2007-2008 Eva Creek Wind Data
Two Minute Mean Wind Speed Analysis
Revision 0
Two Minute Mean Wind Speed Analysis

Prepared by POWER Engineers, Inc. for

Golden Valley Electric Association

2007-2008 Eva Creek Wind Data

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<th>Prep By</th>
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“Issued For” Definitions:
- “Prelim” means this document is issued for preliminary review, not for implementation
- “Appvl” means this document is issued for review and approval, not for implementation
- “Impl” means this document is issued for implementation
- “Record” means this document is issued after project completion for project file
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1.0 SUMMARY
Available wind farm output from a 24 MW prospective wind farm located in the EVA Creek area has been measured with two minute average samples using wind speed data collected from a meteorological tower. The measurements are presented in five sections of this report. Frequency of occurrence data has been scaled up to account for missing data (due to anemometer icing) to represent data for a complete year. Average monthly available wind farm output power has been computed from available valid wind speed measurement data. Two minute wind data has been collected from only one meteorological tower. Hence, the effect of wind speed diversity among the prospective sixteen turbine wind farm could not be determined. The analysis in this report assumes that all sixteen wind turbines distributed across two 2.5 km east-west ridges get the same wind speed at the same time.

Bar charts showing wind farm output indicate that November, December, February and March had the most available wind power with wind farm average outputs exceeding 10 MW. October had the lowest available average output of 5.4 MW. The frequency distribution of available wind farm output levels shows that the number of two minute average occurrences of zero available wind farm power was 46,408 (92,816 minutes or approximately 1,547 hours or 17.7% of the time) and the number of two minute average occurrences of full 24MW available output power was 39,653 (76,306 minutes or approximately 1,322 hours or 15.1% of the time).

Two minute average power ramp rates varied from zero when there was no change in available wind power between measurement intervals to 12 MW/minute when the available wind farm power changed from zero MW to 24 MW or 24 MW to zero MW in a two minute sample interval. There were more low ramp rate intervals than high ramp rate intervals. A total of 121,687 two minute intervals (46% of the total) had low ramp rates between +0.1 MW/minute and -0.1 MW/minute. Of the total 262,800 yearly two minute intervals, 76,090 (29%) were zero (no wind speed change). There were a total of only 1,000 two minute high ramp rate intervals (2000 minutes or 33.3 hours or 0.4% of the time) during the year that ramp rates were greater than +6 MW/minutes and less than -6MW/minute.

Actual two minute available power measurements are plotted versus time for four selected three hour periods during each month of continuous measurement. Typical two minute wind farm power variations tend to be between approximately 1 MW and 4 MW. However, many two minute available power variations are higher. The two minute samples show many small power reversals that appear as a 0.25 cycle/minute power variations superimposed upon slower power changes. Some traces show the 0.25 cycle/minute power variations superimposed upon a general increase or decrease in power that occurs over a period of approximately one hour. At other times the available wind farm power changes over large ranges of approximately 15 MW to 20 MW within five to fifteen minutes. Data from the two minute available power averages from the meteorological tower measurements indicates that any wind speed variation between zero and full rated wind farm output is possible within the sample interval.

2.0 INTRODUCTION
Golden Valley Electric Association, GVEA, has had wind measurements made with meteorological towers at the site of a potential wind farm in the EVA Creek area. This report documents the analysis of wind samples from a single meteorological tower averaged over two minute intervals starting
August 31, 2007 and ending August 5, 2008. Other wind measurements in the Eva Creek area have been made, but two minute samples have only been collected from one meteorological tower.

A prospective wind farm near Eva Creek presently consists of sixteen GE-1.5sle wind turbine generators for a wind generation facility rated at 24 MW. Prospective turbines are located on two parallel east-west ridges. The turbines are spaced along a distance of approximately 2.5 km (1.55 miles) on each east-west ridge and the ridges are approximately 2.5 km apart. Figure 1 shows a topological map of the EVA Creek area and the prospective wind turbine locations. The prospective turbines are numbered 1 through 8 on along the northern ridge and 9 through 16 on the southern ridge.

Figure 1 is marked with Xs at locations where meteorological towers are located. Data analyzed in this report was collected from meteorological tower 3-1 located in Section 12, at the east end of the northern ridge near prospective wind turbine number 8. Meteorological tower 3-1 is located at latitude 64° 03.617’ north and 148° 50.277’ west. Elevation of the ridge is 905 meters (2,970 feet) and the measured wind data is extrapolated for a turbine hub height of 80 meters (263 feet).
3.0 TWO MINUTE WIND DATA

The two minute wind data from meteorological tower 3-1 was supplied by GVEA in two Microsoft Excel data files. One file had 122,070 records and the other file had 122,771 records. The two files were combined into a single file with a total of 244,841 records for analysis. A complete 365 day file of two minute records would have 262,800 records.

Due to early anemometer mechanical problems and icing problems during the measurement period, good data could not be obtained for every single two minute interval during the measurement period. Missing data was indicated in the data files by the word ICE or the letter M in the available energy output column of the data records and a negative wind velocity of -98 m/s or -99 m/s in the wind velocity columns. This information was used during data processing to differentiate mechanical and icing measurement records from valid data.

Figure 2 shows available wind power output from a single GE-1.5sle wind turbine versus wind speed. This wind turbine characteristic was provided by GVEA along with the wind speed data and the conversion to available wind turbine power. The turbine has a 77 meter (253 foot) rotor diameter. Air density for this characteristic is 1.15 kg/m³. The figure indicates that the full 1500 kW turbine rating output is available when the wind speed is 15 m/s (33.5 mph). Full rated power can be produced for wind speeds between 15 m/s and 25 m/s (~60 mph).

Results plotted in the following sections to summarize the two minute data records are scaled up by a factor of sixteen to represent the total prospective output power from a 24 MW wind farm consisting of sixteen wind turbines. This procedure assumes that all turbines in the wind farm get the same wind speed distribution at the same time. Presently two minute wind speed data is available only from a single meteorological tower at a single location. The effect of two minute wind diversity on the total available wind farm output power cannot be estimated from the single tower data.

There were many records of zero power output availability from the prospective wind turbine. Zero output will occur for wind velocities less than 3 m/s (6.7 mph) or greater than 25 m/s (~60 mph). Many records indicate zero wind velocity without the anemometer icing or mechanical problems. These zero wind velocity records are treated as valid measurements with zero power output during the data analysis.
Figure 2: Wind turbine power versus speed characteristic

4.0 MONTHLY WIND DATA

Table 1 indicates time durations of the various monthly wind and measurement conditions for the two minute data samples. Low wind cut-off is the duration of valid wind speed measurements below 3 m/s (6.7 mph) when the wind turbine will not produce power as shown on the left side of Figure 2. High wind cut-off is the duration of valid wind speed measurements above 25 m/s (~60 mph) when the wind turbine will not produce power as shown on the right side of Figure 2. No data is the time duration when the anemometer at the meteorological site was not serviceable due to mechanical problems or icing and no wind speed data was collected. Production time is the time duration when the collected wind speed data was above 3 m/s (6.7 mph) and below 25 m/s (~60 mph) when wind turbine generators could produce real power (kW).

Table 1 indicates that the monthly time was 72 to 170 hours (.8 to 1.9% of the time) when wind power generation was not possible due to low wind speed. In some months, there could be more time than shown in Table 1 when no wind generation was possible, depending upon the actual wind speed during the time when no wind speed data could be collected. Similarly, the monthly time when wind power production was possible could be higher than shown in Table 1 depending upon the actual wind speed when the anemometer was out of service.
The average available total wind farm power in the last column of Table 1 was computed from the valid wind speed measurements each month. Hence, the average could be a little higher or lower depending upon the actual wind speed when measured wind speed data was not available and depending upon the ability to generate during icing conditions. The lowest measured monthly average was 5.37 MW in October and the highest monthly average was 12.70 MW in February. The average available power output from a 24 MW wind farm computed from all the valid measurement data including the partial month of August is 8.96 MW.

Figures 3 through 13 summarize the available two minute wind farm output power levels for each complete month of measurements. Valid measurement data for each month was used to compute the monthly average available output power. These monthly averages are indicated on each figure. All complete months when two minute measurements were made except June and July of 2008 had some measurement periods where measurement data was not available due to anemometer icing. For months with missing data, it was assumed that the missing data samples have the average available monthly power level and this level is plotted on the figures at the missing sample times. Figure 6, December of 2007, and Figure 7, January of 2008, are months with the most missing data (due to anemometer icing). Missing data is indicated by the constant average power levels of the 11.87 MW between December 12 and December 20 on Figure 6 and 9.24 MW between January 4 and January 14 on Figure 7. Similarly, other months with missing measurement data have the missing intervals plotted as the average of the valid data for that month.

The lowest monthly average prospective wind farm output of the two minute measurements is 5.37 MW in October of 2007. The highest monthly average prospective wind farm output of the two minute measurements is 12.70 MW in February of 2008. Bar charts in Figures 3 through 13 contain every two minute sample in each month and they give a good overview of the available wind power. However, since there are 720 (24*60/2) two minutes data points for every day, higher power levels tend to overwrite lower levels and may make the monthly power charts appear to have higher and/or more constant power levels than the actual measurements.

Figure 12 indicates that June 2008 is the month with the most wind variation of the months measured with the two minute samples. The available wind power did not stay at maximum for any extended time (hours or days) during the month. Available power did not get to the maximum 24 MW level anytime between June 14 and June 20.
### Table 1: Measurement Wind Conditions and Average Available Wind Farm Output Power

<table>
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<tr>
<th>Month</th>
<th>Year</th>
<th>Low Wind Cut-off</th>
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<th>Production Time</th>
<th>Total Time</th>
<th>Average Available Farm Pwr.</th>
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<td></td>
<td></td>
<td>Hours</td>
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**Figure 3:** Two minute interval bar chart of available wind farm power, September 2007
Figure 4: Two minute interval bar chart of available wind farm power, October 2007

Figure 5: Two minute interval bar chart of available wind farm power, November 2007
Figure 6: Two minute interval bar chart of available wind farm power, December 2007

Average Recorded Available Power: 11.87 MW

Figure 7: Two minute interval bar chart of available wind farm power, January 2008

Average Recorded Available Power: 9.24 MW
Figure 8: Two minute interval bar chart of available wind farm power, February 2008

Figure 9: Two minute interval bar chart of available wind farm power, March 2008
Figure 10: Two minute interval bar chart of available wind farm power, April 2008

Figure 11: Two minute interval bar chart of available wind farm power, May 2008
Figure 12: Two minute interval bar chart of available wind farm power, June 2008

Figure 13: Two minute interval bar chart of available wind farm power, July 2008
5.0 OCCURRENCES OF TWO MINUTE POWER LEVELS

The number of valid two minute available wind power measurements at each 50 kW level for a single wind turbine were determined and placed in bins between 0 and 1500 kW (the rating of one turbine). The number of occurrences in each bin were then scaled up by the ratio of the number of two minute samples in a year to the number of valid measurement points to obtain enough samples to represent a complete year. The 50 kW single turbine bin size levels were scaled up by a factor of sixteen, to produce 0.8 MW bin sizes, so that the bin power levels represent the available power output of a 24 MW wind farm.

Results of the available yearly wind farm power level frequency of occurrences are plotted in Figure 14. The number of two minute average occurrences of zero available wind farm power is 46,408 (92,816 minutes or approximately 1,547 hours or 17.7% of the time) The number of two minute average occurrences of full 24 MW available output power is 39,653 (76,306 minutes or approximately 1,322 hours or 15.1% of the time). There are a total of 262,800 two minute periods (8,760 hours) in a 365 day year. Data scaling results in 262,800 for the sum of all the occurrence points (y-axis) in Figure 14. This represents the predicted number of occurrences for a complete year.
6.0 WIND POWER RAMP RATE DISTRIBUTION

Power measurements for each two minute interval are converted to ramp rates by dividing the difference between two successive available power averages by the measurement interval, two minutes. The ramp rates are converted to MW/minute for a 24 MW wind farm by multiplying the 1.5 MW single turbine rating by 16 (total number of turbines). The number of ramp rates in each bin was scaled up by the ratio of the total two minute samples in a 365 day year to the number of computed ramp rates to get a frequency distribution of rates representing a complete year. Intervals where the power did not change produce zero ramp rates. These zero ramp rates occur when the wind speed is below the minimum or above the maximum for turbine power production (below 3 m/s [6.7 mph] or above 25 m/s [~60 mph]). Zero ramp rates also occur for wind speeds between 15 m/s and 25 m/s when rated turbine power is available and when the wind speed does not change between consecutive two minute sample intervals.

Figure 2 shows the available output power versus wind speed (meters/second) curve for a single 1.5sle-GE wind turbine-generator considered for the Eva Creek application. Positive ramp rates indicate the available power out was increasing and negative ramp rates indicate that the available power output was decreasing during the measurement interval. Maximum and minimum possible ramp rates from this data for a 24 MW wind farm are +12.0 MW/minute and -12.0 MW/minute. These extreme rates occurred when the available wind farm power went from zero to maximum (24 MW) in a two minute measurement period or from maximum to zero in a two minute measurement period.

The computed power ramp rates were sorted into 0.05 MW/minute bins between +12 MW/minute and -12 MW/minute. The number of two minute intervals in each bin were tabulated. Figures 15 and 16 show the frequency distribution of two minute ramp rates plotted from the binned data. Many of the ramp rates were either zero or very near zero. Figure 15 shows the number of low ramp rates at each level between +2.0 MW/minute and -2.0 MW/minute. There were a total of 121,687 two minute intervals when the ramp rates were between +0.1 MW/minute and -0.1 MW/minute (46% of the total). Of the total 262,800 yearly two minute intervals, 76,090 (29%) were zero (no wind speed change). There are more low ramp rate intervals than high ramp rate intervals. There were a total of only 1,000 two minute high ramp rate intervals during the year when the ramp rates were greater than +6 MW/minute or less than -6 MW/minute. Hence, Figure 16 is plotted with a smaller vertical frequency of occurrence scale and a higher horizontal ramp rate scale to show the number of high ramp rate occurrences. The peaks at the ends of Figure 16 show that the number of two minute available intervals where the available power goes from maximum to zero or from zero to maximum is approximately 260 times each per year. The figures show that the magnitudes of positive and negative ramp rates are about equal. For example, plus and minus 4 MW/minute rates each occurs in approximately 70 two minute intervals per year.
Figure 15: Frequency of occurrence of low amplitude power ramps

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<tr>
<td>+0.05</td>
<td>15,461</td>
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<td>+0.10</td>
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Figure 16: Frequency of occurrence of high amplitude power ramps

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7.0 AVAILABLE WIND POWER TIME PROFILES

In addition to the frequency of the power ramps due to wind changes, the actual time profiles of the available wind power is of interest. System loads tend to be relatively constant over hourly periods. If the generation power varies due to wind, some generation in the system must also vary in an opposite manner to maintain a power balance in the system between total generation and total load. To illustrate expected dynamic requirements of non-wind generation or to determine how to operate the wind turbines, some representative available wind power variations versus time are plotted during each of the eleven months in which two minute wind data was recorded.

Figures 17 through 27 are selected plots of available wind farm power versus time during September of 2007 through July of 2008. These plots assume that all sixteen wind turbines in a 24 MW wind farm get the same wind speed as that measured by the anemometer on meteorological tower 3-1 where the two minute measurements were taken. The charts are intended to be representative of wind power variation that can be expected during variable wind periods. The figures each contain four plots of continuous three hour available wind power measurements. All points plotted are from the actual two minute data measurements and indicate valid available power levels for the prospective 24 MW wind farm. Major time divisions on the charts in the figures are 20 minutes apart so there are 10 two minute measurement points per division as indicated by the markers on each power traces. The chart legends indicate the day and time of each data series plotted.

Typical two minute wind farm power variations tend to be between approximately 1 MW and 4 MW. However, many two minute variations are higher. The two minute samples show many small power reversals that appear as a 0.25 cycle/minute power variation superimposed upon slower power changes. Many traces show the 0.25 cycles/minute power variation superimposed upon a general increase or decrease in power that occurs over a period of approximately one hour (Figures 17, 18, 19 and 22). At other times the available wind farm power changes over large ranges of approximately 15 MW to 20 MW within five to fifteen minutes (Figures 17, 18, 20, 22 and 24). Figure 24, April 2008, has two intervals on the 4/8 trace where the available power changed by approximately 15 MW in one two minute sample interval (7.5 MW/minute).

The most unusual available power variation selected for plotting is shown by the 1/22 (January 22) traces on Figure 21, January, 2008. Initially the 1230-1530 trace is mostly at zero available wind power, but jumps to 24 MW in one interval for single two minute periods between approximately 1230 and 1400. Then the available power stays mostly at 24 MW, but drops to zero MW for single two minute sample periods between approximately 1450 and 1510. There was anemometer icing in the January 2008 raw data. However, no anemometer icing was reported between January 14 and February 11. Zero available wind power measurements (no anemometer icing reported) have been treated as valid data on the figures and for the wind analysis in this report. Figure 21 also shows a three hour power trace later in the same day, January 22, 2008 from 1730 to 2030. During this time the available wind farm power stayed near 24 MW except for a forty minute period between approximately 1900 and 1940 when the available power dropped to approximately 10 MW.

The traces for selected three hour periods in February 2008, Figure 22, show some high available wind power periods. The 2/14 trace indicates that the power reduced from near full power (24 MW) to approximately 6 MW for a period of approximately forty minutes between 1700 and 1740. The 2/8 trace on the figure also shows that the available power slowly increased from approximately 7 MW to
near full power over a two hour period between 0900 and 1100. Similarly, the 2/5 trace shows the available wind power decreasing from near full power to approximately 14 MW over a two hour period between 1400 and 1600.

May and June of 2008, Figures 25 and 26, were months of considerable variation in available wind power. The traces in these two figures show a tendency for low (2 MW to 3 MW) medium (10 MW to 15 MW) and high (20 MW to 24 MW) power levels with the normal 0.25 cycle per minute variations during different time periods. The 5/31 trace on Figure 25 indicates some high (10 MW or more) sample to sample variations. The 5/6 trace shows a three hour period of available power below 4 MW. Figure 26 shows two three hour periods with available power mostly below about 5 MW in June of 2008.
Figure 17: Two minute average available wind power during September 2007
Figure 18: Two minute average available wind power during October 2007
Figure 19: Two minute average available wind power during November 2007
Figure 20: Two minute average available wind power during December 2007
Figure 21: Two minute average available wind power during January 2008
February 2008 Wind Power Vs Time

Figure 22: Two minute average available wind power during February 2008
March 2008 Wind Power Vs Time

Figure 23: Two minute average available wind power during March 2008
Figure 24: Two minute average available wind power during April 2008
Figure 25: Two minute average available wind power during May 2008
Figure 26: Two minute average available wind power during June 2008
Figure 27: Two minute average available wind power during July 2008
8.0 WIND INTEGRATION APPROACHES

A wind farm producing 24 MW is approximately 9% of the 2017 projected 263 MW peak load of the GVEA system and will be a much higher percentage of light system loading. This much wind power penetration will require proper generation resource scheduling and control due to the variable nature of the wind. A power balance must be achieved between generation plus import power and load in the GVEA system. At low levels of wind penetration, wind farms can be operated as wind dependent generation. However, when wind generation becomes higher than normal load fluctuations, compensation other than what is normally used to compensate for variable loads must be employed. Several possible aids to compensate for the variable nature of the wind are as follows:

1. **Available Wind Prediction:** A good prediction of available wind will allow reserve generation to be started and available when the wind power drops off and allow generation to be shut down when wind power is expected to be available for an extended period of time. Without good wind prediction more spinning reserve with existing generation may be required.

2. **Turbine Blade Pitch Control:** By operating the turbine below the maximum available power level using control of the blade pitch angle, wind generation can be maintained when wind speed drops. The amount of additional power that should be made available by blade pitch control will depend upon the prediction of available wind, the size of random wind fluctuations, expected load variations, other available load compensation facilities and other items that affect the load-generation balance. Wind plant control may allow significant smoothing of the wind farm output power.

3. **Energy Storage Systems:** GVEA’s battery energy storage system, BESS, at the Wilson substation could potentially do a lot for keeping the net power produced by the combination of a wind farm and the BESS nearly constant. Power from the BESS in combination with blade pitch control could be used to smooth wind turbine power variations (perhaps on the order of +/-5 MW). When wind predictions indicated that wind power would be low for an extended period of time, power from the BESS could allow reserve generation to be brought on line and relieve the BESS power requirement. Communication between the wind farm and the BESS could allow an integrated control to limit power ramp rates to defined limits. Additional control design work would be required to determine the feasibility, benefits and reliability of this approach.

4. **More Energy Storage:** An upgrade of the power output time duration capability of the BESS to supply 24 MW for a period of an hour or more could be very helpful. Power from the BESS could fill in many of the low power times shown on Figures 3, 6, 7, 8, 9, 10 and 11 (September and December through May). This upgrade would allow a total wind farm plus BESS to be scheduled for output lower than the available wind power. Output from the wind farm in excess of the scheduled total would be used to charge the BESS when available wind farm power is greater than the scheduled net BESS-turbine system output power. The combination of the BESS and the wind farm could be operated together as a single generation resource.

5. **Wind Speed Diversity:** It is possible that the 0.25 cycles/minute available wind power variations observed in the single meteorological tower measurements may be smoothed out by the wind speed diversity across the wind farm area and not be a system operational concern. The prospective wind farm towers span a significant distance (two approximately 2.5 km [1.55 miles] rows, rows approximately 2.5 km apart) across uneven terrain. The wind velocity is...
probably different from tower to tower at the same instants of time even if it averages the same over a period of time (seconds to minutes). If a wind speed change traveled at the maximum useful speed of 25 m/s (~60 mph), it would take 100 seconds for it to get from one wind tower ridge to the other or from one end of a turbine row to the other.

6. **Load-Wind Farm Combination:** This idea may not be feasible, but if there were large loads that were not dependent upon the time that they were powered, they could be scheduled for operation when wind power is available and help keep output power from wind farm nearly constant. A pumped storage facility may be such a load. Maybe some process that needs heat and has a long cooling time constant could also be such a load. Perhaps a grinding process from a quarry or mine could bring out the product during normal work hours and grind it with an automatic control when wind power is available.