WIND RESOURCE ASSESSMENT

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1.0 INTRODUCTION

Wind power technology has become one of the most promising renewable energy technologies for electricity generation in India and elsewhere. It is important to say that wind power is considered one of the most environmental friendly energy sources on a global scale because it produces no emissions. However, financial risk is very high in the wind farm development due to various reasons. It can be reduced if proper wind assessment is done. Wind data particularly, wind speed data are very critical because a small change in the wind speed at a site can have a significant impacts in determining whether the project is economically viable or not.

There are three basic steps to identify and characterise the wind resource in a given region. In general, they are prospecting, validation and optimisation. Under prospecting, the identification of potential windy sites within a fairly large region, in the range of several square kilometre (areas) would be considered. Generally this is carried out by meteorologists who depend on various sources of information such as topographical maps (in India, Survey of India map), climatological data from meteorological stations (e.g. India Meteorological Department), and satellite imageries, etc. A site visit also will be conducted at this stage and a representative location for wind measurement would be identified. Validation process involves a more detailed level of investigation like wind measurements and data analysis. The most imperative and final step is micro survey and micrositing. In this paper, the importance of wind resource assessment and methods for assessment are described briefly

2.0 WIND RESOURCES

The wind over a region can be considered a resource similar to the “fossil fuel” beneath the earth’s surface. But unlike fossil fuel, the wind resource varies with time of day, season of year, and even to some extent from year to year.

Wind is movement of air in the atmosphere relative to surface of the earth. The air moves because of uneven heating of earth’s atmosphere. But the atmosphere is not heated directly by the incoming solar radiation. Radiation is first absorbed by the surface of the earth and is then transferred in various forms back to the overlying air. Since the surface of earth is not homogeneous, the amount of energy that is absorbed varies both in space and time. This creates temperature – density – pressure differences, which in turn create forces that move air from one place to another. Coriolis force is an additional factor, which controls the movements of air.

In terms of energy, wind is kinetic energy of air and power in the wind is the flux of kinetic energy passing through the vertical cross – sectional area (of the rotor of wind turbines).

Power in the wind is given by

$P=1/2\ pAu * u^2$ (1)

$P=1/2\ pAu^3$ (2)

Where pAu □mass per unit volume of air

u=velocity of wind and

A=an area through which the wind passes normally.

The above expression gives the total power available in the wind, for extraction by a wind driven machine: only a fraction of which can be actually extracted. A. Betz of Gottingen showed in 1927 that the maximum fraction of power in the wind that could be extracted by an ideal aero motor was 16/27 or .593.

The power density is a flow of air through a unit vertical cross – sectional area and is given by

$P_d = ½\ \rho u^3$ Watts/ m^2

2.1. WIND CHARACTERISTICS

2.2.1 Topographic Effects on Wind

Topography often plays a major role in modifying the wind speed in a given location. The natural behaviour of air when flowing over topography is to speed up considerably over the crests of hills. With favourable size, orientation and shape, topographic features can increase wind energy yield potential up to 100%. The terrains that are considered most suitable for potential wind energy sites are elevated ridges that are perpendicular (90 degrees) to the prevailing winds. Elevated terrain tends to cause accelerating forces that increase local wind speeds. The ridges intercept the winds and then compress and accelerate air as it moves upwards , increasing the wind speed at the ridge top. Therefore exposed ridges are known to be sources of higher localized winds. Other areas where the wind accelerates are steep divides or valleys that funnel the wind. For the purpose of wind power meteorology, which is primarily concerned with the wind flow from 10 to 200 m above the ground, the effects of the topography can be divided into three typical categories.

Roughness: The collective effect of the terrain surface and its roughness elements, leading to an overall retardation of the wind near the ground, is referred to as the roughness of the terrain.

Obstacle: Close to an object, such as a building or shelterbelt, the wind is strongly influenced by the presence of the obstacle, which may reduce the wind speed considerably.

Orography: The term orography refers to the description of the height variations of the terrain, referenced to a common datum such as the mean sea level. When the typical scale of the terrain features becomes much larger that the height of the points of interest they act as a orographic elements to the wind. , Near the summit or the crest of hills, cliffs, ridges and escarpments, the wind accelerate while near the foot and valley it will decelerate.

2.2.2 *Variation of Wind Speed with Height*

Wind speed is nominally zero at ground level and increases steadily with height. The change of wind speed with height is known as the wind shear or profile. The rate of increase with height strongly depends upon the roughness of the terrain and the changes in this roughness. The variation also depends on the atmospheric stability conditions. Even within the course of 24 hours, the wind profile will change between day and night, dawn and dusk. This can be described by the so called logarithmic wind profile with stability correction. This expression, which is well supported by theoretical considerations, is written

$$u(z) = \frac{u_x}{k}\left(\ln\frac{z}{z_0} - \psi\right) \quad (3)$$

Where u_* is the friction velocity, k the von Karman constant, Z_0 the roughness length, and ψ a stability dependent function, positive for unstable condition, zero for neutral and negative for stable conditions.

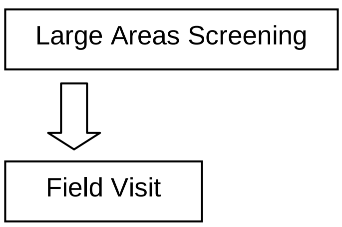
Another option is power law approximation. The expression is as follows.

$$\frac{u_{z1}}{u_{z2}} = \left(\frac{z_1}{z_2}\right)^{\alpha} \quad (4)$$

Where u_{Z1} and u_{Z2} are the wind speed at heights z1 and z2 respectively and α is the power law exponent, with a typical value of 0.14 for most of the homogenous site. A serious problem with this approach is that □□ varies with height, surface roughness and stability, which means this equation is of quite limited applications

3.0 RESOURCE ASSESSMENT

In order to establish wind farms in a successful manner it is important to have a maximum possible accurate estimate of wind resources at a given site. The potential energy yield from the wind varies with the wind speed to the third power, i.e. a site with 10% higher wind speed has an approximately 30% increased wind energy potential yield. Generally wind resource assessment is done in number of phases and the details are as follows. The methodology of wind resource assessment on the basis of local wind measurements is indicated in Fig.1.



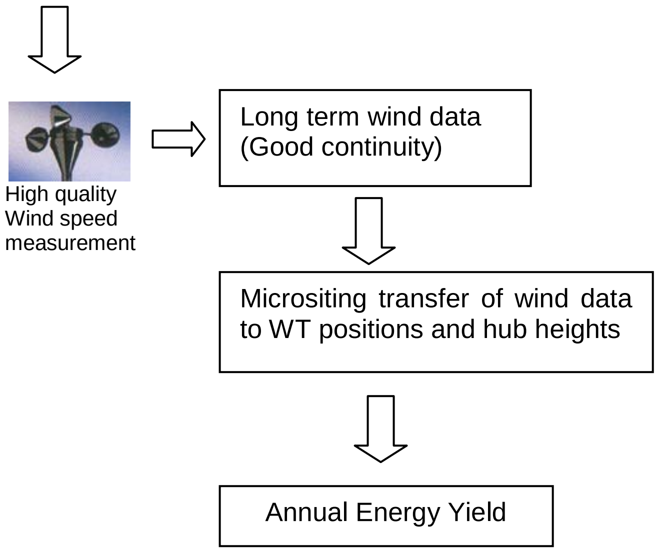


Fig.1. Wind Resource Assessment Methods

3.1 Large area screening & Field visit

This phase may be appropriate if the region is large, and no previous wind measurement programs have been conducted there. A large-area screening usually begins with a review of existing wind resource maps and other meteorological information, analysis of the meteorological characteristics of the state and their possible effect on wind speeds, and the development of screening criteria (such as terrain form, current use, vegetation cover and accessibility to roads and transmission), One recent approach to large-area screening is using geographical information systems (GIS), a computer mapping and analysis tool, to screen potential sites. Wind maps generated through meso scale modelling can also be used for large area screening.

Once a preliminary list of sites is prepared, the next step would be visit to the site. One purpose of such visits is to look for physical evidence to support the wind resource estimate developed in the large-area screening. Consistently bent trees and vegetation, for example, is a sure sign of strong winds. Another purpose is to check for potential sitting constraints. A third purpose of the site visit is to select a possible location for a wind monitoring station.

3.2 WIND MEASUREMENTS

Wind speed, wind direction, and air temperature measurements are required for useful wind resource assessment. Typically, each parameter is scanned every 1 to 2 seconds, and the data points are averaged by a data logger mounted on the tower. Data is normally collected at 10 or 60-minute average intervals. Historically, hourly averaged data have been used, but with the increased capabilities of wind models and computers, the 10-minute averaged data provide additional precision. The data logger calculates and stores the standard deviation of both wind speed and wind direction.

Wind speed is the most important measurement parameter. A 3-cup anemometer is the typical instrument. Several manufacturers offer low-cost, highly accurate, and resilient anemometers that have been used in wind resource monitoring for years. Collecting wind speed data at multiple heights is preferred to avoid errors in simulating turbine performance caused by wind shears. The multiple height data also provide a valuable backup if a sensor at one-height fails. The typical recommended scenario is to measure wind speed at three heights on a tower. For a 50-meter tower, measurements at 10, 25, and 50 meters are normal. For a 60-meter tower, measurements are at 10, 30 and 60 meters. Ten-meter data are the standard height for wind measurements. In areas that contain obstructions or vegetation, particularly within forest canopies, the lowest wind sensor is placed at a height that minimizes effects of surface roughness or obstructions. The 25- to 30-meter height is approximately the lowest level that turbine blades reach in their down position. Turbine performance can be estimated better with these data. The 50- to 60-meter height data represent wind turbine hub height. Turbine performance models require data at hub height. If turbines with hub heights exceeding 60 meters are proposed, the cost to erect and instrument a taller tower is significant. A Sodar provides an alternative for data collection in these cases. For accurate wind speed data it is important to minimize the effect of the tower on the instruments.

Wind direction data are collected at the same heights as wind speed data. A wind vane is used for determining the direction. Optimal layout of the wind farm depends on good wind direction information. Air temperature data are needed to determine the air density term in calculating wind power density and turbine performance. This measurement may be made at 2 to 3 meters above ground. Measuring at this height minimizes the effects of surface heating during daylight hours. Additional data parameters-barometric pressure, vertical wind speed, and precipitation-are recommended, but not mandatory.

The wind speed measurement period at the location must be long enough to cover all meteorological conditions in that region with a sufficient amount of data. Measuring over a period of one year can usually attain this. In order to account for seasonal or long-term variations of the wind potential the local short-term measurements must be correlated with instantaneous measurements of a nearby reference station that has collected long-term data. Once the relations between the local measurements and the measurements at the reference station have been established, the expected long term distribution of wind data at the predicted site is predicted by considering the local short term measurements according to the long term wind histogram. This procedure is often referred to as Measure, Correlate-Predict (MCP) method.

Wind speed measurements are among the most critical aspects for wind resource assessment. This is expressed by the fact the uncertainties in the wind speed are amplified by a factor between two and three to uncertainties in the predicted energy production because of the non linear relation between wind turbine power output and wind speed. Due to the lack of experience lot of wind speed measurements have unacceptable high uncertainties because best practice in selection of the anemometers, anemometer calibration, mounting of the anemometers, the selection of the measurement site as well as the measurement height and the duration of the measurements was not adopted. An international anemometer calibration round robin comparison showed that uncertainties up to more than +/- 3.5 % occurred in the calibrations in different wind tunnels. This translates into 10 % uncertainty in energy yield prediction. Preferably one anemometer should be top mounted (on a pole exceeding the mast) to avoid flow distortion. Booms should be mounted so that the flow field disturbance due to the booms at the mast is minimised. To avoid flow inclination effects the accuracy of the horizontal mounting of the anemometers is important as well. At the current state-of-the-art an uncertainty as low as 1-2 % in the wind speed determination and about 3 % in terms of energy production can be reached. Consequently it must be recommended to plan wind farms on the basis of high quality wind measurements within the wind farm area, especially in regions with complex terrain.

3.3 Micro scale Modelling & Micrositing

Wind farms vary considerably in size and scale depending on the physical limitations of the land, the wind resource available and the amount of energy sought. In a wind farm, turbines will typically be placed in rows perpendicular to the prevailing wind direction. Spacing within a row may be as little as two to four rotor diameters if the winds blow perpendicular to the row almost all the time. If the wind strikes a second turbine before the wind speed has been restored from striking an earlier turbine, the energy production from the second turbine will be decreased relative to the unshielded production. The amount of decrease is a function of the wind shear, the turbulence in the wind, the turbulence added by the turbines, and the terrain. This can easily be in the range of five to ten percent for downwind spacing of around ten rotor diameters. Spacing the turbines further apart will produce more power, but at the expense of more land, more roads, and more electrical wires.

In order to locate the turbines for optimum generation a careful exercise has to be carried out. Each turbine site must be selected based on topography and the optimum location where the highest wind power density are presumed to occur. This crucial step requires an experienced professional with a thorough knowledge of terrain effects on wind.

Micrositing can provide high quality and spatially detailed yield estimates over the wind farm area such that each turbine can be sited for optimal energy yield. Considerations must also be given to turbine interference and design constraints (visual, noise etc.) within the “wind farm designs” stage. Finally energy estimates must be adjusted to reflect the likely long-term yield (typically 20 years) of the wind farm. The micrositing process involves conducting surveys, monitoring and flow modeling at individual sites to quantify the small-scale variations in the wind resource over the area. In complex terrain, micrositing may involve numerous wind speed measurements combined with computer modeling to predict speeds in areas where no measurements are taken.

There are several industry-standard techniques used in practice for modeling wind over a small region and later for micrositing. Some of the models available in the market are Resoft Windfarm, WinPRO, WAsP, GH WindFarmer etc. All these models have limitations due to linearisation of the model equations that restrict their applicability to low terrain slopes (e.g <-03). These models are also limited by the fact that they do not take into account thermal effects such as sea breezes or mountain-valley winds. Though these models have some limitations, they can give good results if ‘handled’ carefully.

4.0 CONCLUSION

An accurate wind resource assessment is a key element of the successful wind farm development. Generally wind resource assessment is done in number of phases. First phase is to identify and quantify wind areas in general. This activity is referred as ‘large area screening’. Second phase is referred to as the “feasibility study” phase with proper wind measurements. The third step is called micrositing’ which provides estimated energy over the wind farm such that each turbine can be sited for optimal energy yield.

5.0 REFERENCES

1. E.L. Peterson, N.G. Mortenson, Lars Landberg, Jorgen Hojstrup and Helmut P. Frank. “Wind Power Meteorology”, Riso National Laboratory, Roskilde, Denmark, December 1997.

2. Albers, Axel: Klug, Helmut, DEWI, DEWI Magazine Nr,15, August 1999-High quality Wind Speed Measurements for Site Assessment.

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