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Summary Report of Wind Farm Data

September 2008

Yih-huei Wan

Technical Report
NREL/TP-500-44348
May 2009

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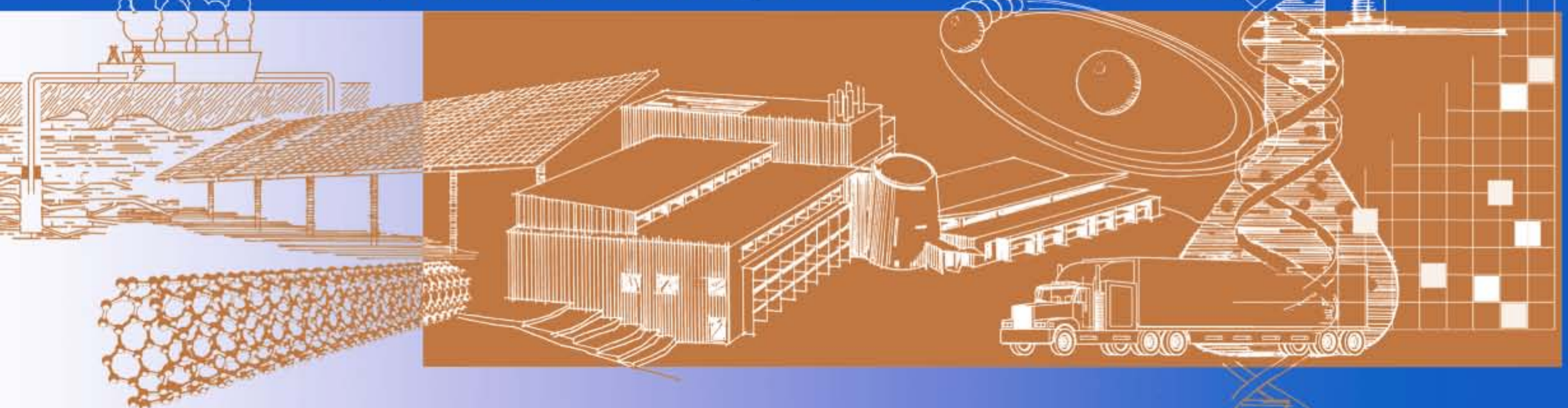

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Executive Summary

The National Renewable Energy Laboratory (NREL) began a project to collect wind power plant output data from several large commercial wind plants during the spring of 2000. The first wind power plant to participate in the project was the Lake Benton II Wind Power Plant connected to Xcel Energy's transmission system in southwest Minnesota. NREL installed recording and communication equipment on site to transmit data back to NREL. The equipment recorded real and reactive power outputs and 3-phase line-to-ground voltages at the wind plant interconnection point at a 1-Hertz sampling rate.

Since then, the number of wind plants participating in the project has gradually increased to include wind power plants in Iowa, Oklahoma, and Texas. In addition to the data collected by the recording equipment installed by NREL at the wind power plants, the project solicited historical wind power data of lower resolution (1-minute, 10-minute, and hourly) from utilities and plant operators/owners to reduce the cost of the program. All together, the project has collected data from more than 25 wind power plants with a total installed wind generating capacity of more than 4 GW. The majority of the data are 1-minute real power time-series data from Texas wind power plants beginning in 2004.

The purpose of collecting these data is to (1) investigate the behavior of wind power and its statistical properties, (2) analyze the spatial and temporal correlation of wind power, (3) validate wind plant and wind forecasting models, and (4) make actual wind power time-series available for standard utility planning and operating study models to evaluate the impacts of wind power use on the electrical grid.

The data collected by NREL have been used in several pioneering wind power integration studies to quantify the impacts of wind power on grid operations and ancillary services. However, as installed wind power capacity continues to increase rapidly, so does the need to expand the scope of data collection activities to include wind power plants in more geographically diverse regions. It is more critical to capture and to better understand spatial diversity of wind power and how it correlates with regional load patterns at higher wind power penetration levels. More importantly, as NREL launches its mesoscale modeling tasks for its western and eastern wind integration studies, it will need more historical wind power data to validate and calibrate the wind plant output models used to generate wind power time series for the United States.

To establish a long-term wind power database, the wind plant data collection project will continue. To expand the scope of the project, NREL will focus on working with utilities and wind power plant operators/owners to retrieve the desired data from the utility energy management systems (EMS) and wind plant supervisory control and data acquisition (SCADA) systems.

Introduction

Wind power plants are different from conventional central-station power plants with large synchronous generators because wind power output is variable and, in general, cannot be controlled by operators. This is one of the main reasons utilities have been reluctant to include wind power in the past. Despite the tremendous growth of wind power in this country, most utilities still do not have experience in integrating wind power into their standard planning and operating processes. At very low penetration levels, the impact of wind power on utility planning and grid operation is mostly negligible because the natural fluctuations of the utility load overwhelm any variations of wind power. As wind power's share in the generation mix grows, its operations will have a greater impact on local grid operations in some regions, and utilities are concerned about system reliability and regulation requirements. Utility operators and planners need data and models to analyze the impacts of integrating wind power into the grid and to plan mitigation strategies if necessary. NREL's wind plant monitoring project is designed to systematically collect long-term, high-resolution wind power data to satisfy this need.

NREL works with wind power plant owners/operators and utilities to gain permission to install data loggers at the points of interconnection to record wind power data or to transmit the wind power data directly from the utility EMS to NREL.

Scope of the Wind Farm Data Collecting Activities

Table 1 lists the wind power plants that are providing data for the project using equipment owned by NREL. Data from these sites are recorded at a rate of 1-Hz and are downloaded daily. Data availability is affected by forced outages of field equipment and communication links.

Table 1. Wind Power Plants Monitored with NREL Equipment.

Name	Location	Turbine Manufacturer	Turbine Size	Total Cap.	Starting Year
Lake Benton	Lincoln County, MN	Zond Z50	750 kW	103 MW	2000
Storm Lake	Buena Vista County, IA	Zond Z50	750 kW	113 MW	2001
Buffalo Ridge	Pipestone County, MN	Zond Z50[1]	750 kW	240 MW	2001
Texas Wind Power Project	Culberson county, TX	Kenetech 330	330 kW	35 MW	2003
Indian Mesa	Pecos County, TX	Vestas V47	660 kW	83 MW	2003
King Mountain	Upton County, TX	Bonus 1.3	1300 kW	79 MW	2003
Trent Mesa	Taylor county, TX	GE 1.5	1500 kW	150 MW	2003

In addition to the wind plants in Table 1, NREL also receives wind power data from utilities in Oklahoma, Washington, and Oregon. Data from the Blue Canyon wind power plant in Oklahoma are 1-minute time series and only from the first phase of the project.[2] Data from the Washington

[1] Five wind power projects feed into Xcel Energy's Buffalo Ridge substation. The two largest projects are Lake Benton I and II, with Zond Z50 turbines. The others are small wind projects of 10 MW or less installed capacity.
[2] The power from the second phase of the project goes to a different utility.

and Oregon wind plants are 2-second historical time series. Table 2 lists the information of those wind plants.

Table 2. Wind Power Plants with Data Provided by Utilities.

Name	Location	Turbine Manufacturer	Turbine Size	Total Cap.	Starting Year
Blue Canyon	Comanche County, OK	NEG Micon	1650 kW	74 MW	2004
Stateline	Walla Walla County, WA	Vestas	660 kW	90 MW	2002
Vansycle	Umatila County, OR	Mitsubishi	600 kW	25 MW	2002
Condon	Gillam County, OR	Mitsubishi	600 kW	50 MW	2002
Nine Canyon	Franklin County, WA	Bonus	1300 kW	20 MW	2002
Klondike	Sherman County, OR	GE	1500 kW	40 MW	2002

In 2008, NREL began receiving historical 1-minute wind power output data for 2004 to 2007 for operating wind power plants in Texas from the Electric Reliability Council of Texas (ERCOT), the electric grid operator in Texas. Table 3 lists the ERCOT wind power plants. It should be noted that Table 3 only includes the wind plants that were in the ERCOT plant information (PI) system at the end of 2007. The data were extracted directly from the wind plant SCADA systems or PI systems and data were not checked for errors by ERCOT. As a result, data quality is not consistent for all wind plants.

Table 3. Wind Power Plants with Data Provided by ERCOT[3].

Name	Location	Turbine Manufacturer	Turbine Size	Total Cap.
Brazos Wind Ranch	Borden and Scurry Counties	Mitsubishi	1000 kW	160 MW
Horse Hollow Wind Energy Center	Taylor and Nolan Counties	GE Siemens	1500 kW 2300 kW	735 MW
Callahan Divide Wind Energy Center	Taylor County	GE	1500 kW	114 MW
King Mountain Wind Farm	Upton County	Siemens	1300 kW	278 MW
Woodward Mountain Wind Ranch	Pecos County	Vestas	660 kW	160 MW
Trent Mesa Wind Project	Taylor and Nolan Counties	GE	1500 kW	150 MW
Desert Sky Wind Farm	Pecos County	GE	1500 kW	160 MW
Indian Mesa Wind Farm	Pecos County	Vestas	660 kW	83 MW
Delaware Mountain Wind Farm	Culberson County	Zond	750 kW	29 MW
Texas Wind Power Project	Culberson County	Kenetech	330 kW	35 MW
Big Spring Wind Power Project	Howard County	Vestas	660 kW 1650 kW	34 MW
Southwest Mesa Wind Farm	Upton County	NEG Micon	700 kW	75 MW
Buffalo Gap I & II	Taylor and Nolan Counties	Vestas GE	1800 kW 1500 kW	120 MW 233 MW
Sweetwater Wind Farm	Nolan County	Mitsubishi Siemens GE	1000 kW 2300 kW 1500 kW	585 MW
Camp Springs I & II	Scurry County	GE	1500 kW	250 MW

[3] The names of the wind power plants are from the ERCOT PI system, and they may differ from their commercially designated names.

Forest Creek Wind Farm	Glasscock and Sterling Counties	GE	1500 kW	124 MW
Sand Bluff	Glasscock and Sterling Counties	GE	1500 kW	90 MW
Capricorn Ridge Wind Farm	Sterling and Coke Counties	GE Siemens	1500 kW 2300 kW	215 MW 149 MW
Lone Creek Post Oak	Shackelford County	Gamesa	2000 kW	200 MW
Red Canyon	Borden, Garza and Scurry Counties	GE	1500 kW	84 MW
Whirlwind	Floyd County	Seimens	2300 kW	60 MW
ENEL Snyder Wind Project	Scurry County	Vestas	3000 kW	63 MW

The Alberta Electric System Operator (AESO) and the Independent Electricity System Operator (IESO) in Ontario, Canada, have both made real-time electricity power system and market information, including wind generation, available on their web sites. AESO's system supply report lists 10 wind power plants with a total installed capacity of 490 MW.[4] The IESO web site shows seven wind power plants totaling 770 MW of installed capacity.[5] Only hourly data streams are archived and available for download in their FTP servers. We download their hourly wind power data.

Of all the data recorded and collected from the different wind power plants, the plants in Minnesota and Iowa have the highest data availability rate. The data availability rate combined with a good working relationship with the crews allows for quick resolution of any problems with equipment or phone lines, and contributed to NREL's decision to maintain its data loggers and the communication links at the Minnesota and Iowa wind plants.

Applications of the Data

High-resolution wind power data (1-second and 1-minute time series) are being used in system integration studies by utilities and to validate the results of mesoscale wind power models.

Standard utility planning and engineering models are used for utility wind integration studies. Actual wind data are used as one of the inputs to those models to evaluate how the electric systems will interact with wind power, and what aspect of the electric system will be impacted by wind power and to what degree. The following organizations have used the data collected by NREL in 2008 for various wind studies.

- Western Interstate Energy Board
- Platte River Power Authority
- Bureau of Reclamation Hydroelectric Power
- BC Hydro
- BC Transmission Operator
- Manitoba Hydro

[4] AESO current system information is available at http://ets.aeso.ca/ets_web/ip/Market/Reports/CSDReportServlet. The historical data are available at http://ets.aeso.ca/.
[5] IESO information is available at http://www.ieso.ca/ and the historical data are available at http://reports.ieso.ca/public/GenOutputCapability/.

The goal of the wind plant power-output data collection project is to make the data available to other researchers and utility planners performing wind studies. NREL has agreed to respect the proprietary nature of the wind power data collected. Therefore, when we provide data for other organizations to use for system studies, we require that the names of the wind power plants and the data itself not to be published. Only statistics derived from the data can be made public.

The data are used to validate the wind power time series created for the Western Wind Integration Studies and Eastern Wind Integration and Transmission Studies by 3Tier and AWS/Truewind, respectively. Step change statistics of the wind power time-series data that is created are compared to similar statistics of actual wind power data collected. Model output statistics (MOS) corrections are applied to the created data based on the comparison.

Outlook of Wind Plant Monitoring

Usefulness of actual wind plant output-data for studying the impacts of wind power on the electric grid has increased with the higher penetration level of wind power in the electric system. Rapid deployment of installed wind power over greater areas also makes it more important to know the effect of wind resource spatial diversity on the behavior of wind power plants, especially its effect on the ramping of wind power. However, the number of new wind power plants and their geographic dispersion necessitate a change of our approach in collecting the data.

NREL installing and maintaining its own data loggers to collect the wind power data results in the highest recovery rate and quality of data, but it is not always practical in terms of cost. The way NREL works with ERCOT to receive high-resolution historical wind-power data directly from system operators represents a model for future data collection projects. Independent system operators (ISO) are making system information transparent to all interested parties – AESO and IESO are two examples. The California Independent System Operator (CAISO) also makes system information, such as actual and forecasted load and actual generation, available on its public web site in real time (updated every minute). Making the archived version of such data available to researchers and academics can avoid proprietary data issues, which is the single biggest obstacle when getting data from plant owners and operators.

There are drawbacks associated with getting data from an ISO. Extracting historical data from PI systems takes time and represents additional work for ISOs. NREL depends on work schedules of ISO staff to perform the data extracting task for us. The data quality is another potential problem. However, the cost of the alternative approach is much higher. One of the goals of the wind plant monitoring project is to expand the scope of the project to include wind power plants in California, Illinois, New York, and Pennsylvania. NREL will try to work with the California ISO and Midwest ISO to gain access to its archived wind power data in much the same way it works with ERCOT.

Currently NREL has a subcontract with Electrotek to maintain and collect 1-second output power data from four wind power plants in Texas. The instruments have been in the field for more than 6 years and their reliability has decreased noticeably; missing data points have increased steadily. Because NREL receives 1-minute output power data from the same wind power plants through ERCOT, it will consider terminating the subcontract with Electrotek and removing the data loggers and communications equipment when the subcontract is completed at the end of 2008.

Another big problem with wind power data collection is the lack of corresponding wind speed and direction data from the wind power plants. Wind power data without corresponding wind resource data from the same wind power plant prevents the data from being effectively used in wind power forecasting applications. Wind speed and direction data from wind power plants are not generally available because such data are considered as "business sensitive" by the wind plant owners and operators. Another reason for the lack of wind data is that such data often do not exist at many wind power plants, especially if the ISOs (through market design) or local utilities do not mandate that plant operators provide wind power forecasting information. After a wind plant starts commercial operation or when the manufacturer's warranty on the turbines has expired, the meteorological towers may no longer be properly maintained and calibrated, and wind data are not recorded because such information is not needed in daily operations. However, utilities are beginning to request wind power forecasting information to help with the integration of ever increasing wind power in their system, and more metrology tower data will become available. NREL will work with the ISO and utilities to obtain archived metrology tower data.

Some Observations of the Data

One observation from the available data is the significant yearly variation of wind resources. Figure 1 below shows monthly production at Lake Benton (Minnesota) from 2000 to 2007. Although a general pattern can be detected, the individual monthly production can change as much as 100% from one year to another.

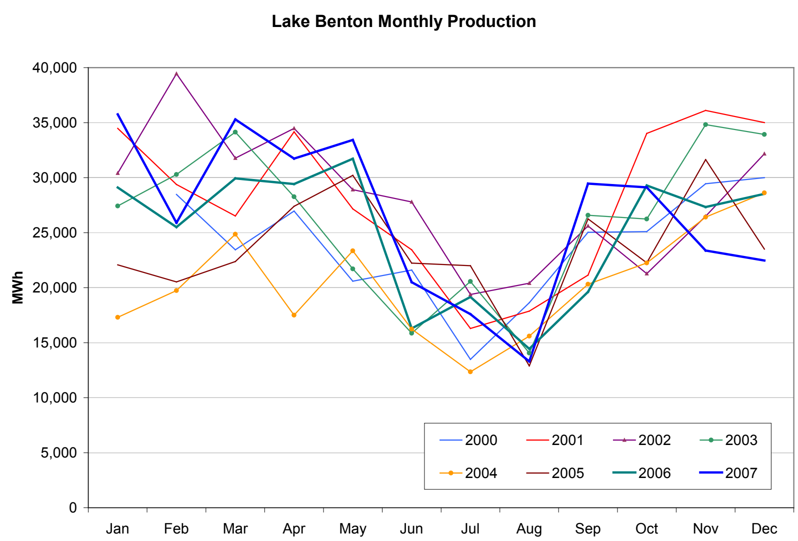

Figure 1. Monthly production of Lake Benton wind power plant.

Figure 2 plots the monthly production of wind power plants near McCamey, Texas. Only data from plants that have been in operation since the beginning of 2004 are included. The pattern is even less clear in Figure 2. These significant yearly variations of wind power points to the need for a long-term data recording program so that the extent of such variations can be better understood, and mitigation strategies can be included in the system planning process. Compared to the nation's hydropower production that customarily references 30-year or even 50-year mean and standard deviation values, wind power does not have long-term statistics that can be confidently used in the system planning process. New extreme values or events seem to appear every year. One reason is the rapid growth the wind industry is experiencing, but this does not diminish the importance of long-term data.

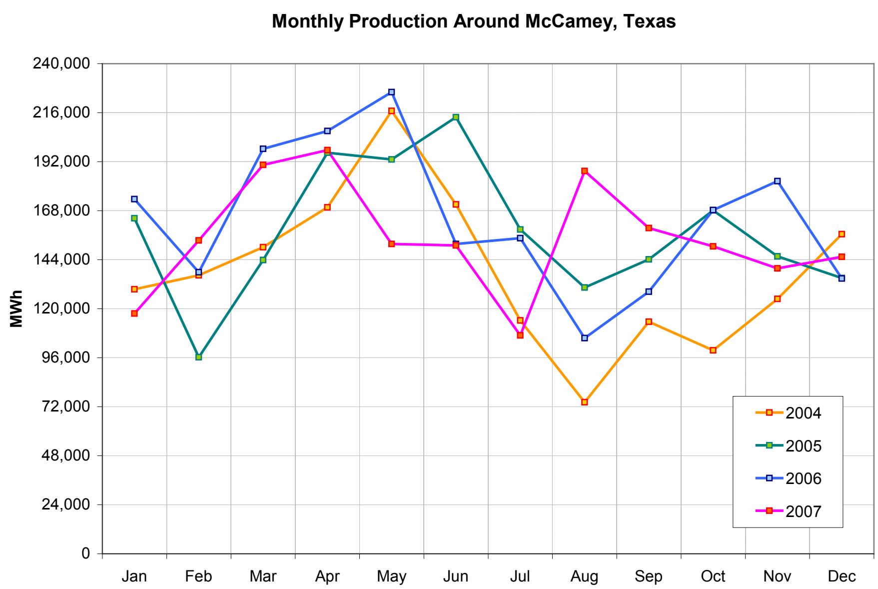

Figure 2. Monthly production of wind plants near McCamey, Texas.

Figures 1 and 2 show other important characteristics of wind power – the spatial and temporal diversity. It is expected that outputs from wind plants separated by long distance will be diverse, and the data support this expectation. Minnesota wind production tends to peak in late winter and early spring months. Texas wind plants also produce more energy during these month, but they tend to peak in late spring months. In addition, the peak production days of Minnesota and Texas wind plants did not coincide during the 2004-2007 period. The days of low wind generally happen during summer months in Minnesota, but not in Texas. The minimum production days do not coincide during the 2004-2007 period either.

Aggregating outputs from many wind power plants will smooth out the overall output power profile. The effect was dramatic when the 2007 data from all Texas wind power plants were summed. Table 4 shows the mean and standard deviation values of the magnitude (absolute values) of hourly step changes, expressed in relation to installed wind power capacity. When all available power data are combined, average step changes and its standard deviation decrease significantly, as expected.

Table 4. Average and Standard Deviation Values of Hourly Ramping of Three Wind Plants

	Brazos 1(84 MW)		Lubbock (244 MW)[6]		All Wind Plant(>3 GW)[7]	
2007	Avg.	St. dev.	Avg.	St. dev.	Avg.	St. dev.
Jan	5.1%	7.5%	3.4%	3.9%	0.7%	0.4%
Feb	5.3%	7.8%	3.7%	3.7%	0.7%	0.4%
Mar	7.2%	7.7%	4.9%	4.0%	0.7%	0.4%
Apr	6.9%	7.2%	4.9%	3.9%	0.7%	0.4%
May	6.0%	7.4%	4.3%	4.1%	0.7%	0.4%
Jun	6.9%	8.1%	4.4%	4.0%	0.7%	0.4%
Jul	4.8%	6.4%	3.8%	3.8%	0.7%	0.4%
Aug	5.6%	6.4%	4.3%	3.8%	0.6%	0.3%
Sep	6.3%	7.2%	4.7%	4.1%	0.5%	0.3%
Oct	4.8%	6.4%	3.5%	4.0%	0.4%	0.4%
Nov	6.3%	7.2%	4.3%	3.6%	0.5%	0.3%
Dec	7.3%	7.8%	4.3%	3.5%	0.5%	0.3%

The distribution of hourly step changes is shown in Figure 3. It can be seen that 91.4% of all hourly changes are less than 300 MW in magnitude (roughly 10% of the wind capacity), and 99.2% of the hourly changes are less than 600 MW in magnitude (20% of the wind capacity). However, the data also reveals that there were 8 occurrences (0.1% of all hourly changes) of hourly changes of 900 MW in magnitude or greater. One occurrence of large hourly changes occurred on October 21, 2007. Figure 4 plots the 1-minute average power profile for that day.

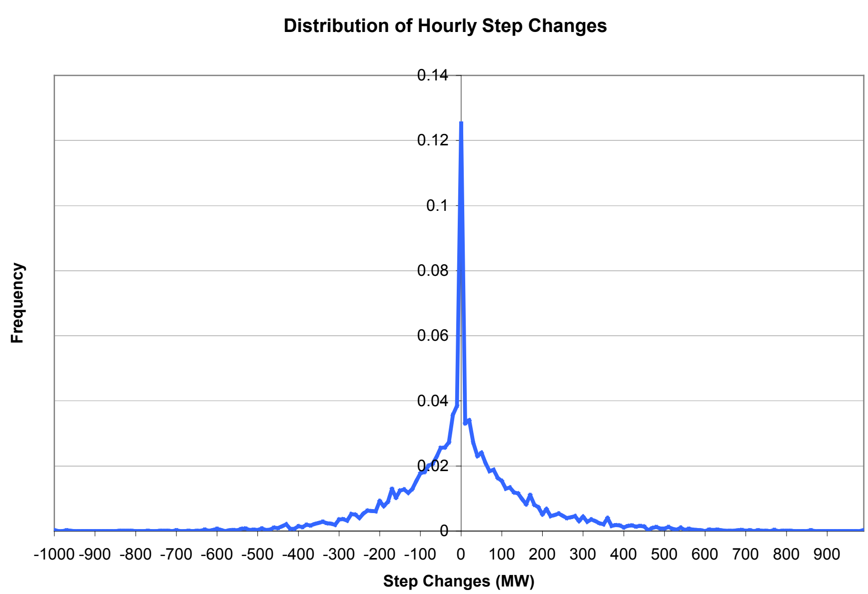

Figure 3. Distribution of hourly wind power changes.

[6] Combined output of wind power plants near Lubbock, including Brazos 1 and 2 and Red Canyon, with a total capacity of 244 MW.

[7] All 2007 data from ERCOT are combined. The total capacity increased significantly during the last 5 months of the year. The percentage values are calculated with a monthly capacity value.

Total wind power actually dropped from a morning high of 2.8 GW to a low of 0.66 GW, and then increased to 2.8 GW again in the evening during a 20-hour period – a swing of more than 2.2 GW. Between the hours of 17:00 and 18:00, wind power was ramping up at a rate of 1.6 GW per hour. Although such large swings happen infrequently, they may cause difficulties in system operations.

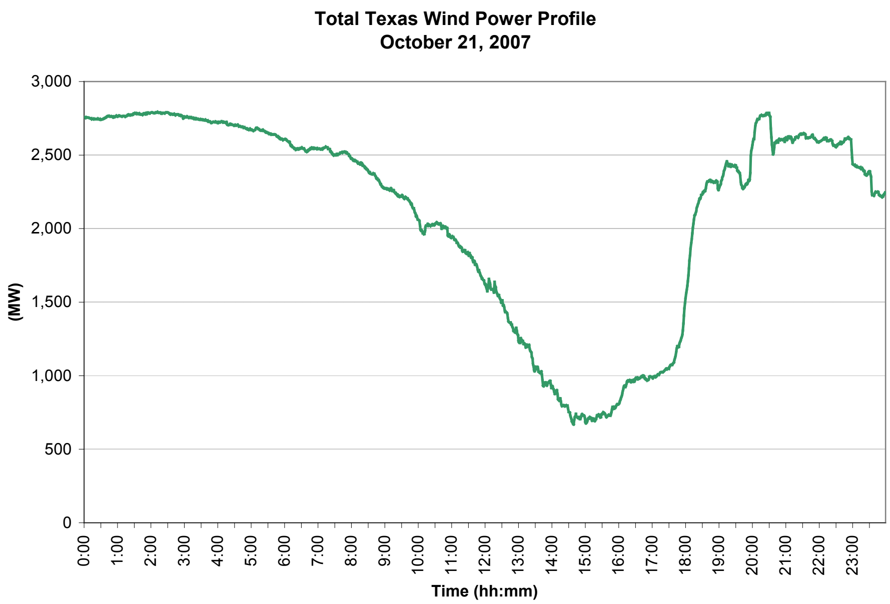

Figure 4. Daily 1-minute average power profile.

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The National Renewable Energy Laboratory (NREL) began a project to collect wind power plant output data from several large commercial wind plants during the spring of 2000. This data is summarized in this report.

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