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WIND RESOURCE ASSESSMENT PROGRAM

DATA PROCESSING PROCEDURES AND DEFINITIONS

The following information summarizes the data processing procedures that are performed on the raw measured data in order to create an annual dataset of "typical" wind speeds, which could then be used to calculate potential power production from wind turbines. There are various methods and reasons for adjusting the raw data, so the purpose of these notes is to document what is typically done in AEA reports. The raw data set from each site is available on the Alaska Energy Authority website (www.akenergyauthority.org) so one could perform their own data processing procedures. The processed data set is also available.

Units – Since most wind turbine specifications are provided in metric units, those units are used in this report.

1 meter/second = 2.24 mph = 1.95 knots
1 meter = 3.28 feet
1 ˚C = 5/9 (˚F – 32)

Max/Min Test – All of the 10-minute data values were evaluated to ensure that none of them fell outside of the normal range for which the equipment is rated.

Tower Shadow – The tower itself can affect readings from the anemometer at times when the anemometer is located downwind of the tower. To avoid this effect, two anemometers were placed at the top level so that neither would be in the wake of the tower at the same time. One data set is compiled from the 2 anemometers depending on the direction of the wind at any given time.

Icing – Anomalies in the data can suggest when the sensors were not recording accurately due to icing events. Since wind vanes tend to freeze before the anemometers, icing events are typically identified whenever the 10-minute standard deviation of the wind vane is zero (the wind vane is not moving) and the temperature is at or below freezing. Some additional time before and after the icing event are removed to account for the slow build up and shedding of ice on the sensors.

Filling Gaps – Whenever measured met tower data is available, it is used. Two different methods are used to fill in the remaining portion of the year. First, if nearby airport data is available, a linear correlation equation is defined between the airport and met tower site, and airport data is adjusted to fill the gap. If neither met tower nor airport data is available for a given timestep, the software program Windographer (www.mistaya.ca) is used. Windographer uses statistical methods based on patterns in the data surrounding the gap, and is good for filling short gaps in data.

Long-term Estimates – The year of data collected at the met tower site can be adjusted to account for inter-annual fluctuations in the wind resource. To do this, a nearby weather station with a consistent historical record of wind data and with a strong correlation to the met tower location is needed. If a suitable station is not available, there is a higher level of uncertainty in the wind speed that is measured being representative of a typical year.

Turbulence Intensity – Turbulence intensity is the most basic measure of the turbulence of the wind. Turbulence intensity is calculated at each 10-minute timestep by dividing the standard deviation of the wind speed during that timestep by the average wind speed over that timestep. It is calculated only when the mean wind speed is at least 4 m/s. Typically, a turbulence intensity of 0.10 or less is desired for minimal wear on wind turbine components.

Wind Shear – Typically, wind speeds increase with height above ground level. This vertical variation in wind speed is called wind shear and is influenced by surface roughness, surrounding terrain, and atmospheric stability. The met tower is equipped with anemometers at different heights so that the wind shear exponent, α, can be calculated according to the power law formula:

$$\left(\frac{H_1}{H_2}\right)^{\alpha} = \left(\frac{v_1}{v_2}\right)$$ where H_1 and H_2 are the heights and v_1 and v_2 are the measured wind speeds.

Wind shear is calculated only with wind speed data above 4 m/s. Values can range from 0.05 to 0.25, with a typical value of 0.14.

Scaling to Hub Height – If the wind turbine hub height is different from the height at which the wind resource is measured, the wind resource can be adjusted using the power law formula described above and using the wind shear data calculated at the site.

Air Density Adjustment – The power that can be extracted from the wind is directly related to the density of the air. Air density, ρ, is a function of temperature and pressure and is calculated for each 10-minute timestep according to the following equation (units for air density are kg/m^3):

$$\rho = \frac{P}{R \times T}$$

Where P is pressure (kPa), R is the gas constant for air (287.1 J/kgK), and T is temperature in Kelvin. Since air pressure is not measured at the met tower site, the site elevation is used to calculate an annual average air pressure value according to the following equation:

$$P = 1.225 - (1.194 \times 10^{-4}) \times \text{elevation}$$

Since wind turbine power curves are based on a standard air density of 1.225 kg/m3, the wind speeds measured at the met tower site are adjusted to create standard wind speed values that can be compared to the standard power curves. The adjustment is made according to the following formula:

$$V_{s\tan dard} = V_{measured} \times \left(\frac{\rho_{measured}}{\rho_{s\tan dard}}\right)^{\frac{1}{3}}$$

Wind Power Density – Wind power density provides a more accurate representation of a site's wind energy potential than the annual average wind speed because it includes how wind speeds are distributed around the average as well as the local air density. Units of wind power density are watts per square meter and represent the power produced per square meter of area that the blades sweep.

Wind Power Class – A seven level classification system based on wind power density is used to simplify the comparison of potential wind sites. Areas of Class 4 and higher are considered suitable for utility-scale wind power development.

Classes of Wind Power Density

Class	10 m		30m		50m		Rating
	WPD (W/m^2)	Speed (m/s)	WPD (W/m^2)	Speed (m/s)	WPD (W/m^2)	Speed (m/s)	
1	<100	<4.4	<160	<5.1	<200	<5.6	Poor
2	100 - 150	4.4 - 5.1	160 - 240	5.1 - 5.8	200 - 300	5.6 - 6.4	Marginal
3	150 - 200	5.1 - 5.6	240 - 320	5.8 - 6.5	300 - 400	6.4 - 7.0	Fair
4	200 - 250	5.6 - 6.0	320 - 400	6.5 - 7.0	400 - 500	7.0 - 7.5	Good
5	250 - 300	6.0 - 6.4	400 - 480	7.0 - 7.4	500 - 600	7.5 - 8.0	Excellent
6	300 - 400	6.4 - 7.0	480 - 640	7.4 - 8.2	600 - 800	8.0 - 8.8	Outstanding
7	>400	>7.0	>640	>8.2	>800	>8.8	

Weibull Distribution – The Weibull distribution is commonly used to approximate the wind speed frequency distribution. The Weibull is defined as follows:

$$P(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left(\frac{-v}{c}\right)^{k}$$

Where P(v) is the probability of wind speed v occurring, c is the scale factor which is related to the average wind speed, and k is the shape factor which describes the distribution of the wind speeds. Typical k values range from 1.5 to 3.0, with lower k values resulting in higher average wind power densities.

Gross Capacity Factor – The gross capacity factor is defined as the actual amount of energy produced divided by the maximum amount of energy that could be produced if the wind turbine were to operate at rated power for the entire year.

Net Capacity Factor – The gross wind turbine output is reduced by inefficiencies such as transformer/line losses, turbine downtime, soiling of the blades, yaw losses, array losses, and extreme weather conditions. There are also uncertainties in the measurement and analysis of the wind resource. Each factor is summarized below.

Potential Losses	**Amount of potential loss**	**Root Mean Square (RMS)**
Inefficiencies in Power System		
Transformer/line losses	1%	
Turbine downtime (availability)	5%	
Soiling/icing of blades	1%	
Array and yaw losses	2%	
Extreme weather conditions	1%	
Other	1%	
Total	11%	5.7%
Uncertainty in Wind Resource Estimate		
Sensor accuracy	3%	
Inter-annual wind speed variation	3%	
Other	1%	
Total	7%	4.4%
Grand Total		**10.1%**

It is assumed that each of these potential losses is independent of each other; therefore, to calculate the total loss, the root mean square of the individual factors is calculated as follows:

$$RMS_{\text{Power System Losses}} = \sqrt{1^2 + 5^2 + 1^2 + 2^2 + 1^2 + 1^2} = 5.7$$

As shown, the total potential loss due to inefficiencies in the power system and uncertainties in the wind resource measurement is 10.1%. The gross capacity factor is multiplied by 0.9 to account for these factors, resulting in the net capacity factor.