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MASTER

Meteorological Validation Program

CANDIDATE WIND TURBINE GENERATOR SITE
SEMI-ANNUAL DATA SUMMARY
FOR
CULEBRA, PUERTO RICO
JANUARY 1980 THROUGH JUNE 1980

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Prepared for
U.S. Department of Energy
Division of Distributed Solar Technology
Wind Systems Branch
Washington, DC

December 1980

PACIFIC NORTHWEST LABORATORY
Richland, Washington 99352

1.0 INTRODUCTION

This report summarizes wind speed and direction data collected on meteorological towers at 13 candidate and wind turbine generator installation sites from January 1980 through June 1980. The basic method of data collection is by digital data cassette recording systems. For the digital data reported, an instantaneous sample is recorded every 2 minutes.

Section 2.0 of this report provides an explanation of each data summary table as well as information on how specific values were computed. The rest of the report presents the annual summarized data for each site. This report was prepared for the Department of Energy's Wind Systems Branch, Division of Distributed Solar Technology, by the Pacific Northwest Laboratory (PNL). Comments regarding this or other data reports should be directed to Mr. William F. Sandusky of PNL at 509-376-4823 (FTS 444-4823) or Dr. David S. Renné of PNL at 509-376-4623 (FTS 444-4623).

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2.0 SUMMARY TABLES

Summarized data for each site are presented in eight (8) tables. Discussion of data represented in each table and the method of calculation are given below. Wind speeds are reported in meters per second, elevation in meters, and direction in degrees.

A value reported less than -900.00 indicates missing data. A value less than or equal to -900.00 or zero at the mid-level indicates that data are not collected at this level.

TITLE AND FUNCTION

Table 1.1

Sensor Performance. Sensor performance provides the percentage of time the recording system was operating and the percentage of time acceptable data were acquired by the meteorological sensors. The values given under the label "% on-line" are obtained by dividing the total number of data scans collected by the total possible number of data scans. The values given under the label "% recovered" are obtained by dividing the total number of acceptable data scans collected by the total possible number of data scans.

Table 1.2

Annual Means and Standard Deviations. This table provides the mean wind speed, wind direction, and standard deviation of wind speed for each sensor level.

Table 1.3

Maximum Wind Speed. The highest recorded wind speed for each level is given along with date and time of occurrence. Corresponding wind direction and wind speed values at the other sensor levels are also given.

Table 1.4

Wind Speed and Direction Versus Time-of-Day. Mean wind speed and direction values and standard deviation of wind speed are reported for each hour of

the day for the reporting period. Data reported for 00:00 represent the average of the data recorded between 23:00 and 00:00. Data are provided for each level of instrumentation.

Table 1.5

Frequency Distribution of Wind Speed. For each sensor level, the total number of observations and percentage of occurrence are given for a number of classes of wind speed. The recovery rate for each wind speed sensor is given at the bottom of the table.

Table 1.6.

Cumulative Frequency Distribution of Wind Speed. Both the cumulative number of observations and percentage of cumulative frequency distribution of wind speed are given for various intervals. The value of 2.0 under the wind speed column represents wind speed occurrences up to and including 2.0 m/s. Information is given for each sensor level.

Table 1.7.

Wind Speed Persistence Frequency. The occurrence of the duration of wind speed in various speed class intervals is given as a function of time. The value of 3.0 under the hours column means that the wind in the indicated speed class persists between 2.5 and 3 hours. Data are given for the top sensor level.

Table 1.8.

Power Law Exponent. The power law exponent between sensor levels is computed as indicated in the notes. These values are averaged according to wind direction intervals from the highest wind direction sensor. The value under the Alpha (A, B, C) column indicates a best fit value of the other three values. If the site only has two levels of instrumentation, no best fit value will be calculated. The percentage of occurrence of wind direction for each sensor level is also given.

Table 1.9.

Turbulence Intensity. The turbulence intensity for each sensor level is given as a function of wind direction. Values reported are based on first computing an hourly turbulence intensity, as noted in the table, from the 30 instantaneous values obtained during the hour. All the hourly values are summed and then divided by the number of hours in the month to produce a monthly average value.

SITE ID:
 SITE LOCATION: ALL SITE SUMMARY
 DATA: JANUARY 1980 THROUGH JUNE 1980

3.1 ALL SITE SUMMARY

SITE CODE	SENSOR LEVEL	% SAMPLE RECOVERY	MEAN	WIND SPEED S.D.	MAX.
TX (C)	9.1	94.4	6.3	2.9	18.4
RI (C)	9.1	93.2	5.5	2.4	14.9
NC (C)	18.2	86.4	6.7	4.3	27.1
NM (C)	9.1	92.9	5.5	2.9	19.6
AK (C)	9.1	87.6	6.8	3.9	20.2
PR (C)	9.1	87.1	5.8	2.1	13.7
MA (C)	18.2	94.0	4.4	2.4	19.0
SD (C)	9.1	89.9	4.3	2.6	17.5
NB (C)	9.1	98.7	4.5	2.5	21.6
NY (C)	18.2	78.9	6.0	3.3	19.1
CA (C)	9.1	90.9	4.5	2.6	17.7
KS (C)	9.1	88.7	4.7	2.7	17.6
SG (C)	9.1	95.4	6.9	4.1	18.1
RI (B)	30.0	93.2	6.9	2.9	19.5
NC (B)	45.7	86.5	8.0	4.2	29.3
NM (B)	30.0	89.1	6.9	3.2	22.4
TX (A)	45.7	95.0	8.4	3.7	22.2
RI (A)	45.7	93.3	7.9	3.3	21.3
NC (A)	76.2	86.8	8.5	4.4	28.4
NM (A)	45.7	89.9	7.6	3.4	23.8
AK (A)	21.8	87.7	7.5	4.4	22.1
PR (A)	45.7	87.1	6.7	2.1	15.2
MA (A)	45.7	93.5	6.6	3.5	26.3
SD (A)	45.7	90.5	6.2	3.2	21.4
NB (A)	45.7	98.3	6.0	3.1	27.2
NY (A)	45.7	79.2	7.1	3.6	20.7
CA (A)	45.7	90.9	6.8	3.6	20.0
KS (A)	45.7	87.8	6.3	3.5	22.8
SG (A)	45.7	92.1	9.0	5.6	22.8

CULEBRA, PUERTO RICO

SITE ID: PR
 SITE LOCATION: CULEBRA, PR.
 DATA : JANUARY 1980 THROUGH JUNE 1980

1.1 SENSOR PERFORMANCE

TOTAL POSSIBLE SAMPLES: 4368

SENSOR	% ON-LINE	% RECOVERED
WS(A)	100.0	87.1
WD(A)	100.0	87.1
WS(C)	100.0	87.1
WD(C)	100.0	87.0

Handwritten: $\frac{5.000 \text{ m/s}}{5.000 \text{ m/s}} = 1.0$
 $\frac{2.29 \text{ m/s}}{2.29 \text{ m/s}} = 1.0$

1.2 ANNUAL MEANS AND STANDARD DEVIATIONS

	HEIGHT (METERS)	MEAN WS	MEAN WD	STD DEV SPEED
SITE DATA (A)	45.7	6.7	94.4	2.1
(C)	9.1	5.8	93.9	2.1

1.3 MAXIMUM WIND SPEED

ELEVATION (METERS)	WIND SPEED	WIND DIR.	DATE	TIME	OTHER LEVELS
(A) 45.7	15.2	62.8	01/11/80	03:00	(B)-999.9 (C) 13.2
(C) 9.1	13.7	74.0	01/11/80	21:00	(A) 14.6 (B)-999.9

NOTES:

1. SITE ELEVATION: 80 METERS ABOVE SEA LEVEL.
3. SENSOR LEVEL B NOT AVAILABLE AT SITE PR.

SITE ID: PR
 SITE LOCATION: CULEBRA, PR.
 DATA : JANUARY 1980 THROUGH JUNE 1980

 1.4 WIND SPEED AND DIRECTION VERSUS TIME-OF-DAY

TIME OF DAY	LEVEL A		LEVEL B		LEVEL C	
	WS	WD	WS	WD	WS	WD
00:00	6.4	92.6	0.0	0.0	5.4	93.1
01:00	6.4	92.8	0.0	0.0	5.4	93.2
02:00	6.4	92.5	0.0	0.0	5.4	92.5
03:00	6.4	92.2	0.0	0.0	5.4	93.0
04:00	6.4	92.3	0.0	0.0	5.4	93.0
05:00	6.4	92.3	0.0	0.0	5.4	93.0
06:00	6.5	92.4	0.0	0.0	5.4	92.2
07:00	6.5	91.3	0.0	0.0	5.7	90.0
08:00	6.7	89.7	0.0	0.0	6.1	88.6
09:00	7.0	92.0	0.0	0.0	6.4	90.0
10:00	7.1	94.0	0.0	0.0	6.5	92.3
11:00	7.2	96.7	0.0	0.0	6.4	95.2
12:00	7.2	98.4	0.0	0.0	6.4	97.5
13:00	7.1	99.5	0.0	0.0	6.3	98.5
14:00	7.1	98.6	0.0	0.0	6.3	97.4
15:00	7.0	98.1	0.0	0.0	6.2	96.8
16:00	6.9	97.6	0.0	0.0	6.1	95.7
17:00	6.5	96.7	0.0	0.0	5.7	97.4
18:00	6.5	98.7	0.0	0.0	5.5	97.8
19:00	6.7	96.6	0.0	0.0	5.6	96.4
20:00	6.7	92.9	0.0	0.0	5.6	93.5
21:00	6.6	92.3	0.0	0.0	5.6	92.3
22:00	6.6	92.3	0.0	0.0	5.6	92.8
23:00	6.5	93.1	0.0	0.0	5.5	93.6

SITE ID: PR
 SITE LOCATION: CULEBRA, PR.
 DATA : JANUARY 1980 THROUGH JUNE 1980

 1.5 FREQUENCY DISTRIBUTION OF WIND SPEED

WIND SPEED	LEVEL A COUNT	LEVEL B % COUNT	LEVEL C % COUNT	%
0.0- 0.5	3	0.1	0	0.0
0.5- 1.0	6	0.2	0	0.0
1.0- 1.5	6	0.2	0	0.0
1.5- 2.0	16	0.4	0	0.0
2.0- 2.5	21	0.6	0	0.0
2.5- 3.0	39	1.0	0	0.0
3.0- 3.5	54	1.4	0	0.0
3.5- 4.0	109	2.9	0	0.0
4.0- 4.5	204	5.4	0	0.0
4.5- 5.0	262	6.9	0	0.0
5.0- 5.5	333	8.8	0	0.0
5.5- 6.0	420	11.0	0	0.0
6.0- 6.5	436	11.5	0	0.0
6.5- 7.0	443	11.6	0	0.0
7.0- 7.5	330	8.7	0	0.0
7.5- 8.0	256	6.7	0	0.0
8.0- 8.5	236	6.2	0	0.0
8.5- 9.0	131	3.4	0	0.0
9.0- 9.5	140	3.7	0	0.0
9.5-10.0	90	2.4	0	0.0
10.0-11.0	132	3.5	0	0.0
11.0-12.0	76	2.0	0	0.0
12.0-13.0	28	0.7	0	0.0
13.0-14.0	28	0.7	0	0.0
14.0-15.0	4	0.1	0	0.0
15.0-16.0	1	0.0	0	0.0
16.0-17.0	0	0.0	0	0.0
17.0-18.0	0	0.0	0	0.0
18.0-19.0	0	0.0	0	0.0
19.0-20.0	0	0.0	0	0.0
20.0-21.0	0	0.0	0	0.0
>21.0	0	0.0	0	0.0

RECOVERY RATES
 LEVEL A LEVEL B LEVEL C
 87.1 0.0 87.1

SITE ID: PR
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 DATA : JANUARY 1980 THROUGH JUNE 1980

 1.6 CUMULATIVE FREQUENCY DISTRIBUTION OF WIND SPEED

WIND SPEED	LEVEL A		LEVEL B		LEVEL C	
	CFD (ABS)	CFD (%)	CFD (ABS)	CFD (%)	CFD (ABS)	CFD (%)
0.5	3	0.08	0	0.00	6	0.16
1.0	9	0.24	0	0.00	16	0.42
1.5	15	0.39	0	0.00	25	0.66
2.0	31	0.81	0	0.00	72	1.89
2.5	52	1.37	0	0.00	164	4.31
3.0	91	2.39	0	0.00	325	8.54
3.5	145	3.81	0	0.00	533	14.00
4.0	254	6.68	0	0.00	793	20.84
4.5	458	12.04	0	0.00	1066	28.01
5.0	720	18.93	0	0.00	1403	36.86
5.5	1053	27.68	0	0.00	1771	46.53
6.0	1473	38.72	0	0.00	2155	56.62
6.5	1909	50.18	0	0.00	2509	65.92
7.0	2352	61.83	0	0.00	2814	73.94
7.5	2682	70.50	0	0.00	3039	79.85
8.0	2938	77.23	0	0.00	3240	85.13
8.5	3174	83.44	0	0.00	3393	89.15
9.0	3305	86.88	0	0.00	3517	92.41
9.5	3445	90.56	0	0.00	3614	94.96
10.0	3535	92.93	0	0.00	3673	96.51
11.0	3667	96.40	0	0.00	3763	98.87
12.0	3743	98.40	0	0.00	3788	99.53
13.0	3771	99.13	0	0.00	3801	99.87
14.0	3799	99.87	0	0.00	3806	100.00
15.0	3803	99.97	0	0.00	3806	100.00
16.0	3804	100.00	0	0.00	3806	100.00
17.0	3804	100.00	0	0.00	3806	100.00
18.0	3804	100.00	0	0.00	3806	100.00
19.0	3804	100.00	0	0.00	3806	100.00
20.0	3804	100.00	0	0.00	3806	100.00
21.0	3804	100.00	0	0.00	3806	100.00
>21.0	3804	100.00	0	0.00	3806	100.00

SITE ID: PR
 SITE LOCATION: CULEBRA, PR.
 DATA : JANUARY 1980 THROUGH JUNE 1980

 1.7 WIND SPEED PERSISTENCE FREQUENCY (LEVEL A)

HOURS	NUMBER OF OCCURENCES			
	PERS.	WIND SPEED, M/S		
	< 4	4-12	12-20	>20
<.1	0	0	0	0
.1-.2	0	0	0	0
.2-.4	0	0	0	0
.4-.8	0	0	0	0
.8-1	34	20	8	0
1.5	0	0	0	0
2.0	19	10	5	0
2.5	0	0	0	0
3.0	11	4	0	0
3.5	0	0	0	0
4.0	4	5	2	0
4.5	0	0	0	0
5.0	6	2	0	0
6.0	2	5	0	0
7.0	4	3	0	0
8.0	2	4	0	0
9.0	2	7	0	0
10.0	0	4	0	0
12.0	0	3	0	0
14.0	0	5	0	0
16.0	0	4	1	0
18.0	0	1	0	0
20.0	0	5	1	0
>20	1	53	0	0

SITE ID: PR
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 1.8 POWER LAW EXPONENT

WIND DIR (ELEV A)	ALPHA (A,B)	ALPHA (B,C)	ALPHA (A,C)	ALPHA (A,B,C)	ZA	ZB	XC
N	0.00	0.00	0.21	0.00	0.89	0.00	0.76
NNE	0.00	0.00	0.22	0.00	2.10	0.00	1.03
NE	0.00	0.00	0.14	0.00	5.81	0.00	3.39
ENE	0.00	0.00	0.03	0.00	24.26	0.00	21.23
E	0.00	0.00	0.06	0.00	27.84	0.00	42.25
ESE	0.00	0.00	0.15	0.00	18.64	0.00	16.11
SE	0.00	0.00	0.17	0.00	9.17	0.00	5.73
SSE	0.00	0.00	0.28	0.00	4.94	0.00	2.68
S	0.00	0.00	0.31	0.00	4.02	0.00	3.39
SSW	0.00	0.00	0.29	0.00	0.63	0.00	1.55
SW	0.00	0.00	0.12	0.00	0.24	0.00	0.39
WSW	0.00	0.00	-0.35	0.00	0.03	0.00	0.08
W	0.00	0.00	0.01	0.00	0.05	0.00	0.08
WNW	0.00	0.00	0.09	0.00	0.16	0.00	0.11
NW	0.00	0.00	0.13	0.00	0.13	0.00	0.18
NNW	0.00	0.00	0.17	0.00	0.97	0.00	0.92

 NOTES:

$$\begin{aligned}
 & \text{ALPHA} \\
 & 1. \frac{WS(UP)}{WS(LO)} = \frac{Z(UP)}{Z(LO)} \\
 & \text{ALPHA} = \frac{\log(WS(UP)/WS(LO))}{\log(Z(UP)/Z(LO))}
 \end{aligned}$$

WHERE; Z=ELEVATION
 WS=WIND SPEED