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MASTER

Meteorological Validation Program

CANDIDATE WIND TURBINE GENERATOR SITE
ANNUAL DATA SUMMARY
FOR
CULEBRA, PUERTO RICO
JANUARY 1979 THROUGH DECEMBER 1979

Prepared for U.S. Department of Energy
Division of Distributed Solar Technology
Wind Systems Branch, Washington, DC
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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PACIFIC NORTHWEST LABORATORY
Richland, Washington 99352

1.0 INTRODUCTION

This report summarizes wind speed and direction data collected on meteorological towers at 14 candidate and wind turbine generator installation sites from January 1979 through December 1979. 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 509-942-4823 (FTS 444-4823) or Dr. David S. Renné of PNL at 509-942-4623 (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 month. 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.

SITE ID:
 SITE LOCATION: ALL SITE SUMMARY
 DATA: JANUARY 1979 THROUGH DECEMBER 1979

 ALL SITE SUMMARY

SITE CODE	SENSOR LEVEL	% SAMPLE RECOVERY	WIND SPEED		
			MEAN	S.D.	MAX.

TX (C)	9.1	94.5	5.8	2.7	17.7
RI (C)	9.1	83.3	4.6	2.2	14.6
NC (C)	18.2	96.6	5.5	3.8	28.8
NM (C)	9.1	79.6	5.3	2.9	21.3
AK (C)	9.1	63.4	6.2	3.7	18.8
PR (C)	9.1	75.1	6.5	2.5	29.1
MA (C)	18.2	93.2	4.3	2.3	15.5
SD (C)	9.1	87.2	4.5	2.6	16.2
NB (C)	9.1	81.4	4.8	2.5	15.4
MI (C)	18.2	96.5	5.0	2.9	19.3
NY (C)	18.2	98.2	5.6	3.3	20.1
CA (C)	9.1	93.2	4.7	2.5	16.0
KS (C)	9.1	84.5	5.1	2.6	16.4
SG (C)	9.1	90.4	5.6	3.8	18.7

RI (B)	30.0	55.2	5.7	2.6	16.2
NC (B)	45.7	89.1	7.0	3.9	29.9
NM (B)	30.0	79.6	6.7	3.2	25.0

TX (A)	45.7	94.5	7.6	3.3	22.3
RI (A)	45.7	83.1	7.0	3.1	21.5
NC (A)	76.2	93.5	7.8	4.5	34.6
NM (A)	45.7	79.6	7.3	3.3	27.3
AK (A)	21.8	64.5	7.1	4.2	22.9
PR (A)	45.7	74.7	7.4	2.6	31.7
MA (A)	45.7	93.5	6.5	3.6	25.5
SD (A)	45.7	87.3	6.5	3.2	19.1
NB (A)	45.7	81.3	6.2	3.1	18.8
MI (A)	45.7	95.7	7.2	3.7	25.6
NY (A)	45.7	92.9	6.7	3.5	21.4
CA (A)	45.7	86.2	6.4	3.4	20.5
KS (A)	45.7	84.8	7.0	3.1	19.1
SG (A)	45.7	90.0	7.2	5.2	24.3

CULEBRA, PUERTO RICO

SITE ID: PR
 SITE LOCATION: CULEBRA, PR.
 DATA : JANUARY 1979 THROUGH DECEMBER 1979

 1.1 SENSOR PERFORMANCE

TOTAL POSSIBLE SAMPLES: 8760

SENSOR	% ON-LINE	% RECOVERED
WS(A)	100.0	74.7
WD(A)	100.0	76.4
WS(C)	100.0	75.1
WD(C)	100.0	74.7

 1.2 ANNUAL MEANS AND STANDARD DEVIATIONS

	HEIGHT (METERS)	MEAN WS	MEAN WD	STD DEV SPEED
SITE DATA	(A) 45.7	7.4	223.0	2.6
	(C) 9.1	6.5	127.9	2.5

 1.3 MAXIMUM WIND SPEED

ELEVATION (METERS)	WIND SPEED	WIND DIR.	DATE	TIME	OTHER LEVELS
(A) 45.7	31.7	65.3	09/01/79	02:00	(B)-999.9 (C) 29.1
(C) 9.1	29.1	70.2	09/01/79	02:00	(A) 31.7 (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 1979 THROUGH DECEMBER 1979

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	7.4	221.9	0.0	0.0	6.3	57.1
01:00	7.3	246.1	0.0	0.0	6.2	143.2
02:00	7.2	65.3	0.0	0.0	6.1	203.4
03:00	7.2	76.4	0.0	0.0	6.1	177.2
04:00	7.2	58.7	0.0	0.0	6.2	131.4
05:00	7.3	105.7	0.0	0.0	6.2	33.7
06:00	7.2	350.2	0.0	0.0	6.1	141.0
07:00	7.1	171.3	0.0	0.0	6.3	231.7
08:00	7.3	173.7	0.0	0.0	6.6	168.7
09:00	7.6	235.6	0.0	0.0	6.9	29.2
10:00	7.7	227.6	0.0	0.0	7.0	88.8
11:00	7.8	19.9	0.0	0.0	7.0	34.7
12:00	7.8	189.9	0.0	0.0	7.0	160.7
13:00	7.6	322.0	0.0	0.0	6.9	75.5
14:00	7.5	142.3	0.0	0.0	6.7	313.0
15:00	7.4	140.5	0.0	0.0	6.5	129.0
16:00	7.3	220.0	0.0	0.0	6.4	128.0
17:00	7.4	25.2	0.0	0.0	6.4	122.5
18:00	7.5	297.0	0.0	0.0	6.4	196.5
19:00	7.6	242.9	0.0	0.0	6.5	103.7
20:00	7.5	315.9	0.0	0.0	6.5	191.0
21:00	7.5	264.8	0.0	0.0	6.5	132.0
22:00	7.5	242.4	0.0	0.0	6.5	120.1
23:00	7.4	285.6	0.0	0.0	6.3	106.4

SITE ID: PR
 SITE LOCATION: CULEBRA, PR.
 DATA : JANUARY 1979 THROUGH DECEMBER 1979

1.5 FREQUENCY DISTRIBUTION OF WIND SPEED

WIND SPEED	LEVEL A COUNT	LEVEL B % COUNT	LEVEL C % COUNT	%
0.0- 0.5	0	0.0	0	0.0
0.5- 1.0	2	0.0	3	0.0
1.0- 1.5	10	0.2	19	0.3
1.5- 2.0	21	0.3	54	0.8
2.0- 2.5	48	0.7	131	2.0
2.5- 3.0	73	1.1	180	2.8
3.0- 3.5	101	1.5	259	4.0
3.5- 4.0	156	2.4	286	4.4
4.0- 4.5	224	3.4	344	5.3
4.5- 5.0	315	4.8	368	5.7
5.0- 5.5	380	5.8	580	9.0
5.5- 6.0	525	8.0	641	10.0
6.0- 6.5	659	10.1	600	9.3
6.5- 7.0	679	10.4	581	9.0
7.0- 7.5	613	9.4	466	7.2
7.5- 8.0	568	8.7	404	6.3
8.0- 8.5	438	6.7	322	5.0
8.5- 9.0	346	5.3	279	4.3
9.0- 9.5	238	3.6	219	3.4
9.5-10.0	223	3.4	171	2.7
10.0-11.0	377	5.8	241	3.7
11.0-12.0	222	3.4	121	1.9
12.0-13.0	123	1.9	61	0.9
13.0-14.0	78	1.2	43	0.7
14.0-15.0	32	0.5	21	0.3
15.0-16.0	34	0.5	9	0.1
16.0-17.0	21	0.3	9	0.1
17.0-18.0	13	0.2	3	0.0
18.0-19.0	8	0.1	5	0.1
19.0-20.0	4	0.1	5	0.1
20.0-25.0	7	0.1	0	0.0
>25.0	9	0.1	6	0.1

RECOVERY RATES
 LEVEL A LEVEL B LEVEL C
 74.7 0.0 75.1

SITE ID: PR
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 DATA : JANUARY 1979 THROUGH DECEMBER 1979

 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	0	0.00	0	0.00	0	0.00
1.0	2	0.03	0	0.00	3	0.05
1.5	12	0.18	0	0.00	22	0.34
2.0	33	0.50	0	0.00	76	1.18
2.5	81	1.24	0	0.00	207	3.22
3.0	154	2.35	0	0.00	387	6.02
3.5	255	3.89	0	0.00	646	10.05
4.0	411	6.28	0	0.00	932	14.49
4.5	635	9.70	0	0.00	1276	19.84
5.0	950	14.51	0	0.00	1644	25.56
5.5	1330	20.31	0	0.00	2224	34.58
6.0	1855	28.33	0	0.00	2865	44.55
6.5	2514	38.40	0	0.00	3465	53.88
7.0	3193	48.77	0	0.00	4046	62.91
7.5	3806	58.13	0	0.00	4512	70.16
8.0	4374	66.81	0	0.00	4916	76.44
8.5	4812	73.50	0	0.00	5238	81.45
9.0	5158	78.78	0	0.00	5517	85.79
9.5	5396	82.42	0	0.00	5736	89.19
10.0	5619	85.83	0	0.00	5907	91.85
11.0	5996	91.56	0	0.00	6148	95.60
12.0	6218	94.97	0	0.00	6269	97.48
13.0	6341	96.85	0	0.00	6330	98.43
14.0	6419	98.04	0	0.00	6373	99.10
15.0	6451	98.53	0	0.00	6394	99.42
16.0	6485	99.05	0	0.00	6403	99.56
17.0	6506	99.37	0	0.00	6412	99.70
18.0	6519	99.57	0	0.00	6415	99.75
19.0	6527	99.69	0	0.00	6420	99.83
20.0	6531	99.76	0	0.00	6425	99.91
21.0	6538	99.86	0	0.00	6425	99.91
22.0	6547	100.00	0	0.00	6431	100.00

SITE ID: PR
 SITE LOCATION: CULEBRA, PR.
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 1.7 WIND SPEED PERSISTENCE FREQUENCY (LEVEL A)

HOURS	NUMBER OF OCCURENCES			
	PERS. < 4	WIND SPEED, M/S 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	0	0	0	0
1.5	47	38	32	0
2.0	22	21	10	0
2.5	0	0	0	0
3.0	17	11	7	1
3.5	0	0	0	0
4.0	7	13	1	0
4.5	0	0	0	0
5.0	2	8	2	0
6.0	5	5	2	1
7.0	3	2	1	0
8.0	1	6	2	0
9.0	1	5	4	0
10.0	1	4	2	0
12.0	1	2	0	0
14.0	1	2	1	0
16.0	1	7	0	0
18.0	0	2	0	0
20.0	0	1	0	0
>20	2	50	2	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)	%A	%B	%C
N	0.00	0.00	0.12	0.00	1.07	0.00	0.82
NNE	0.00	0.00	0.26	0.00	2.86	0.00	1.46
NE	0.00	0.00	0.15	0.00	12.07	0.00	7.48
ENE	0.00	0.00	0.03	0.00	36.67	0.00	36.45
E	0.00	0.00	0.06	0.00	27.48	0.00	39.01
ESE	0.00	0.00	0.16	0.00	11.01	0.00	7.59
SE	0.00	0.00	0.21	0.00	4.28	0.00	2.58
SSE	0.00	0.00	0.25	0.00	1.88	0.00	1.42
S	0.00	0.00	0.31	0.00	1.10	0.00	1.01
SSW	0.00	0.00	0.30	0.00	0.58	0.00	0.86
SW	0.00	0.00	0.39	0.00	0.14	0.00	0.45
WSW	0.00	0.00	0.33	0.00	0.06	0.00	0.17
W	0.00	0.00	0.07	0.00	0.09	0.00	0.08
WNW	0.00	0.00	0.31	0.00	0.08	0.00	0.09
NW	0.00	0.00	-0.06	0.00	0.15	0.00	0.09
NNW	0.00	0.00	0.14	0.00	0.49	0.00	0.44

 NOTES:

$$\begin{aligned}
 & \text{ALPHA} \\
 & \text{WS(UP)} \quad \text{Z(UP)} \\
 1. \quad \frac{\text{WS(UP)}}{\text{WS(LO)}} &= \frac{\text{Z(UP)}}{\text{Z(LO)}} \\
 & \text{LOG(WS(UP)/WS(LO))} \\
 2. \quad \text{ALPHA} &= \frac{\text{LOG(WS(UP)/WS(LO))}}{\text{LOG(ZUP/ZLO)}}
 \end{aligned}$$

WHERE; Z=ELEVATION
 WS=WIND SPEED