger and larger blade diameters are being considered by designers. Shear intensities, as well as turbulence intensities, are site-specific wind characteristics which may affect the selection and/or placement of a turbine. It is important to determine the frequency and intensity of the shear at potential turbine sites and to consider this wind characteristic in the installation decision process.

Empirically, it has been found that in homogeneous terrain, wind profiles tend to obey a power law,

$$\left(\frac{\bar{v}_2}{\bar{v}_1}\right) = \left(\frac{z_2}{z_1}\right)^p ,$$

where $\bar{v}_2$ is the mean wind speed at level z_2 , and $\bar{v}_1$ is the mean wind speed at level z_1 , and p is the power law coefficient. Observed wind profiles over uniform terrain compare quite well with this relationship, but only over limited ranges of heights. However, these ranges are usually large enough for most practical applications. Furthermore, the applicability of a physically derived log profile^[4] is not ensured for all sites under all conditions; hence the analytical approximation of the observed wind profile by use of the power law relationship is recommended. Intuitively, the physical essence in a log profile can be obtained by considering the effects of height, roughness and stability. It is therefore desirable to approximate the observed wind profile by separate power laws

based on multiple levels of observation. The specification of the "best" power law exponents should account for the differences in stability by whatever means available (e.g., net radiation measurements, temperature lapse rate, cloud cover, etc.). The power law exponent will then be analytically derived and specified with respect to height, direction (roughness) and stability class.

The power law relationship has two basic purposes: first, as a convenient indicator of the intensity of shear; and secondly, as a means to extrapolate wind characteristic from the observed levels to the levels critical to the intended machine(s). Shear intensities should be examined from the standpoint of maxima, minima, means and standard deviations with respect to all levels of instrumentation. The extrapolation of wind characteristics requires the approximation of the wind profile by a power law exponent, p , with respect to height, direction and stability.

2.6 PERSISTENCE/DURATION

The frequency and duration of WECS operating modes are a function of machine characteristics, as well as wind characteristics. Operating modes are generally defined in terms of the cut-in, rated and cut-out wind speed specifications and the yaw rate of the machine. Machine characteristics differ with design, therefore, the operating characteristics need to be compared to the wind flow at a site.

The frequency and duration of wind speeds below cut-in, between cut-in and rated, between rated and cut-out, and above cut-out can be used to determine the extent and duration of downtime and time running at rated. Long stretches of downtime are undesirable; long stretches of running at rated are highly desirable. Such wind characteristics at a given site are therefore useful in the selection of a specific WECS design.

The frequency and magnitude of wind direction changes, as well as the dwell time within a direction interval, can be compared to the designed yaw rate and pointing strategies of the various WECS machines. These data may be used to select the WECS design with the optimum operating characteristics for the site.

2.7 REPRESENTATIVENESS OF THE SAMPLE PERIOD

The wind statistics gathered at a site during a relatively short period of observation may or may not be representative of the historical mean flow at the site. One rather simple indicator of the representativeness of the sampling period is to compare the mean wind speed at the site to the mean wind speed at a nearby National Weather Service (NWS) observing station. The monthly mean wind speeds at the NWS station during the period of onsite observations are compared to the long-term monthly means to determine if the current period were above or below average. The monthly mean wind speed from the turbine site is then compared to the NWS station during the entire observing period to determine if the changes in monthly means are correlated. If so, then the representativeness of the observing period as determined for the NWS station would also indicate the representativeness of the onsite observations to the long-term mean at the site.

The NWS station selected for comparison should meet as many of the following conditions as possible:

- 1) be located within 150 km of the site,
- 2) have history of observations covering at least 20 years, the last ten of which are from the same observing location, and
- 3) have similar terrain and climate.

The above criteria do not guarantee the effectiveness of the comparison; they are merely guidelines. In some cases there may be no NWS station within 150 km; then one has to select the nearest station with long-term records. If there are many NWS stations which are comparable, the examination of several may be useful.

The comparison is an attempt to determine the representativeness of the sample period. It cannot be used to adjust the wind characteristics in unrepresentative periods, nor to predict the wind flow in the future; it is an indicator of how representative the observation period was.

3. MEASUREMENT PROGRAM REQUIRED

To arrive at the desired wind characteristics information for potential WECS sites, a comprehensive field measurement program should be conducted for at least one year and preferably longer. The analysis provided for the decision process requires that monthly data summaries be prepared from onsite measurements of wind speed and direction. The data set should include continuous records of wind speed and direction at multiple levels on tall towers.

3.1 INSTRUMENTATION

The configuration of instruments will depend on the complexity of the potential site. Sites, almost without exception, should be instrumented with a tall tower and three levels of serial recording instruments. Even in the Great Plains, site-to-site differences may make such installations cost effective. The specification of wind characteristics at relevant machine heights at the potential site is critical to the siting decision strategy.

Because blade diameters and hub heights differ with machine design, measurements designed for one machine will not correspond to the same heights for all WECS designs. Measurements made at predetermined elevations based on existing requirements may have to be adapted for application to different WECS with different specifications. This means that the wind characteristics will have to be determined from data at existing measurement levels. The atmosphere's nonlinear behavior requires that measurements be made at more than one level. Three levels of measurements, preferably at the hub and at the top and bottom of the disc of rotation of the largest machine being considered, should provide sufficient data to determine the wind characteristics at critical

machine elevations. If the installation of a sufficiently tall tower is not feasible, the minimum measurement program should include a 50 m tower, instrumented at 10 m, 30 m and 50 m. Wind characteristics will then have to be extrapolated to the critical heights using the power law relationships derived in Section 2.5. This method is less precise and less desirable than obtaining actual measurements, but can be useful if applied with caution.

The wind speed (WS) and wind direction (WD) sensors can be any of a great variety of commercial models. Because of the remote placement these units may have, durable, low power-drain systems should be considered. Low power-drain, light-chopper cupwheels are recommended, but tachometer-generator devices will suffice for wind speed. (Tachometer generators require more frequent and involved calibration.) High resolution potentiometer vanes are also recommended. The sensors should have specifications of $\pm 1\%$ accuracy and a 2-3 m distance constant for WS, and a 2-3 m distance constant and .5-.7 damping ratio for WD.

3.2 DATA MANAGEMENT

The serial data from the sensors should be recorded on magnetic tape to facilitate data reduction. Low power-drain, AC/DC cassette recorders are commercially available to handle several data channels on each tower. Some units can even be powered by solar cells. Compatible cassette tape readers which interface directly with a computer are likewise available.

It is recommended that the data on the cassette tapes be converted to engineering units and placed on 9-track tapes for further reduction. The data cassette and a record copy 9-track tape should be kept for Quality Assurance (QA) purposes. All data analyses should use a working copy of the 9-track tape.

Data from the WS and WD sensors should be sampled every two minutes on a routine basis. Such a sample rate provides 30 samples per hour from which hourly means and standard deviations are determined.

Separate high frequency (~ 2 Hz), short duration (~ 30 min) samples from the tower sensors should be taken for turbulence analysis. These samples should include winds from all directions and wind speeds above cut-in.

Monthly statistical summaries should be compiled from the routine data from the towers. The turbulence data should be analyzed on a case-by-case basis and also summarized monthly in a cumulative fashion. Monthly summaries for each level should include at least the following items:

a) Tabular Statistics

- 1) average monthly wind speed
- 2) joint frequency distribution of speed and direction by stability class
- 3) frequency distribution of speed
- 4) average wind speed and direction for each hour of the day
- 5) maximum wind speed encountered and direction
- 6) average and standard deviation of the duration of winds below 4 m/s, between 4 m/s and 25 m/s, and above 25 m/s
- 7) eight wind shear power law exponents, representing power law profile exponents associated with the eight major directions, versus stability class
- 8) turbulent intensity by direction, speed and stability class

b) Plots

- 1) average monthly wind speed (at 10 m)
 - (a) at the site
 - (b) at a nearby NWS station
 - (c) the historical average

- 2) hourly mean wind speed
- 3) hourly mean wind directions
- 4) velocity frequency distribution
- 5) wind speed and direction matrix (joint frequency distribution)

3.3 QUALITY ASSURANCE

A rigid quality assurance program is necessary to ensure the reliability and quality of the data taken at each site. Complete records of all activities are essential to the validity of the measurement program.

A log book is kept at each site to record in detail all relevant data (e.g., names, dates, times, places, causes, results, extent, etc.) of such activities as maintenance visits, calibrations, installations, outages and cause, etc. A casual observation of the weather conditions and readings from the instruments are also noted.

Sensors need to be wind-tunnel tested at the start and finish of the measurement program. In addition, quarterly preventive maintenance and field calibration are conducted. Tachometer generators need special attention and periodic wind tunnel testing. Spare calibrated sensors will help alleviate long gaps in the data collection effort.

4. CONCLUSIONS

This onsite meteorological measurement program for wind characterization provides data for assessing the proper wind turbine machine to put on an intended site. One year or more of onsite meteorological data, primarily wind speed and direction, need to be collected at three levels (two in homogeneous terrain). Digital samples every two minutes for routine measurements and higher frequency (~ 2 hz) measurements for turbulence determinations are recommended. These data are reduced to provide the following basic wind characteristics from which appropriate assessments can be made:

- joint frequency distribution of wind speed and direction
- diurnal and seasonal variation of wind speed
- turbulence (σ_v , σ_θ)
- shear ($\Delta v/\Delta z$; $\Delta \theta/\Delta z$)
- persistence/duration (dwell)

5. REFERENCES

1. Cliff, W. C., The Effect of Generalized Wind Characteristics on Annual Power Estimates from Wind Turbine Generators, PNL-2436, Battelle, Pacific Northwest Laboratories, Richland, WA 99352, October 1977.
2. Wind Energy Mission Analysis, Lockheed-California Company, SAN/1075, September 1976.
3. Wind Energy Mission Analysis, General Electric Company, COO/2578, February 1977.
4. Panofsky, H. A., Wind Structure in Strong Winds Below 150 m, Wind Engineering, 1, pp. 91-103, 1977.

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