

Wind Performance Characteristics

Modern wind turbine systems are used for generating electricity in many regions of the world. Their unit sizes and modes of application span a large range. In this paper, the performance characteristics of wind systems are described. By wind systems, we mean electricity-generating wind turbines as used predominantly in the arrays of windfarms and, in much smaller numbers and sizes, for distributed generation and as a component of hybrid power systems. In the United States at the end of 1995, the installed windfarm generation capacity was 1,750 megawatts (MW). Worldwide, the total installed capacity was in excess of 5,000 MW.¹ Most of this capacity has been installed since 1981, the year of the initial, large-scale windfarm installations in California.

After a description of the range of wind turbine applications, the principal wind turbine and wind system performance characteristics are defined and discussed with illustrative examples. A fundamental descriptor of a wind turbine's performance is its power curve, the relationship between the turbine's electric power output and the wind speed. An equally fundamental descriptor of the wind regime in which the wind turbine operates is the wind speed frequency distribution. The wind speed frequency distribution gives the number of hours per year that the wind speed lies within a narrow wind speed interval. Together, these determine the wind turbine energy production and, with allowance for losses, windfarm energy production.

Other important parameters are the measures of wind turbine reliability (availability), wind system energy productivity (capacity factor) and the degree to which a wind system is supplying power to a load compared to that supplied by the conventional generating systems on line (penetration). The significant advances in wind turbine reliability and maintenance costs that have occurred since 1981 are reviewed. Next, the time variability of the electric power generated by wind systems is discussed. The differences between the electrical output of a single wind turbine and a windfarm are pointed out. Finally, a topic of central importance to utilities, the technical characteristics of the electric power provided by wind systems are reviewed.

Wind system economic characteristics are touched upon only briefly as they are treated in a companion paper.²

Historical perspective

The configuration of grid-connected wind systems has evolved from the early Danish model of the seventies to that of the large California and later European windfarm installations. The pioneering installations in Europe were principally in Denmark. As the California windfarms were being designed and installed during the early eighties, the Danish installations of the 1970s and later typically consisted of small clusters of machines geographically dispersed throughout much of the country. Typically, a grid-connected wind installation consisted of at most three or so wind turbines. Local farmers, manufacturers and other citizens formed cooperatives to own and operate the wind turbines, and to use and sell the power produced by the machines. By contrast, the California model has been the

Two types of grid-connected windfarms include:

- *Small clusters of machines geographically dispersed*
- *Many machines in close geographic proximity*

formation of windfarms, that is, the commercial aggregation of large numbers of machines in close geographical proximity. While there are differences in sizes of installations (due principally to differing land use constraints), the more recent European installations have followed the California model.

These differing approaches and scales of installations have implications for wind in the United States. In the future, we can expect to see two classes of installations. For some states and regions in the United States, it may be appropriate to emulate the early Danish model. That is, it may be both easier and more appropriate initially to install small clusters of wind turbines and then later to consider larger, windfarm installations. The desirability of this approach depends on many factors. These include the nature of the grid and the load (whether dispersed or concentrated geographically), the demands for additional power (load growth) and the technical characteristics (strength) of the transmission/distribution system. In utility terms, the contrast here is between the appropriateness and advantages of distributed generation vs. central station generation.

The range of wind turbine applications

Application classes

Electricity-generating wind turbines can be applied in a variety of contexts. These range from individual, isolated installations to large arrays of turbines. They may be connected to an existing grid or be integrated with other non-grid-connected power sources. The range of applications may be grouped into three classes. *Windfarms*, large arrays of wind turbines, interconnected to the utility grid, form one end of the application spectrum. In terms of installed capacity and economic impact, windfarms currently are by far the largest application class of wind turbines.

The other two application classes typically utilize a smaller number of wind turbines of smaller unit size. These are wind turbines used as grid-connected, *distributed generation*, and wind turbines closely integrated with other power sources and capable of operation without the presence of a larger utility grid. These are *hybrid power systems*. Both classes have historical precedents in this country and in Europe.

Wind systems consist of electricity-generating wind turbines used in windfarm arrays, for distributed generation or turbines used as a component of hybrid power systems.

Windfarms

In this country, we may be most familiar with the large windfarms in California and, more recently, elsewhere in the country. These windfarms are comprised of arrays of wind turbines interconnected electrically so as to deliver their power to the utility grid. From an electrical power flow perspective, the windfarm acts in parallel with the utility's conventional generating capacity to supply the power demands of the connected load.

The arrays can consist of hundreds of machines with a combined windfarm power rating of hundreds of megawatts. Usually, however, the power rating of the windfarm is but a small fraction of the conventional generation capacity on the grid, typically no more than 15 percent. The conventional sources almost always supply the larger fraction of the power required by the load. In general the ratio of wind generating capacity to that of the total capacity (wind plus conventional) serving a utility load at any given moment is measured by the *wind penetration WP*:

$$WP \equiv \frac{\text{Wind Capacity}}{\text{Wind Capacity} + \text{Conventional Capacity}} \quad (1)$$

For example, suppose at a given time of day, the utility load was 1,100 MW and that this demand was being met by a combination of wind and conventional generating sources. If the wind capacity on line was 100 MW and the conventional capacity was ,1000 MW, then the wind penetration value at this time would be 0.909 or 9.1 percent.

With current wind turbine electrical technology, the maximum value of wind penetration with which most U.S. utility systems are comfortable lies in the range of 10 percent to 15 percent. This upper limit on the amount of wind that can be accommodated by a utility system reflects concerns about the technical characteristics of the power supplied by the wind system, that is, the power quality. Specifically, the concern is over the impact of the time-varying, wind-generated electrical power on the short-term voltage and frequency stability of the combined power supplied to the load. As indicated by the breadth of the range, the acceptable penetration value depends on a number of factors. These include the details of the wind technology; the operating characteristics of the conventional generation sources; and the capacity and length of the transmission lines connecting the sources to the load.

The upper boundary on the amount of wind power that can be integrated with conventional sources is not a hard and fast limitation. For example, hybrid power systems, typically much smaller in total generating capacity, achieve much higher fractions. In some situations, the wind penetration value can reach 100 percent, that is, the load is supplied entirely by the wind turbine component of the hybrid system. Further, even when integrated with conventional utility generation systems, the value of this wind penetration upper limit will increase as more operating experience is gained, as the technology changes and as the control systems of the wind and conventional sources are more tightly integrated.

Currently, the power ratings of wind turbines designed primarily for windfarm use range from approximately 300 kW to 750 kW, with corresponding rotor diameters ranging from 35 meters (m) (115 ft) to 50 m (164 ft). Over the past decade and a half of intensive development of these systems, their unit size has increased, and their reliability and economics have improved dramatically. The economics of large-scale, grid-connected wind systems now approach those of some conventional power generation systems.

While there are economic and operational benefits associated with the aggregation of large numbers of wind turbines into a windfarm, windfarms do not have to comprise hundreds of wind turbines as in the large California windfarms. Just as there is a range of wind turbine sizes, there also is a range of

Windfarm characteristics

- *Wind turbines are connected to the electric grid*
- *Wind generating capacity supplies are a small fraction of utility system load*
- *Wind turbines require some electrical support from utility grid*

windfarm sizes. The large California installations form one end of the windfarm size range. The other end can be a small cluster of grid-connected turbines. Such an installation may be useful for example, in serving a municipal utility, a farm or ranching cooperative or an industrial facility.

Regardless of the size, the defining characteristics of a windfarm are 1) the wind turbines are connected to a utility grid, 2) the wind generating capacity usually is a small fraction of the conventional capacity supplying

the utility system load (low values of wind penetration) and 3) the wind turbines require some level of electrical support from the utility grid. Depending on the details of the generator and other electrical technology employed in the wind turbine, this support can range from a simple frequency reference (for synchronization of the wind-generated electricity to that of the conventional sources) to the consumption of reactive power (required for operation of the wind turbine generators). Regardless of the windfarm size, standard utility techniques and components (e.g., transformers and protective switchgear) are used to connect the wind turbines to the grid. The wind turbine is the only non-standard utility component.

Distributed generation

As we think about wind turbines, we are likely to recall the very early water-pumping windmills used extensively in the first half of this century in ranches and farms of the Plains states. These early, small-scale wind turbines have been supplanted by their modernized, more efficient equivalents used primarily to generate electricity. Although there are no technical reasons why larger units cannot be used, the unit

size of these systems typically ranges from 1 kW to perhaps 50 kW. They are intended for use individually or in small clusters. They may or may not be connected to the existing utility grid.

When connected to the grid, these systems are called *distributed wind generation systems*. From both utility and customer perspectives, distributed generation can be useful in providing end-of-line voltage support to an extensive grid. Distributed wind systems also can be used as an alternative to extension of the grid to distant loads. As will be noted, wind system applications form a continuum. Thus in many instances, the distinction between a windfarm and a distributed system may not be clear. The only difference may be one of the size or the number of the wind turbines.

When not connected to the grid, but connected directly to a load, the electric power is unregulated. The power quality and delivery characteristics are determined only by the load and the output of the wind turbine. In general, the output of the wind turbine depends on the wind speed. Thus the load must be capable of using such unregulated power without damage to either the load or the wind turbine generator. An example of such a load is electric resistance heating. Development work is under way to improve the regulation of the power from wind turbines not connected to the grid. Of particular interest is work aimed at successfully connecting an induction motor directly to a non-grid-connected wind turbine. Application examples include wind turbines used for water pumping, ice making and refrigeration.

A windfarm power rating generally represents no more than 15 percent of a grid's conventional generation capacity. **Hybrid power systems**

Hybrid power systems employ wind turbines and possibly other renewable power sources together with diesel generators to form the equivalent of a miniature grid. While the unit size of wind turbines in these applications typically ranges from 1 kW to 50 kW, much larger machines and hybrid power systems have been fielded. They may be used with diesel generators, energy storage such as is provided by batteries and, where appropriate, other renewable power sources such as photovoltaics or hydropower. Used in this mode, such systems are often called hybrid power systems. They typically are used where there is no utility grid. Because of the close coupling and control of all generation sources and some or all of the connected load, the wind component of hybrid power systems can achieve 100 percent penetration. That is, given suitable wind conditions, the wind system can supply nearly all of the power demanded by the load.

A continuum of applications

From the preceding discussion, it is evident that there is a continuum of wind turbine sizes and scale of installations. There also is a continuum of applications. The differences between windfarms, distributed systems and hybrid power systems are the size of the installation, the degree of wind penetration, whether the grid is used for frequency or reactive power support and the degree of integration with other power sources.

Windfarms are composed of numbers of wind turbines connected to an existing, typically much larger grid system managed by a utility. Wind turbines in grid-connected, distributed applications are but a very small-scale windfarm. Hybrid power systems, while they may be connected to an existing grid system, form their own utility by virtue of the integration and close operational coupling of conventional generation sources.

Wind system energy productivity

Overview

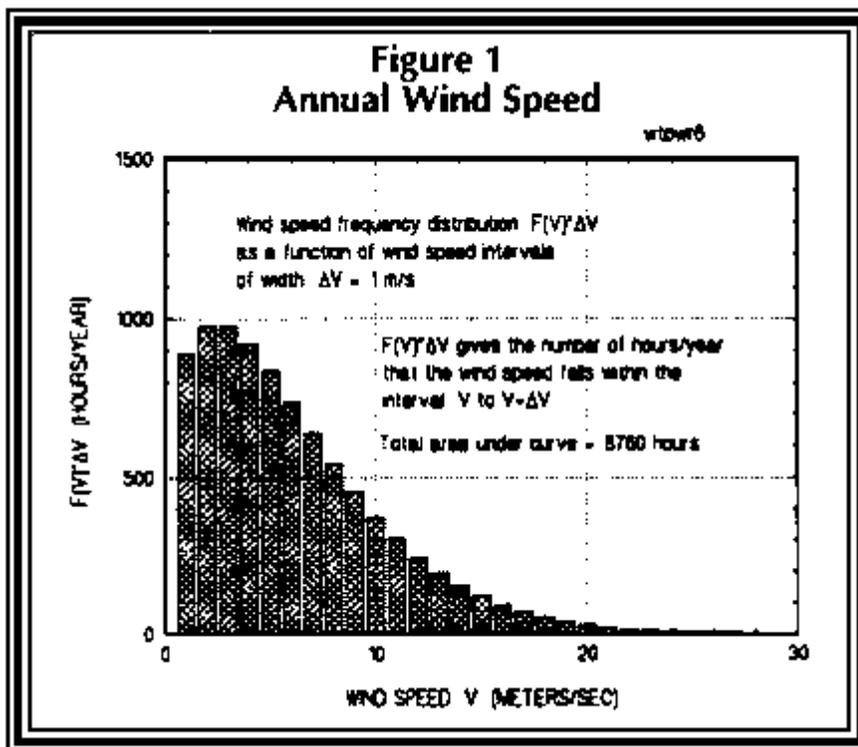
During the year, there are times when the wind does not blow, or blows at speeds below the cut-in wind speed of a turbine. Obviously, wind systems do not produce energy during all of the 8,760 hours in a year. Even when a wind system does produce energy, it does not always do so at its full rated power. What is required is a measure of the energy productivity of the wind system. This measure is the *capacity factor CF*, a descriptive parameter defined and used in the utility industry.

The capacity factor is a measure of the energy production of a wind system or of any energy generation system. However, as a simple ratio of energies, this parameter says nothing about the physical processes associated with the conversion of power carried by the wind into electric power. Required is a description of the relationship between the power output of a wind turbine as a function of wind speed (the power curve) and the variation of wind speeds throughout a given period (the wind speed frequency distribution). Together, these functions describe the matching of the wind turbine power generation characteristics to those of the wind regime in which the wind turbine is situated. Together, these functions can be used to predict or estimate the wind turbine energy production.

After accounting for losses in the electric power collection system, interactions between wind turbines in a windfarm and other losses, the individual wind turbine outputs can be summed to form an estimate of the windfarm energy production. These estimates or projections are most often cast in terms of a calendar year and are referred to as the annual energy production of the wind turbine or windfarm.

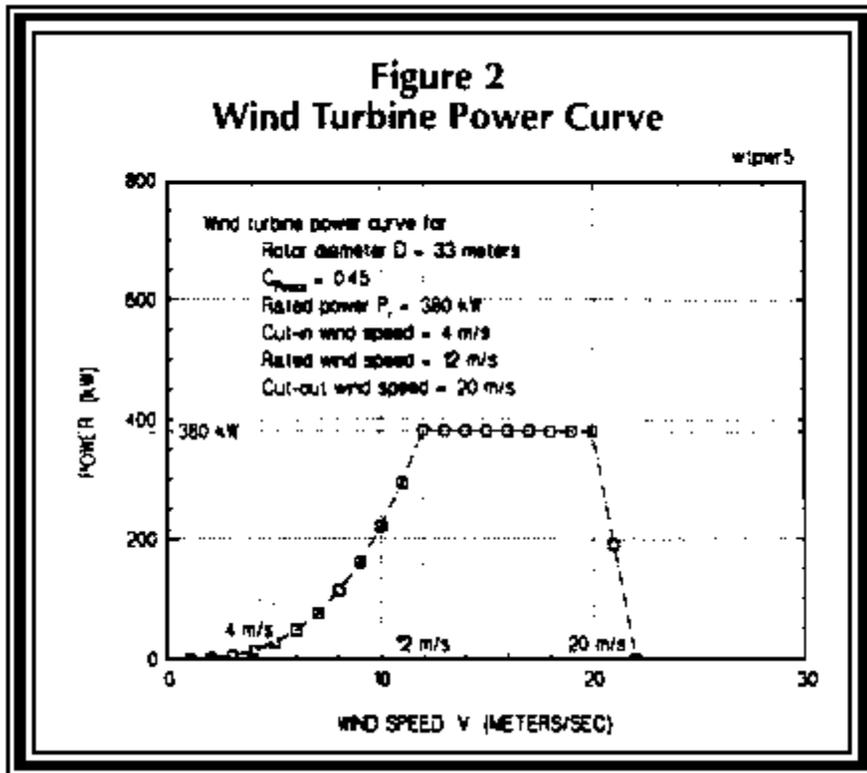
How descriptions of the wind resource and the wind turbine yield estimates of annual energy production

The strength of the wind resource is described quantitatively by the *wind speed distribution*. The *wind turbine power curve* is the quantitative relationship between the electric power output and the incident wind speed. Together, the wind speed distribution and the wind turbine power curve determine the annual energy production. These functions and this relationship are illustrated below.



Wind speed frequency distribution. Graphed in figure 1 is the discrete version of a hypothetical wind speed distribution at the wind turbine site. The wind speed distribution function $F(v) \cdot \Delta v$ gives the number of hours per year that the wind speed lies within the small wind speed interval or bin of width Δv located between the wind speed values v and $v + \Delta v$. The value used for the constant bin width Δv in figure 1 is $\Delta v = 1$ m/s (2.24 mph). The integer index k identifies the wind speed bins. For example, the bin $k = 2$ corresponds to the wind speed bin encompassing the range 1 to 2 m/s. The height of the bar for $k = 2$ indicates that the wind speed lies within this interval for about 980 hours/year. As noted on the graph, the sum of all the bars is 8,760 hours, the number of hours in a year.

Wind Turbine Power Curve. Plotted in figure 2 is the power curve for a hypothetical 380 kW wind turbine. The power curve $P(v)$ is the continuous function that specifies the wind turbine's electric power output as a function of wind speed. The discrete version, indicated by the small square symbols, is denoted by P_k where the integer index k is the same as that used for the wind speed distribution.



As indicated by the annotation in figure 2, a wind turbine power curve usually is described in terms of four distinct wind speed regions. These are described in table 1 with illustrative values referenced to figure 2. Of the four regions, note that the wind turbine generates and delivers power only in the wind speed ranges defined by regions 2 and 3. In region 1, there is not enough energy in the wind to produce useable power. In region 4, the winds are too energetic to justify the added structural strength and cost relative to the small number of hours per year that wind speeds occur within region 4.

Operating Region	Operational Description: Power Output vs. Wind Speed	Illustrative Wind Speed Range (with reference to figure 2)
Region 1	Wind speeds too low to produce useable electric power	0 to cut-in wind speed; 0 to 4 m/s
Region 2	Production of electric power increasing with wind speed	Cut-in to rated wind speed; 4 to 12 m/s
Region 3	Production of electric power	Rated wind speed to cut-out

	at constant, rated power level. Wind turbine blades purposely made less efficient as wind speed increases	wind speed; 12 m/s to 20 m/s
Region 4	No electric power output. Winds too energetic to justify added strength and cost for the small number of hours per year beyond cut-out wind speed	Cut-out wind speed to survival wind speed; 20 m/s to rated survival wind speed

Estimates of annual energy production. These functions, the wind speed frequency distribution and the wind turbine power curve, when multiplied together and summed over all wind speeds (all values of the index k), provide an estimate of the annual energy production:

$$\begin{aligned}
 E_{YR} &= (\text{Hours/Yr}) * \Delta V * \sum (F_k * P_k) \\
 &= (8760 \text{ Hrs/Yr}) * (1 \text{ m/s}) * \sum (F_k * P_k) \quad (\text{Watt-Hours/Yr}) \quad (2)
 \end{aligned}$$

Given a measured or an assumed wind speed frequency distribution and a wind turbine power curve, the relationship of equation 2 can be used to estimate the annual energy production to be expected from that wind turbine operating in the wind regime described by the wind speed distribution.

Capacity factor as a measure of energy production

The capacity factor CF is a parameter often used to describe the energy production performance of a wind turbine. The capacity factor CF_{Yr} is a measure of the annual energy production. It is defined as the ratio of the (actual or estimated) energy produced to the energy production that would result from operation at full-rated power for every hour of the year:

$$CF_{Yr} \equiv \frac{\text{Energy Production / Year}}{(\text{Power Rating} \times 8760 \text{ Hours / Year})} \quad (3)$$

Thus by definition, the range of capacity factor values is from 0 to 1, or from 0 percent to 100 percent. Capacity factor values in the range 24 percent to 30 percent have been achieved by the better performing windfarm installations in California, with 28 percent being a value achieved by a good installation. For example, if a 100 MW wind system generated and delivered 245 million kWh during a given year, the corresponding capacity factor would be 28 percent:

$$CF_{Yr} = \frac{245 \text{ million kWh}}{(100 \text{ MW} \times 8760 \text{ Hours})} = 0.28 \quad (4)$$

As a further example, we can use equation 3 to calculate the annual energy production of a hypothetical 500 kW wind turbine operating at a capacity factor of 0.28. The result is 1.226 million kWh/yr.

In reviewing wind system capacity factor values, one should ascertain the period of interest. While it is usually one year, capacity factors also can be defined for one month. If that month is one of very high, sustained wind speeds, then the corresponding capacity factor value can be misleading if interpreted as an annual average value.

Capacity factor of conventional sources. In passing, we note that conventional sources also are intermittent but in a different way. They are subject to various types of outages, for example, due to maintenance and malfunctions. Capacity factors for conventional power generation systems are significantly higher but not 100 percent. Representative values might be in the range 60 percent to 70 percent, depending on the type of plant, its age and other factors.

Wind system reliability

Hybrid power systems can use wind turbines with diesel generators to form a miniature grid. The impact of design and manufacturing Advances

The first large-scale windfarms in California were installed in the early eighties, from 1981 through about 1983. These first-generation wind turbines experienced many failures, some quite spectacular. These early failures were the result, in part, of inadequate understanding of the wind gust forces on the flexural or fatigue failure modes of structural components. With vastly improved knowledge about the actual gust structure of the wind, the development and widespread use of improved modeling and design tools, improved manufacturing techniques, and millions of hours of operating experience, the reliability of current wind turbine designs has improved dramatically.

The reliability improvements encompass not only the major structural components but also the supporting subsystems of the wind turbine. These include, for example, the wind turbine computer controller, yaw system and pitch control system. In addition, there have been improvements in the quality assurance and inspection programs of manufacturers. Designers have given significant attention to the repairability and maintainability of the wind turbine subsystems. Finally, the interval between major overhauls has been extended, for example, from five years to 10 years or more.

There are several measures of these improvements and of the current reliability. These measures include the mean-time-between-failures (MTBF) for major components and subsystems, the mean-time-to-repair (MTTR) and the cost to correct a failure. An often-encountered, system- wide measure of reliability is the availability.

Availability

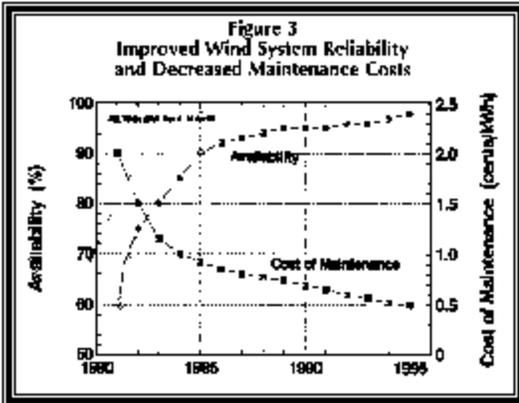
A commonly-used operational measure of wind turbine and windfarm reliability is the *Availability A*. The value for a windfarm for a given period may be built up from the daily values of availability for each wind turbine. However, in general, for a specified period (e.g., a day, week, month or year), availability is defined as the ratio of hours that the wind system was able to generate power to the number of hours in the time period:

$$A_1 \equiv \frac{\text{Hours Wind Turbine Capable of Operation}}{\text{Hours in Period}} \quad (5)$$

Another, more difficult-to-determine and possibly more ambiguous definition is the ratio of actual hours of operation to the number of hours that the wind speeds were in the operational range:

$$A_2 \equiv \frac{\text{Actual Hours of Operation}}{\text{Hours when wind speeds were in operational range}} \quad (6)$$

No matter how defined, a perfect availability value would be 100 percent. That is, the system would have no outages or malfunctions that prevented the system from generating power. Modern windfarms now routinely achieve availability values of 98 percent or greater, up from 60 percent or (much) less in the early eighties.



Maintenance costs

The impact of the design and manufacturing advances achieved over the past 15 years has shown up not only in increased availability but also in reduced costs of maintenance for these systems. Availability has increased from values near 60 percent to values between 98 percent and 99 percent for recent windfarm installations. Over this same period, maintenance costs have been brought down from more than 2.5 cents/kWh to less than 1 cent/kWh in current designs. The trends of improved availability and decreased maintenance costs are illustrated by the representative values plotted in figure 3.

Time variability of the power

The most significant technical characteristic of the electric power produced by wind systems is its variation with time. This reflects the time-variability of the wind resource. In this section we examine the range of time scales and their implications for wind system performance.

The range of time scales

The variability of the wind-generated electric power occurs on a wide range of time scales. The time scales of interest range from seconds to years. The shortest of these time scales, a few seconds or less, is of primary interest to the designers of wind turbines. The time scales of most interest to the utility or other users of the wind-generated electricity range from tens of minutes to years. The time scales, the group having most interest and the reasons for that interest are listed in table 2.

Time scale	Of interest to	Reason for interest
Tens of seconds or less	Wind turbine designers	Structural strength against wind-induced loads, structural vibrations and flexural failure of components; possible voltage and frequency fluctuations
Tens of minutes to hours	Power system operators	Ability to follow or compensate for the varying power contributed by the wind system; wind forecasting
One day	Power system	Predictability of a diurnal cycle and output operators in some wind regimes; correlation with the diurnal load profile
Month-to-month	Power system planners	Predictability of seasonal variations and output in most wind regimes; correlation and operators with the seasonal load profile
One year	Power system operators and the financial community	Predictability of annual output in most wind regimes; ability to cover debt in an average wind year

Year-to-year	Financial community	Interannual variability and ability to cover debt in a substandard wind year
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Forecasting the wind

While wind varies with time, it is not completely random. On time scales that are relevant to utility power system operators, wind is statistically predictable. It is statistically predictable in the same sense that the electrical power demanded by a utility's load is predictable. In fact, some utility analysts model the output of wind systems as a negative load. The fact that wind has a significant non-random component implies that the wind can be forecast. The degree of accuracy depends on understanding the physical processes driving the wind, the accuracy of wind measurements, the capability of the mathematical and computer techniques employed and how far into the future the prediction extends. Forecasting the wind speed and duration for use in planning the next day's dispatch of utility generation resources, including wind systems, is an active area of research in the United States and Europe.

For time scales extending from a month to a year, the ability to forecast wind speeds and the corresponding energy production has been developed to a significant degree. The detailed energy production projections made by wind meteorology specialists form the basis for the financing, wind turbine siting and construction of all windfarms.

Correlation with the load

All utility loads have a significant predictable component. For example, the hourly demand during a summer day or a winter day is fairly well known. Also fairly well known is the month-to-month demand profile. The diurnal and monthly load profiles can be compared with the historical or expected electrical output from a windfarm.

Thus to the extent that there exists a correlation between the time profiles of the wind-generated electricity and the load demand, the wind system may be given a capacity value in addition to the energy value. The more correlated these profiles are, the more the wind-generated electricity can reliably supply part of the load. Depending on the capacity and cost structure of the conventional sources and the degree of wind penetration, the wind-generated electricity can be more useful and valuable than otherwise.

Output of a single wind turbine

There is a significant difference in the short-term (seconds to minutes) temporal characteristics of the electric power from a single wind turbine compared to that from a windfarm. Over a significant range of operating wind speeds, the electrical power output of a single wind turbine corresponds closely to the temporal characteristics of the wind flow field incident on the wind turbine. The inertia of the rotor averages out wind temporal fluctuations on the order of a second or less. Depending on the characteristics of the wind turbine control system, wind fluctuation components with periods greater than this can be reproduced in the power output of an individual turbine.

The wind turbine control system can contribute to smoothing of the electric power output. Typically this occurs when the wind speeds are high enough that, in the face of changing input wind speeds, the control system modulates the efficiency of the wind turbine aerodynamic blades so as to maintain the electrical output at a constant value equal to the wind turbine power rating.

***Wind turbine reliability has improved dramatically since the early 1980s.* Output of a windfarm**

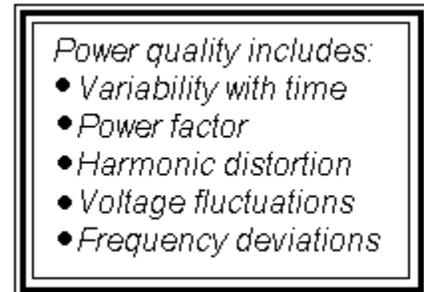
In contrast, however, the electrical power output of a windfarm typically is considerably smoothed relative to that of a single turbine. The degree of smoothing depends on the geographical extent of the windfarm, the average wind speed, the control characteristics of the wind turbines and, finally, details of the terrain and how they influence the distribution of wind speeds across the windfarm.

The fundamental reason for the smoothing is that the wind gust structure, both in space and time, typically becomes increasingly uncorrelated over distances greater than several rotor diameters. Relative to the fluctuations of a single wind turbine, a complete lack of correlation would imply that the fluctuations in the windfarm electrical power output are reduced by the square root of the number of uncorrelated machines in the windfarm contributing to the power output.

As windfarms continue to be installed across large geographical areas, the same principle of areal smoothing of the aggregated output of the windfarms may apply. As with the wind turbines in an individual windfarm, such smoothing could occur as a result of the lack of correlation of the fluctuations in the wind fields incident upon the distributed windfarms.

Power quality

Since windfarms in the United States are connected to the utility grid, utility system planners and operations managers are interested in the technical characteristics of the electric power provided. Taken together, these characteristics often are referred to as *power quality*. We have already discussed an important characteristic of the wind-generated electricity, its variability with time. Other power quality parameters include 1) power factor, 2) harmonic distortion, 3) voltage fluctuations and 4) frequency deviations. In the context of modern, grid-connected windfarms, the first and perhaps the second of these parameters are of most concern to utility engineers. However, none represent significant incompatibility with the balance of the utility system.



With the exception of its intermittency, the technical characteristics of the electric power supplied by modern windfarms are comparable to those of the power supplied by conventional generation sources.

Notes

1. American Wind Energy Association news release, April 12, 1996.
2. "Wind Energy Costs."

For further information

Further information about the performance characteristics of wind energy systems may be obtained from published articles and reports, laboratories maintained by the U.S. Department of Energy, the American Wind Energy Association and from wind turbine manufacturers and developers. Organization addresses and reference sources are listed below.

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Wind/Hydro/Ocean Division
Mail Stop EE-121
1000 Independence Avenue
Washington, DC 20585

Wind Energy Technology: Generating Power from the Wind (WET), published bimonthly by the U.S. Department of Energy, Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831. The March-April 1995 issue bears the publication numbers DOE/ WET-95/2 (PB95-933102) and

ISSN:0896-5102 CODEN:WETWET. The publications are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, telephone (703) 487-4650.

Wind Energy Bibliography (Report NREL/SP-440-6642), May 1995, published by the National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401-3393. Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, telephone (703) 487-4650.

Wind Project Performance, 1994 Summary (Report P500-95-003), by Juanita Loyola, California Energy Commission, Sacramento, CA 95814, August 1995.

Collected Papers on Wind Turbine Technology (Report DOE/NASA/5776-2 and NASA CR-195432), David Spera, ea., U.S. Department of Energy, Conservation and Renewable Energy Technology, Office of Management and Administration, Washington, DC, May 1995.

The Integration of Renewable Energy Sources into Electric Power Distribution Systems, Vol. 1, National Assessment (ORNL-6775/V1), by P.R. Barnes, J.W. Van Dyke, F.M. Tesche and H.W. Zaininger, Oak Ridge National Laboratory, June 1994.

The Integration of Renewable Energy Sources into Electric Power Distribution Systems, Vol. 2, Utility Case Assessments (ORNL-6775/V2), by H.W. Zaininger, P.R. Ellis and J.C. Schaefer, Oak Ridge National Laboratory, June 1994.

The electrical power output of a windfarm typically is smoother than that of a single wind turbine.

National Wind Coordinating Committee

The content and form of the papers in this series have been reviewed and approved by the National Wind Coordinating Committee. Committee members include representatives from investor-owned utilities, public utilities, state legislatures, state utility commissions, state land commissions, consumer advocacy offices, state energy offices and environmental organizations. The purpose of the National Wind Coordinating Committee is to ensure the responsible use of wind power in the United States. The committee identifies issues that affect the use of wind power, established dialogue among key stakeholders and catalyzes appropriate activities.

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