ELECTRIC POWER RESEARCH INSTITUTE

California Solar Initiative
Screening Distribution Feeders:
Alternatives to the 15% Rule

Task 4: Collect High-Resolution PV Data

Summary of Results

Chris Trueblood
Cameron Riley
David Freestate

24 July 2015

© 2015 Electric Power Research Institute, Inc. All rights reserved.

Presentation Contents

Task 4: Collect High-Resolution PV Data

- Overview and Sites Monitored
- Solar Radiation Characteristics
- Energy-Based Performance
- Power Output Characteristics
- Variability
  - Establishing Rate-Rate Datasets
  - Ramp Rates for Individual Sites
  - Ramp Rates for Site Clusters

© 2015 Electric Power Research Institute, Inc. All rights reserved.

Objectives and Overview

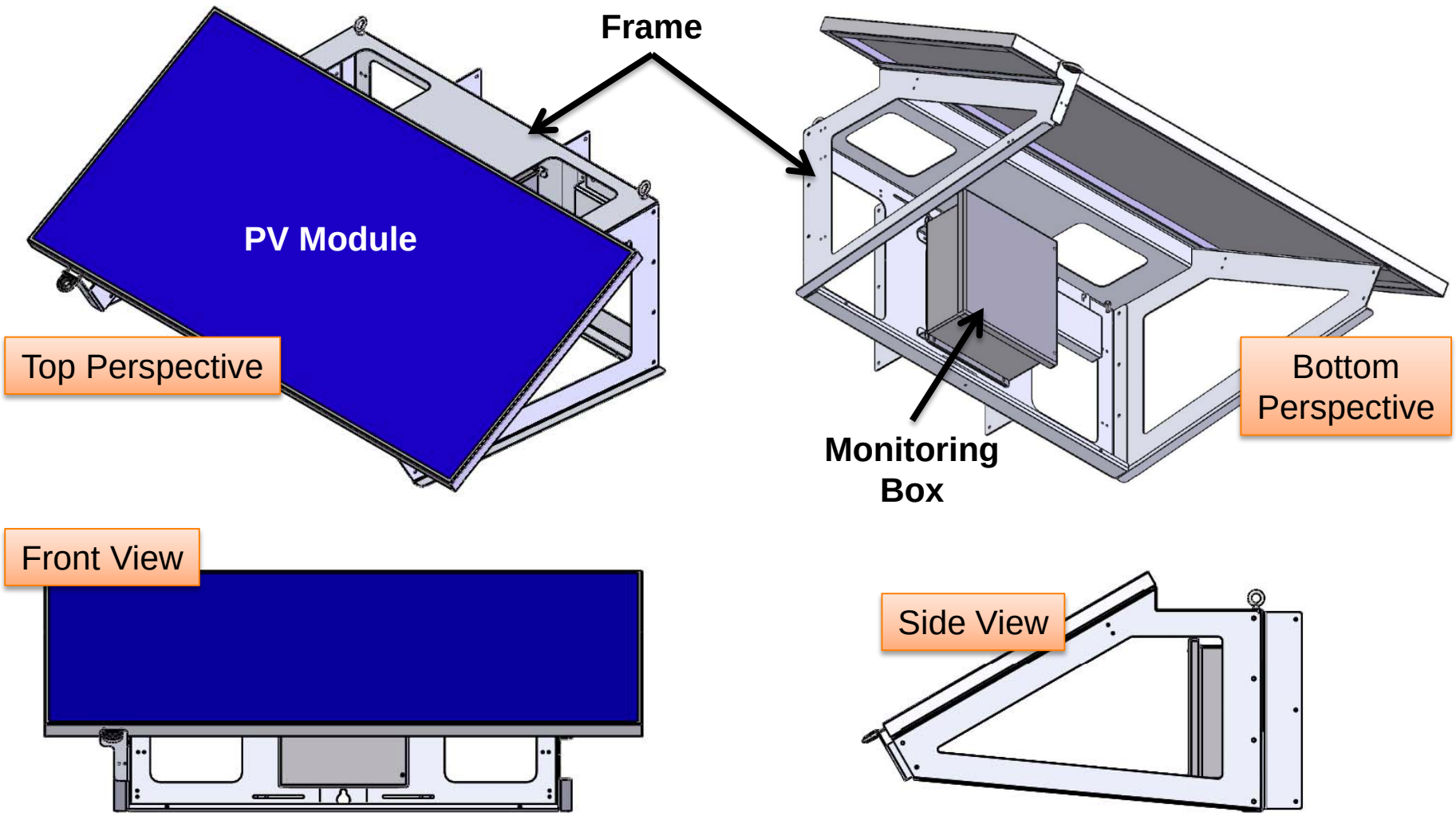
Task 4: Collect High-Resolution PV Data

- The purpose of this task is to collect high-resolution, time-series solar data that can be used to define the PV output to understand the impacts of high penetration when performing scenario analysis.
- In parallel to the modeling efforts, high-resolution solar data was collected to define the PV output to understand the impacts of high penetration when performing scenario analysis.
- In order to understand the specific effects of PV output variability, high-resolution solar output data was collected utilizing single-module solar monitoring systems mounted on utility poles to capture time-series measurements of actual PV output and solar resource.
- In total, 20 monitoring systems have been installed across selected simulation feeders. This ensures data collected accounts for the spatial relationships of measuring points, as well as, the time synchronization of PV power into the grid to account for the diversity in distributed PV outputs.
- The monitoring units include an ac power meter to measure PV system output (real and reactive power, voltages, and currents) and a pyranometer to measure plane-of-array solar irradiance. Data was recorded at 1-second intervals to adequately capture variability of solar caused by cloud movements.
- Monitoring systems in the San Diego area were deactivated prior to 2015, and data from 2014 was used for those sites' analyses (for other sites, 2015 data was used). Solar measurement data was analyzed for the 6-month period January-June.

© 2015 Electric Power Research Institute, Inc. All rights reserved.

Single-Module PV Monitoring System

PV module, pole-mount frame, and monitoring box are pre-assembled



© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

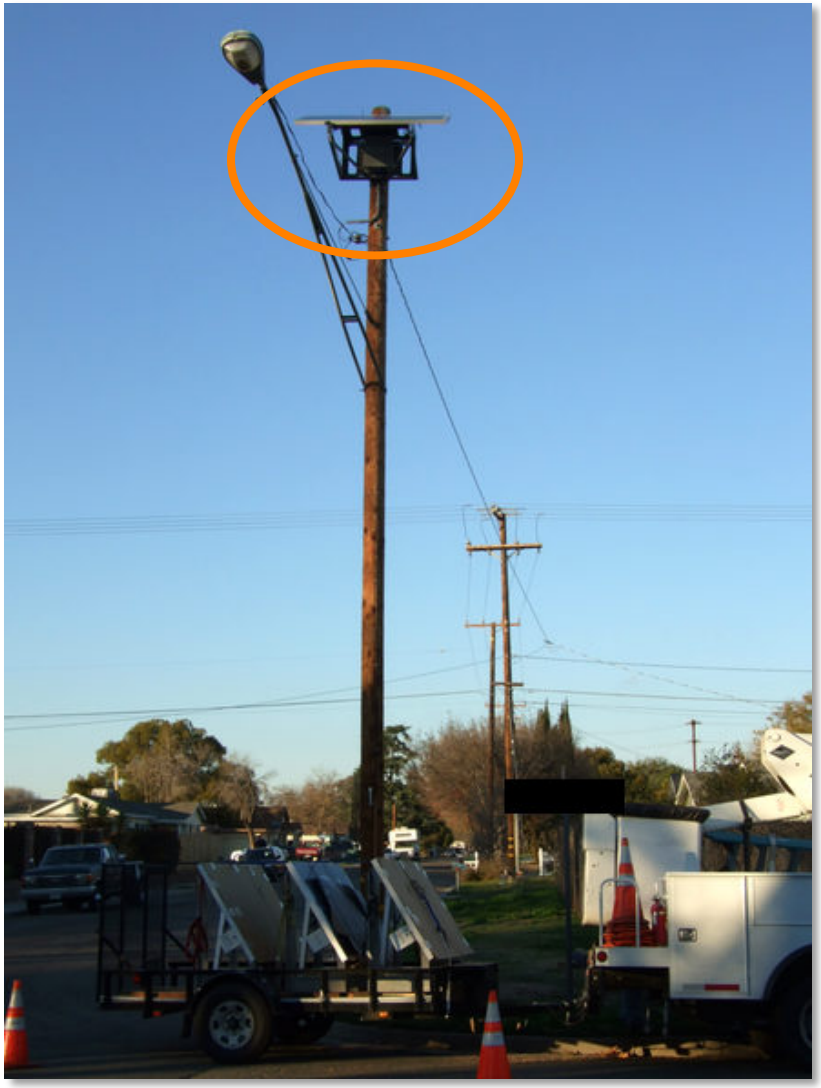
Single-Module Solar Monitoring Systems

Installed in California on utility poles

© 2015 Electric Power Research Institute, Inc. All rights reserved.

Single-Module Solar Monitoring Systems

Installed in California on utility poles



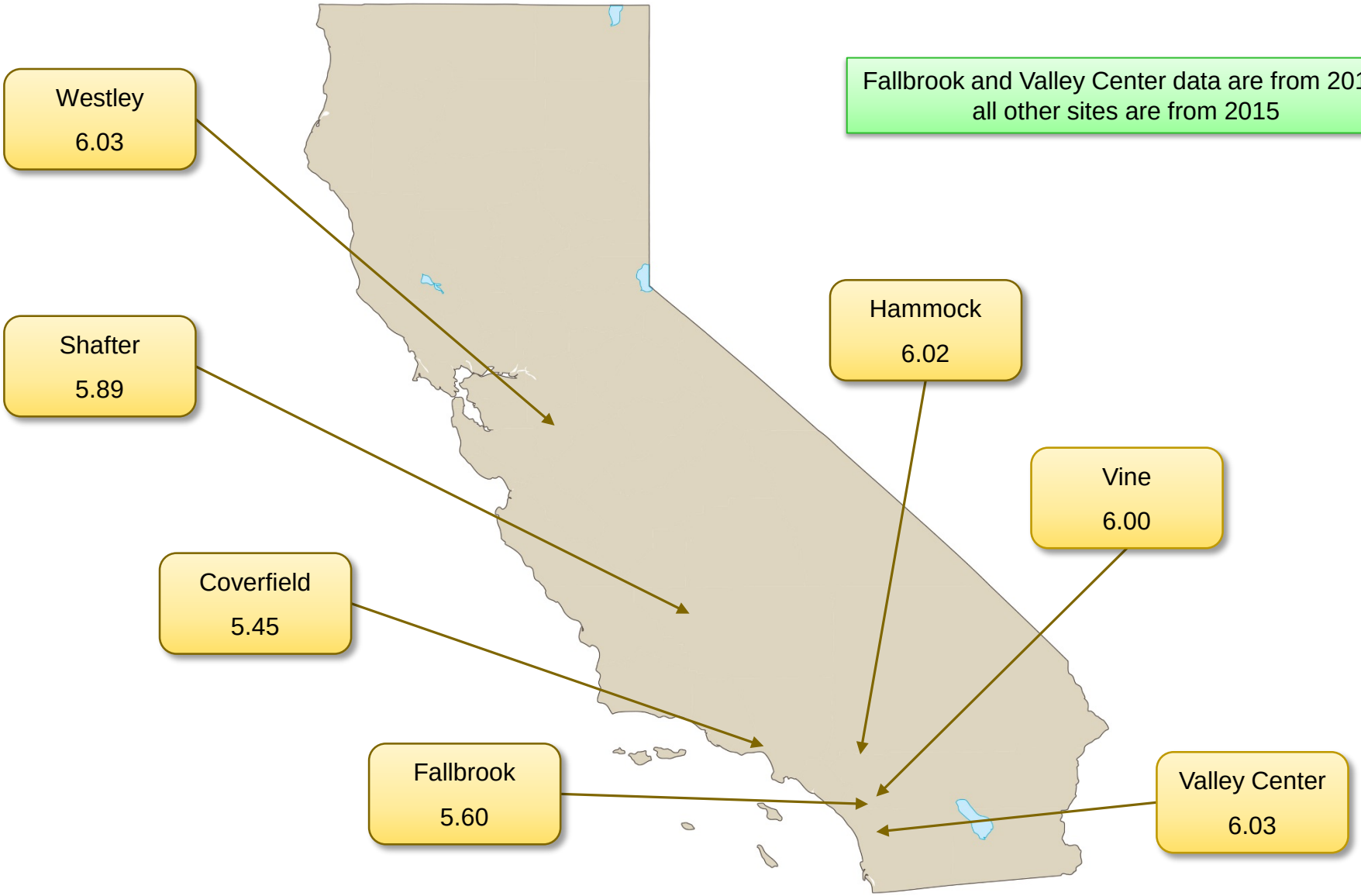
© 2015 Electric Power Research Institute, Inc. All rights reserved.

Solar Radiation Characteristics

California Solar Initiative
Screening Distribution Feeders: Alternatives to the 15% Rule
Task 4: Collect High-Resolution PV Data

© 2015 Electric Power Research Institute, Inc. All rights reserved.

Average Daily Insolation (kWh/m^2/day) – Jan. to June



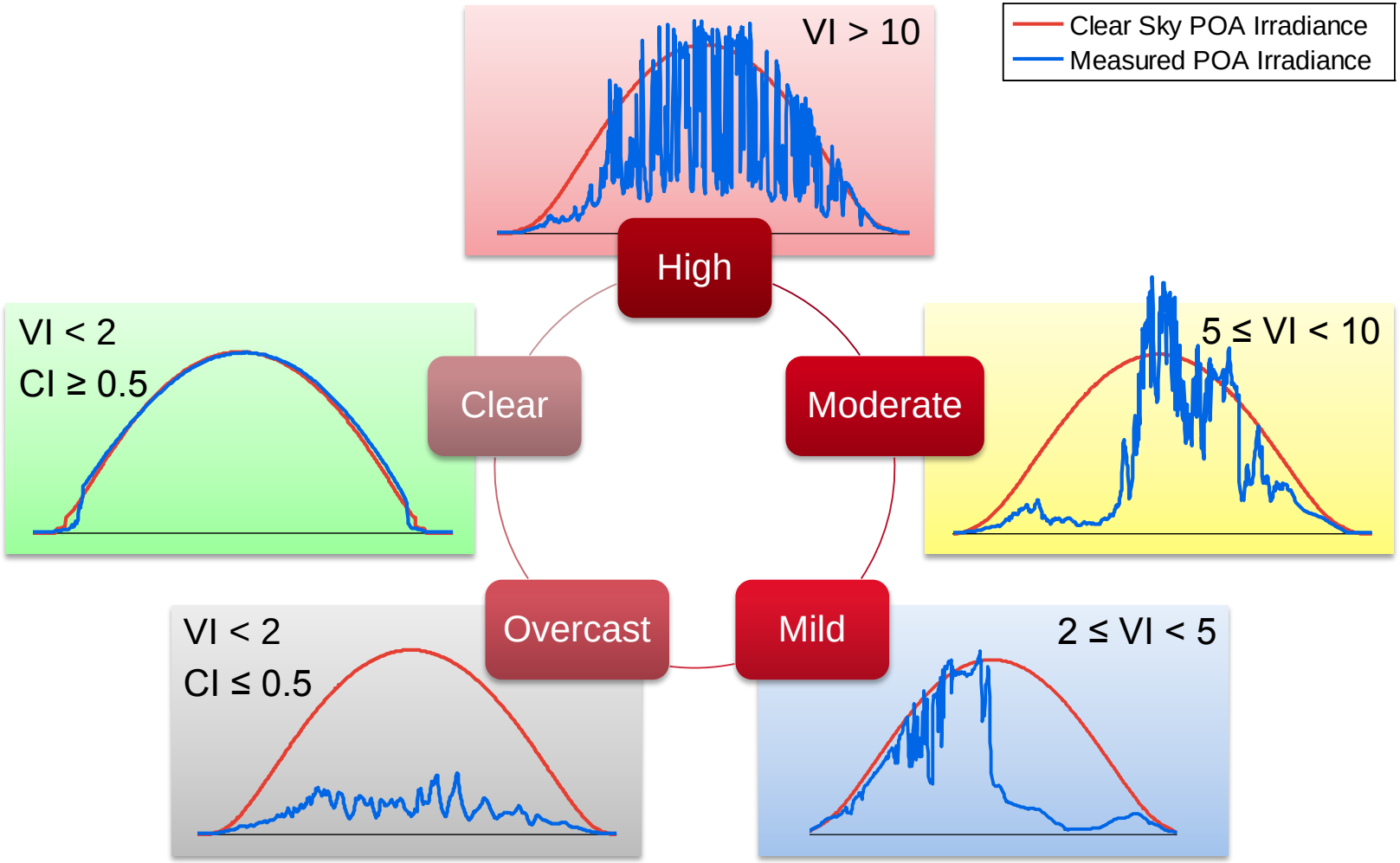
Fallbrook and Valley Center data are from 2014; all other sites are from 2015

© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Categories for Daily Variability Conditions

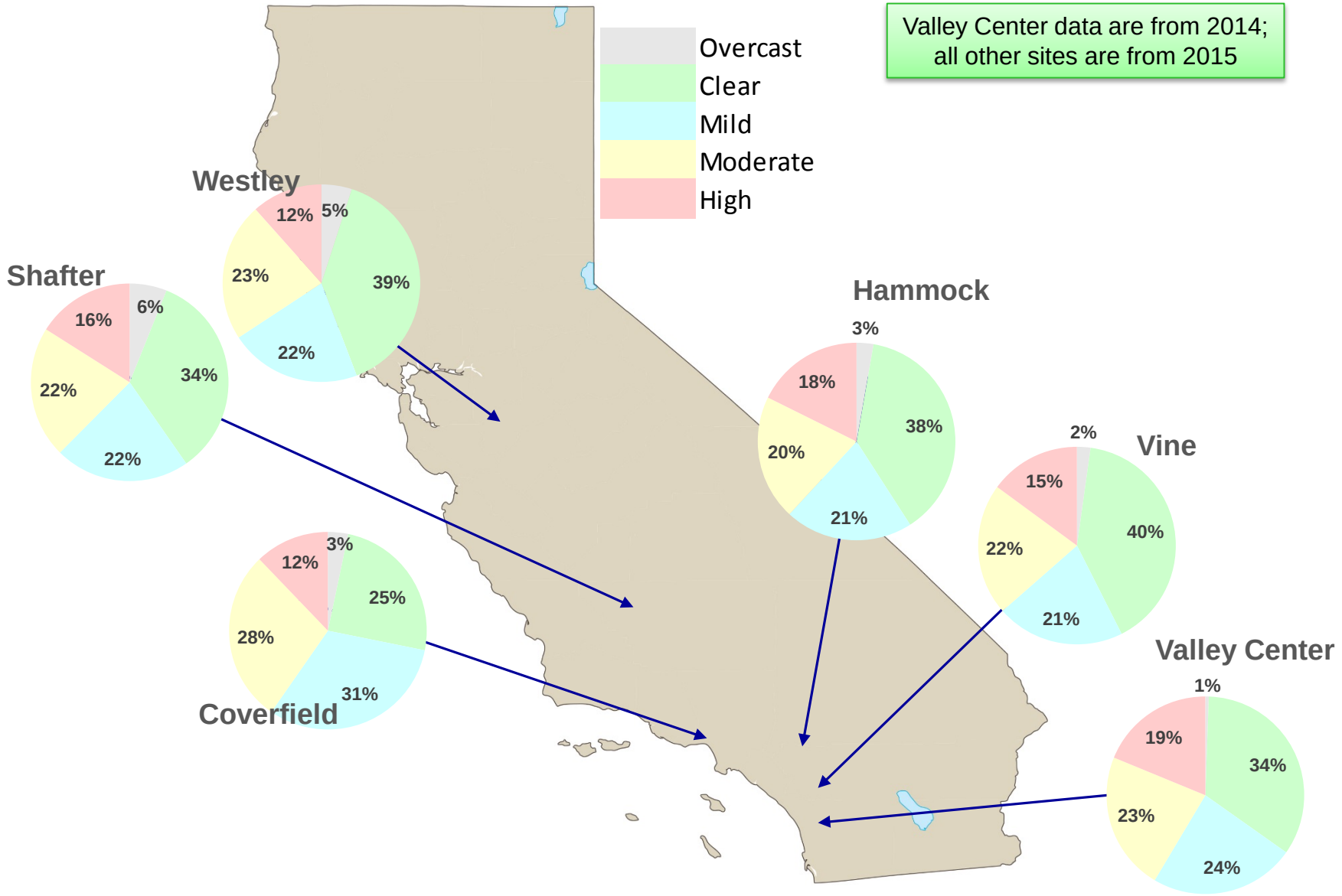
Sandia's variability index (VI), clearness index (CI) to classify days



© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Daily Variability Conditions – Jan. to June



© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Solar Resource Calendar – Westley (January 2015)

Calendar based on irradiance, 1-min averages

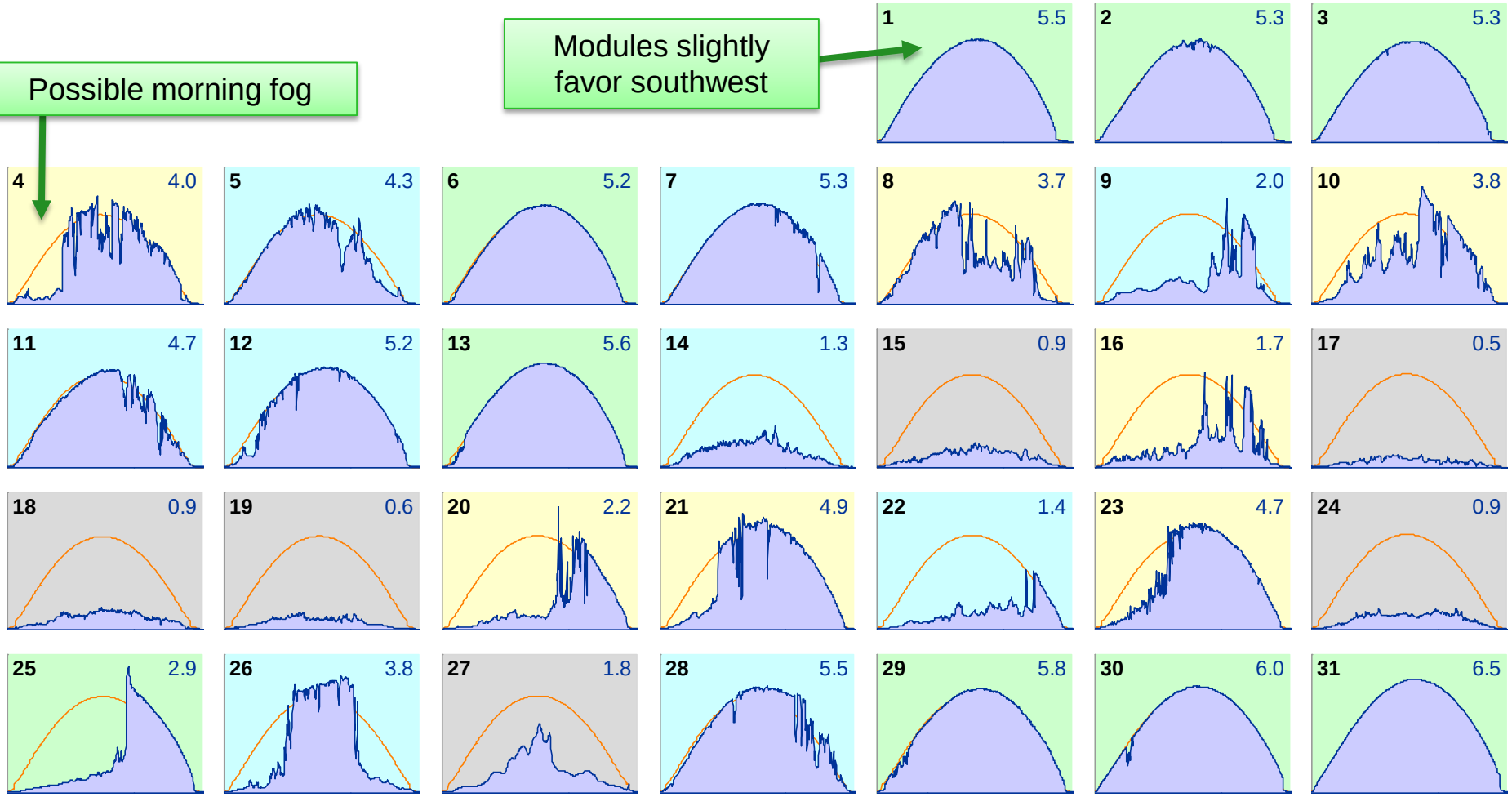
January 2015

Overcast | Clear | Mild | Moderate | High

Sun | Mon | Tue | Wed | Thu | Fri | Sat

Possible morning fog

Modules slightly favor southwest



© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

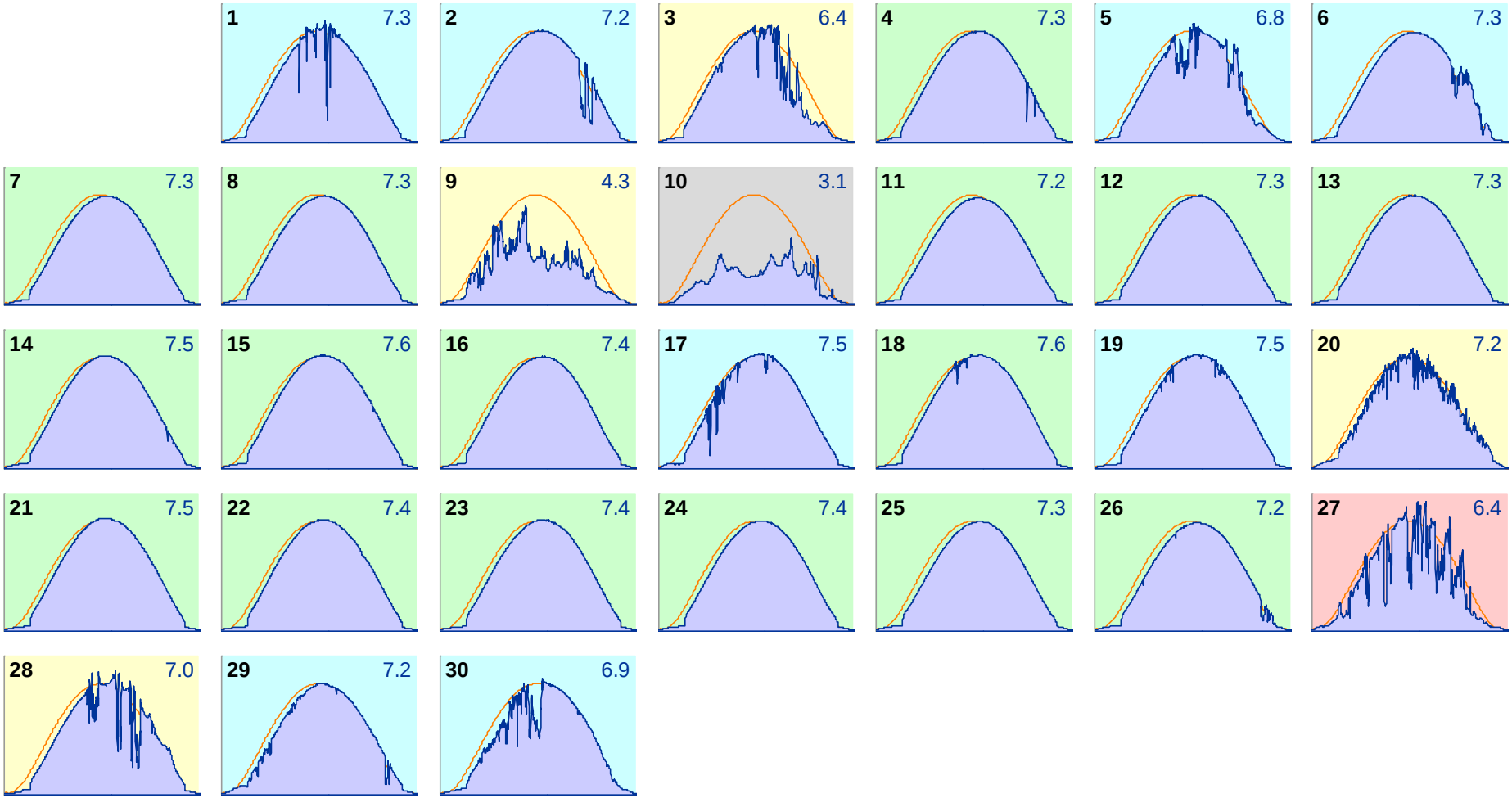
Solar Resource Calendar – Westley (June 2015)

Calendar based on irradiance, 1-min averages

June 2015

Overcast | Clear | Mild | Moderate | High

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1 7.3	2 7.2	3 6.4	4 7.3	5 6.8	6 7.3
7 7.3	8 7.3	9 4.3	10 3.1	11 7.2	12 7.3	13 7.3
14 7.5	15 7.6	16 7.4	17 7.5	18 7.6	19 7.5	20 7.2
21 7.5	22 7.4	23 7.4	24 7.4	25 7.3	26 7.2	27 6.4
28 7.0	29 7.2	30 6.9				



© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

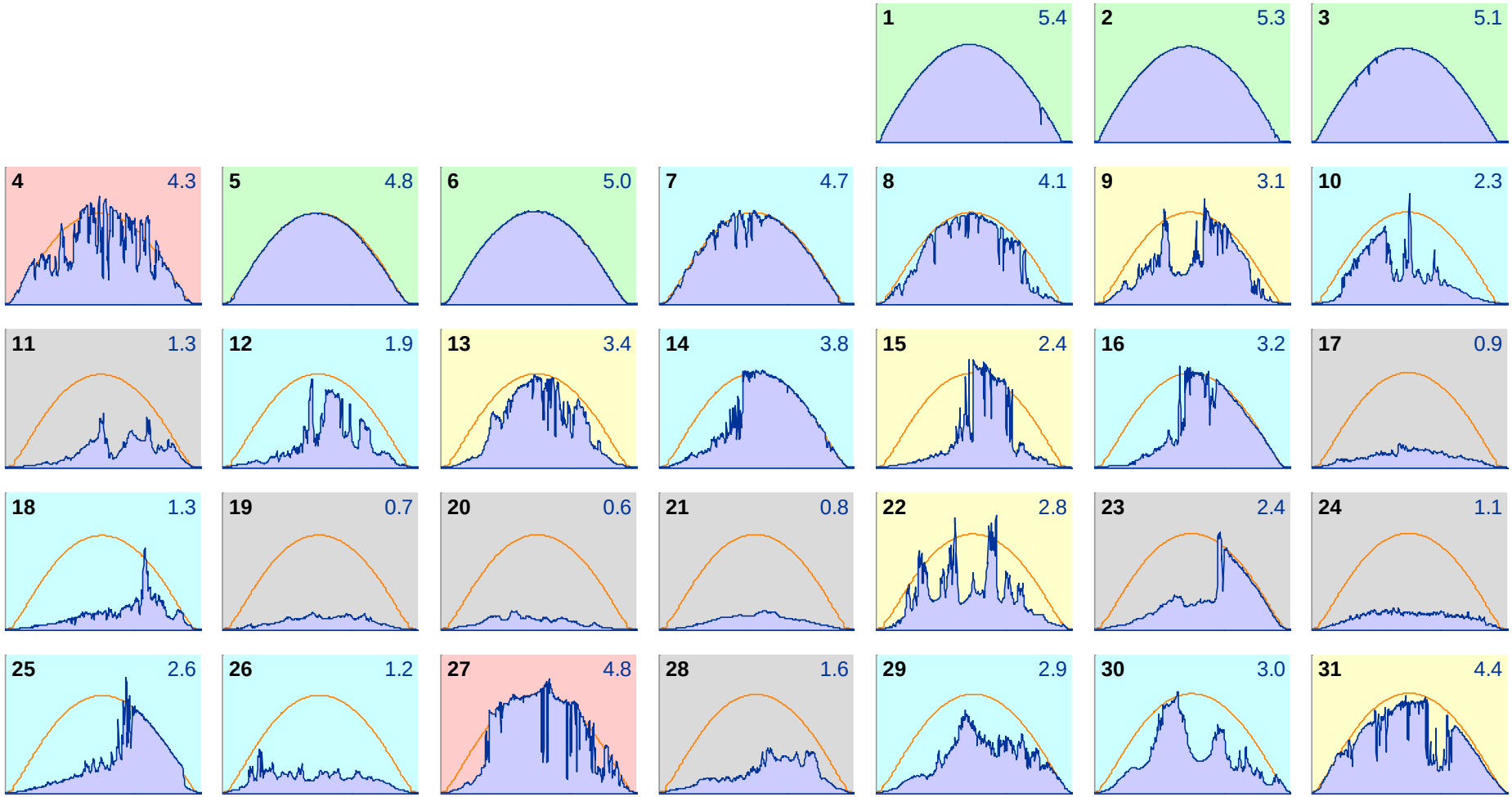
Solar Resource Calendar – Shafter (January 2015)

Calendar based on irradiance, 1-min averages

January 2015

Overcast | Clear | Mild | Moderate | High

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				1 5.4	2 5.3	3 5.1
4 4.3	5 4.8	6 5.0	7 4.7	8 4.1	9 3.1	10 2.3
11 1.3	12 1.9	13 3.4	14 3.8	15 2.4	16 3.2	17 0.9
18 1.3	19 0.7	20 0.6	21 0.8	22 2.8	23 2.4	24 1.1
25 2.6	26 1.2	27 4.8	28 1.6	29 2.9	30 3.0	31 4.4



© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

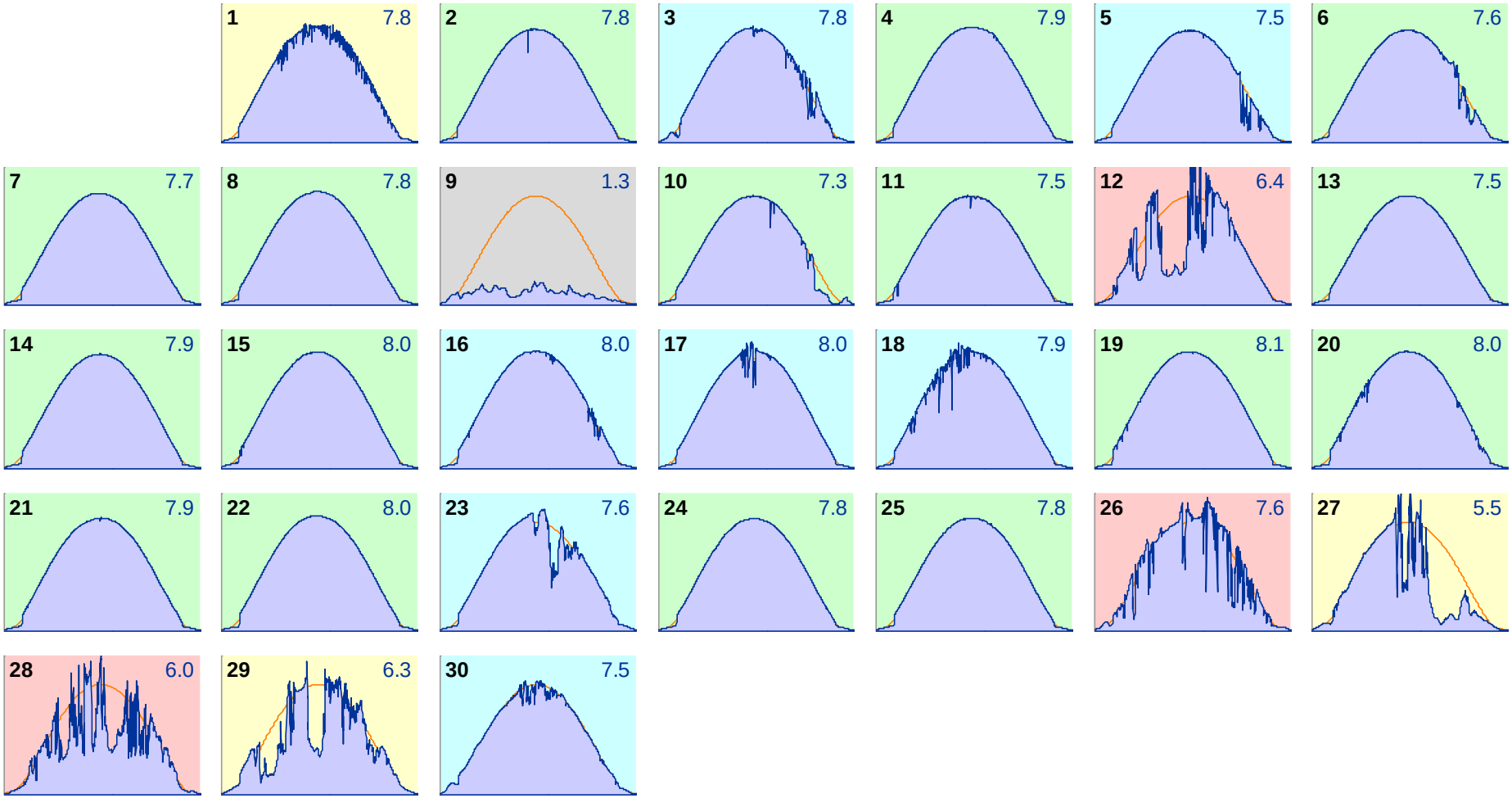
Solar Resource Calendar – Shafter (June 2015)

Calendar based on irradiance, 1-min averages

June 2015

Overcast | Clear | Mild | Moderate | High

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1 7.8	2 7.8	3 7.8	4 7.9	5 7.5	6 7.6
7 7.7	8 7.8	9 1.3	10 7.3	11 7.5	12 6.4	13 7.5
14 7.9	15 8.0	16 8.0	17 8.0	18 7.9	19 8.1	20 8.0
21 7.9	22 8.0	23 7.6	24 7.8	25 7.8	26 7.6	27 5.5
28 6.0	29 6.3	30 7.5				



© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

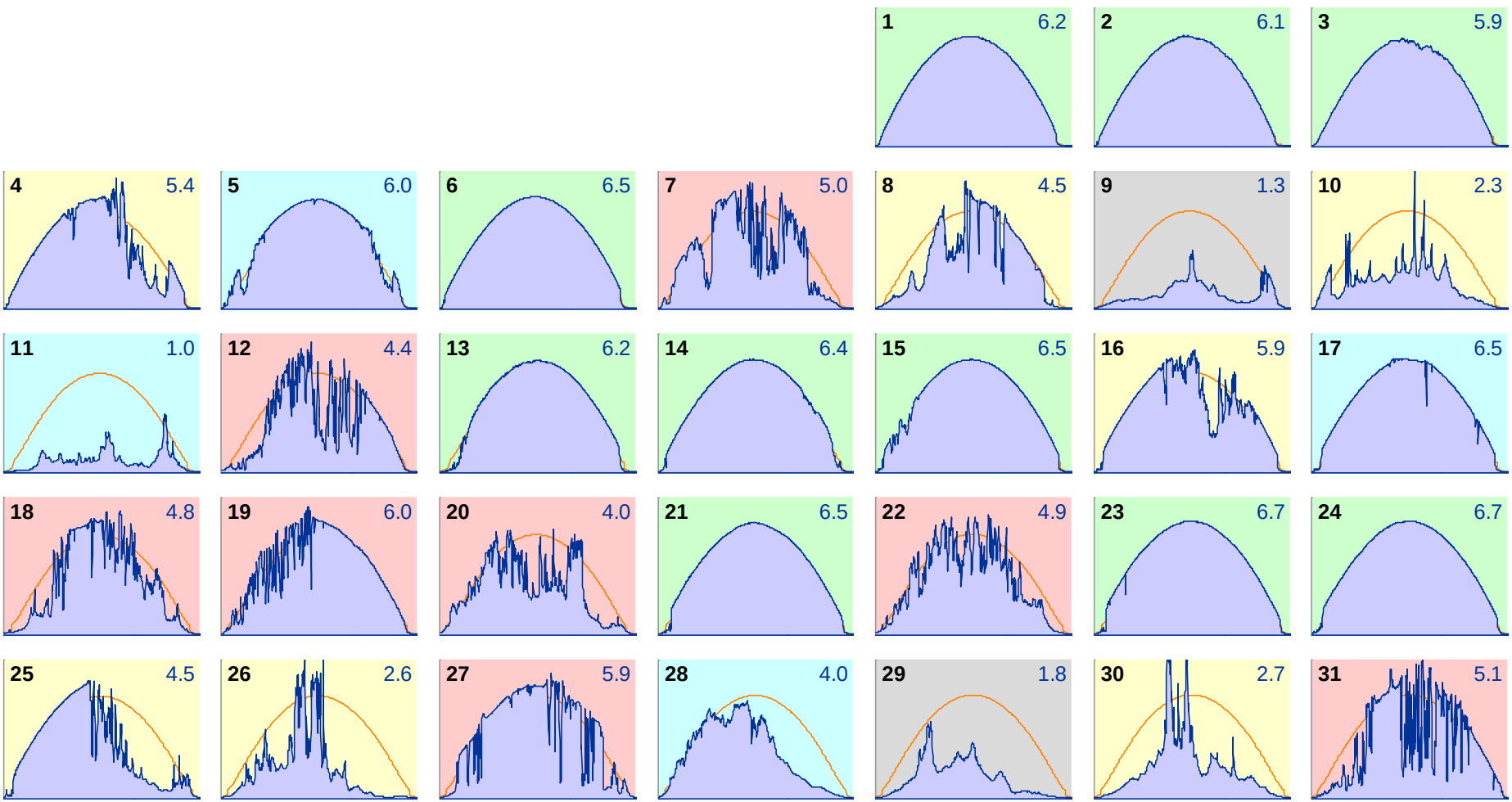
Solar Resource Calendar – Hammock (January 2015)

Calendar based on irradiance, 1-min averages

January 2015

Overcast | Clear | Mild | Moderate | High

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				1 6.2	2 6.1	3 5.9
4 5.4	5 6.0	6 6.5	7 5.0	8 4.5	9 1.3	10 2.3
11 1.0	12 4.4	13 6.2	14 6.4	15 6.5	16 5.9	17 6.5
18 4.8	19 6.0	20 4.0	21 6.5	22 4.9	23 6.7	24 6.7
25 4.5	26 2.6	27 5.9	28 4.0	29 1.8	30 2.7	31 5.1



© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

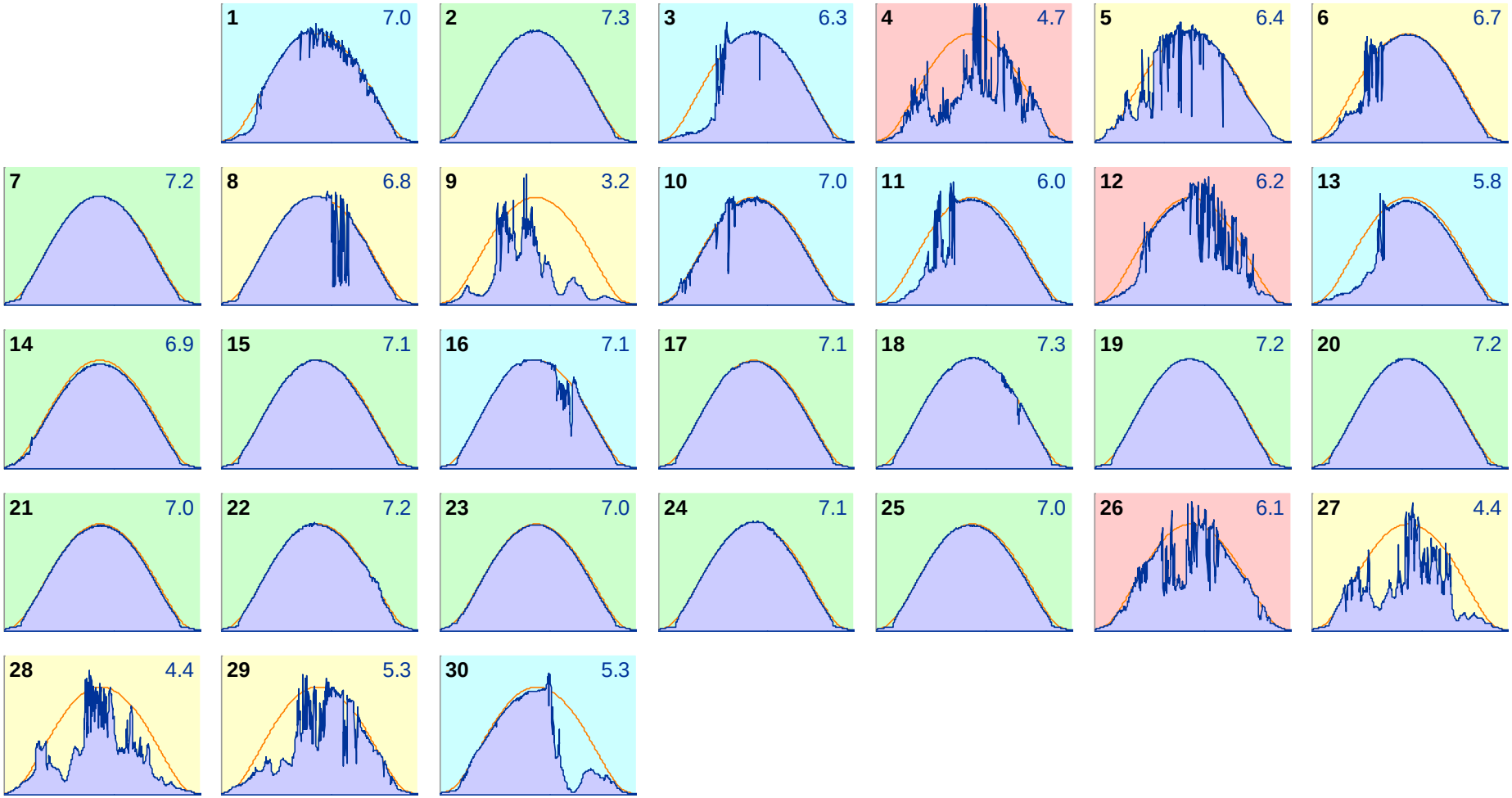
Solar Resource Calendar – Hammock (June 2015)

Calendar based on irradiance, 1-min averages

June 2015

Overcast | Clear | Mild | Moderate | High

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1 7.0	2 7.3	3 6.3	4 4.7	5 6.4	6 6.7
7 7.2	8 6.8	9 3.2	10 7.0	11 6.0	12 6.2	13 5.8
14 6.9	15 7.1	16 7.1	17 7.1	18 7.3	19 7.2	20 7.2
21 7.0	22 7.2	23 7.0	24 7.1	25 7.0	26 6.1	27 4.4
28 4.4	29 5.3	30 5.3				



© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Solar Resource Calendar – Coverfield (January 2015)

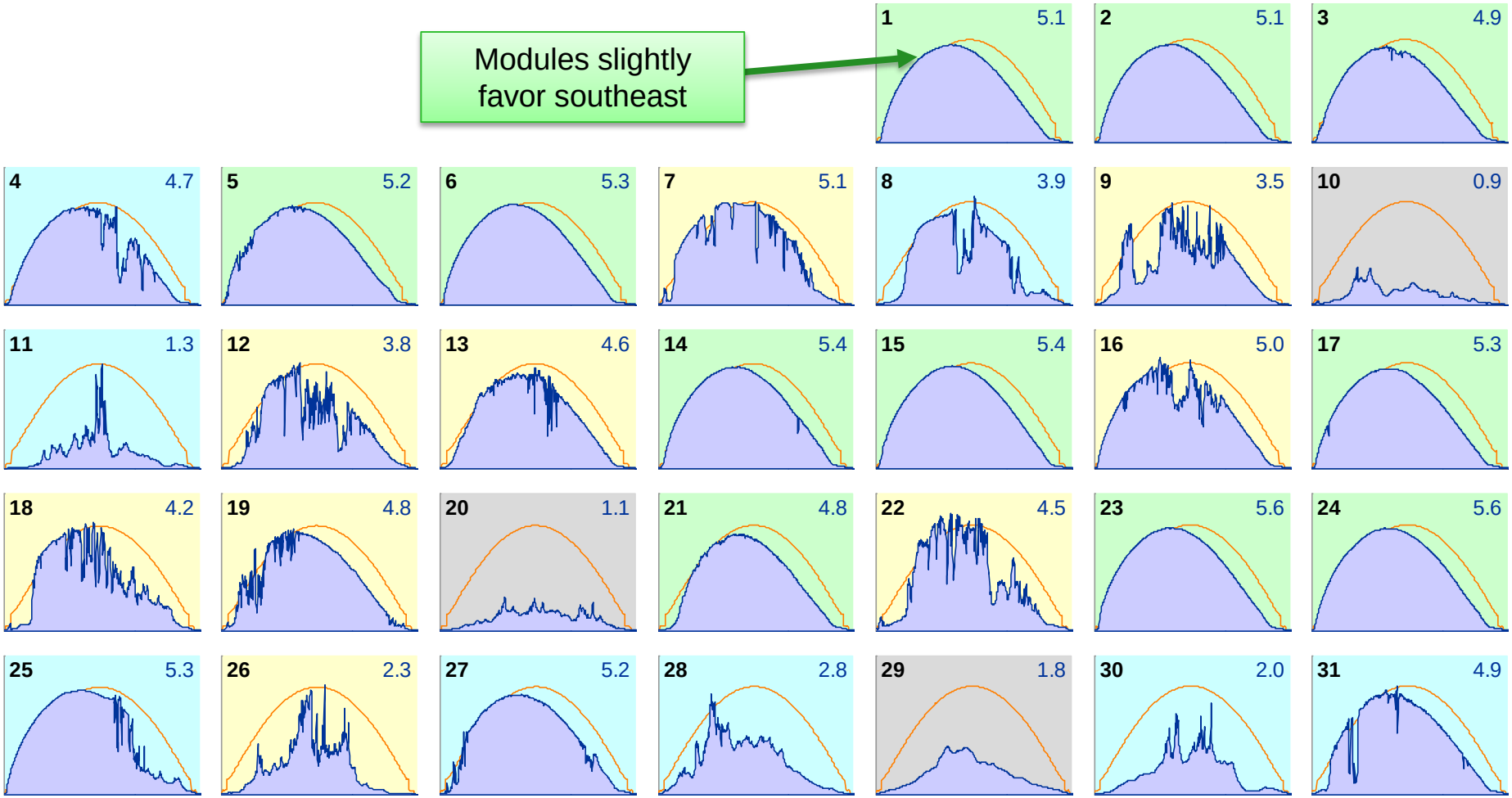
Calendar based on irradiance, 1-min averages

January 2015

Overcast | Clear | Mild | Moderate | High

Sun | Mon | Tue | Wed | Thu | Fri | Sat

Modules slightly favor southeast



© 2015 Electric Power Research Institute, Inc. All rights reserved.

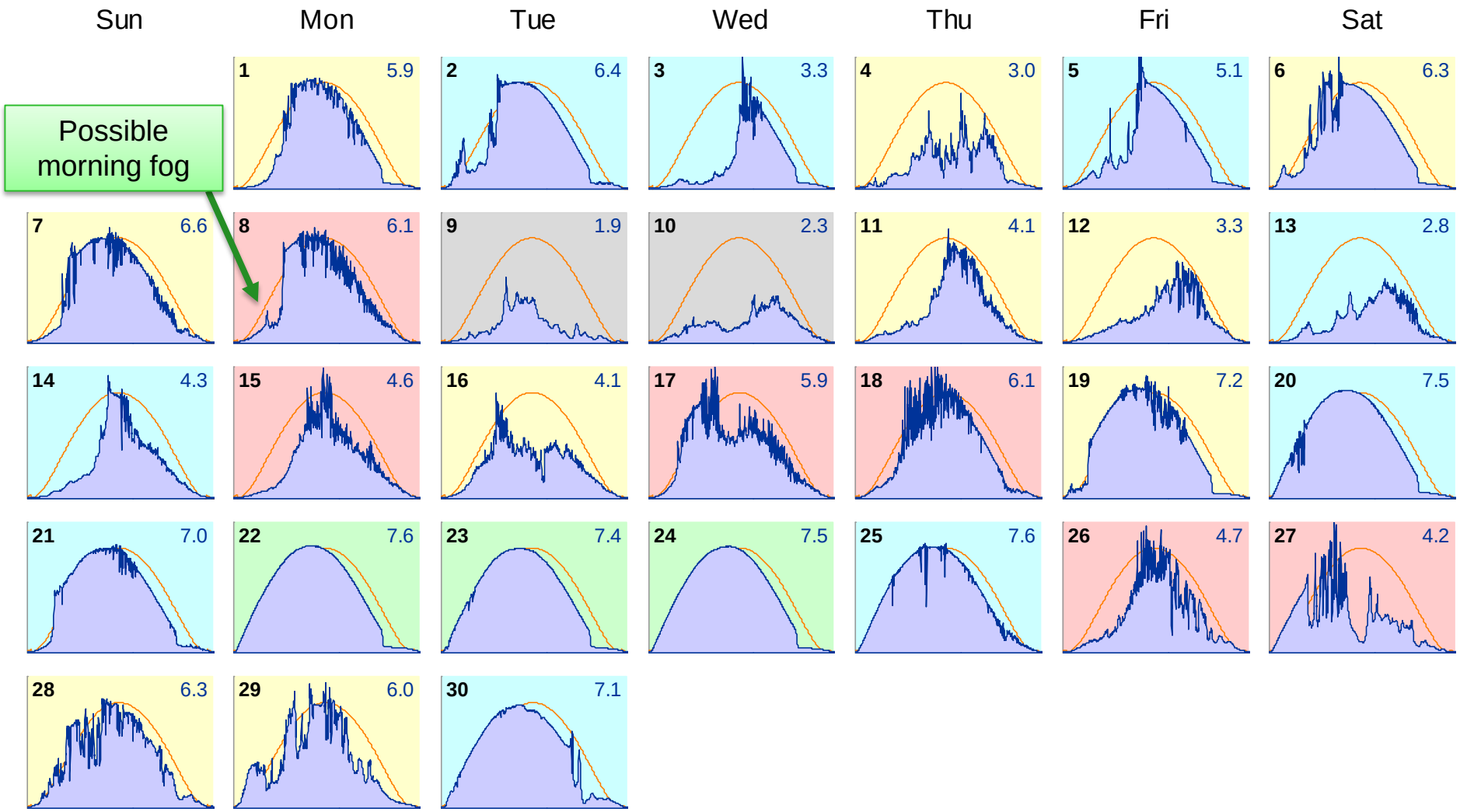
EPRI ELECTRIC POWER RESEARCH INSTITUTE

Solar Resource Calendar – Coverfield (June 2015)

Calendar based on irradiance, 1-min averages

June 2015

Overcast | Clear | Mild | Moderate | High



© 2015 Electric Power Research Institute, Inc. All rights reserved.

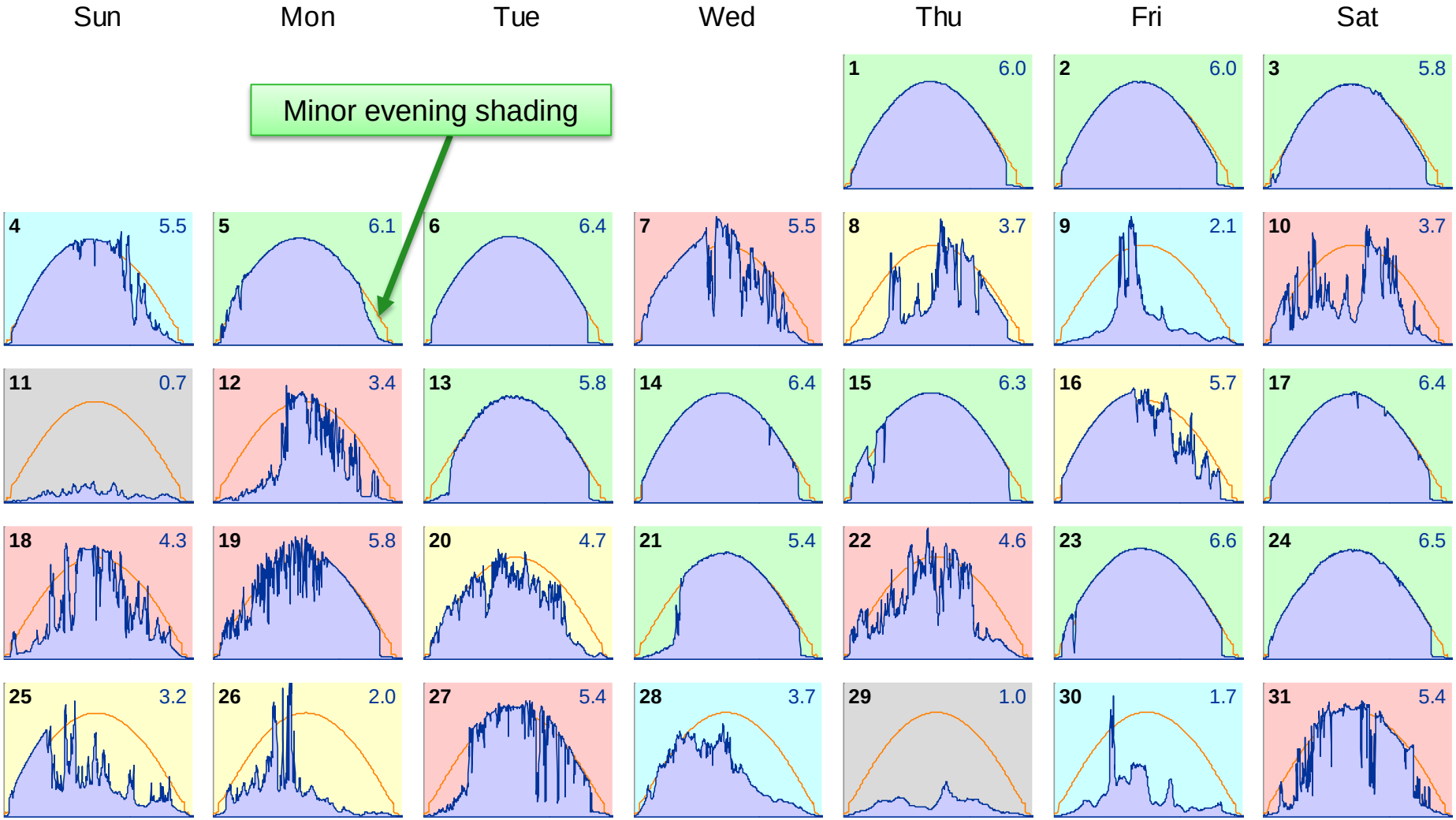
EPRI ELECTRIC POWER RESEARCH INSTITUTE

Solar Resource Calendar – Vine (January 2015)

Calendar based on irradiance, 1-min averages

January 2015

Overcast | Clear | Mild | Moderate | High



© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

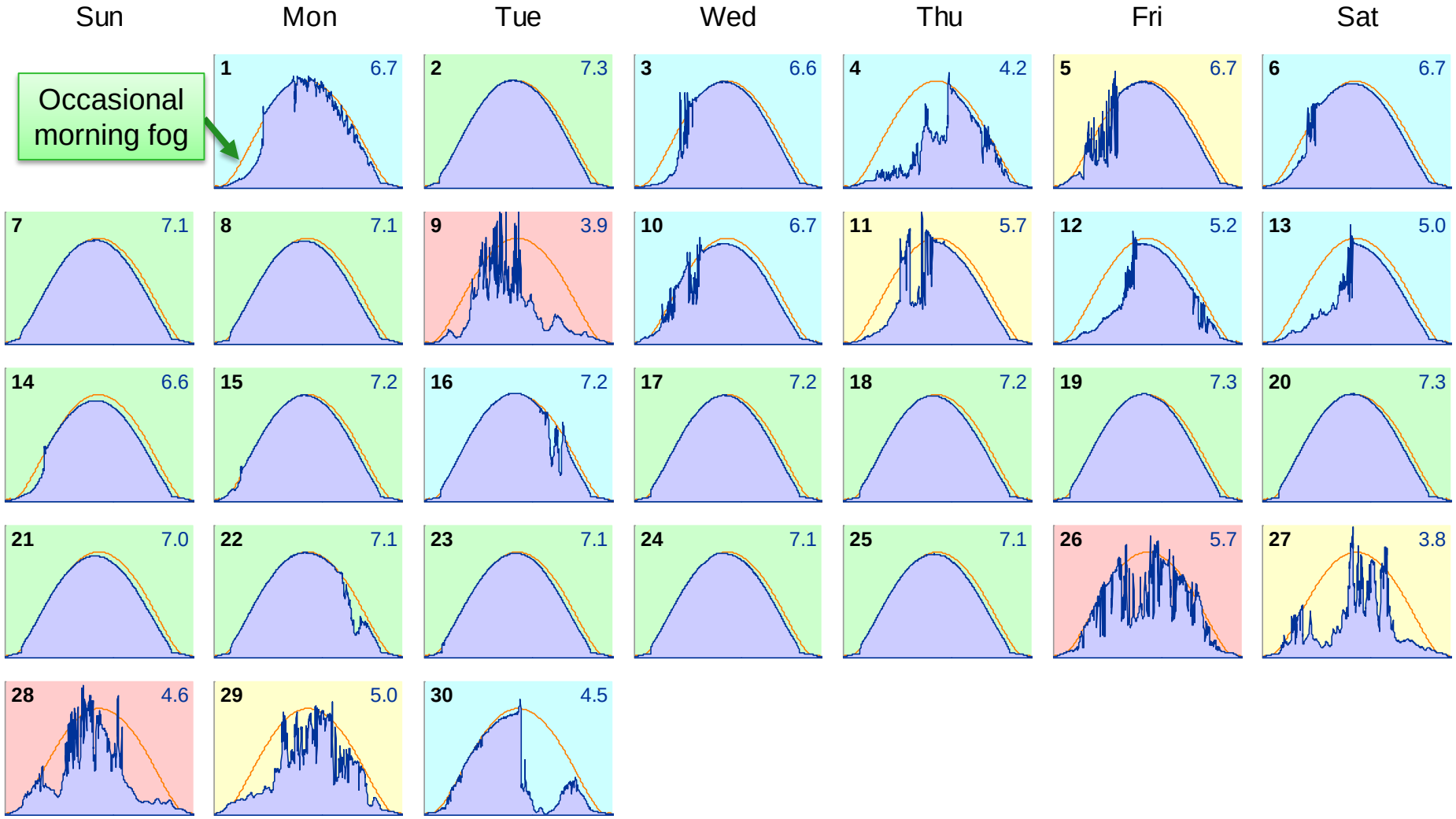
Solar Resource Calendar – Vine (June 2015)

Calendar based on irradiance, 1-min averages

June 2015

Overcast | Clear | Mild | Moderate | High

Occasional morning fog



© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Solar Resource Calendar – Fallbrook (January 2014)

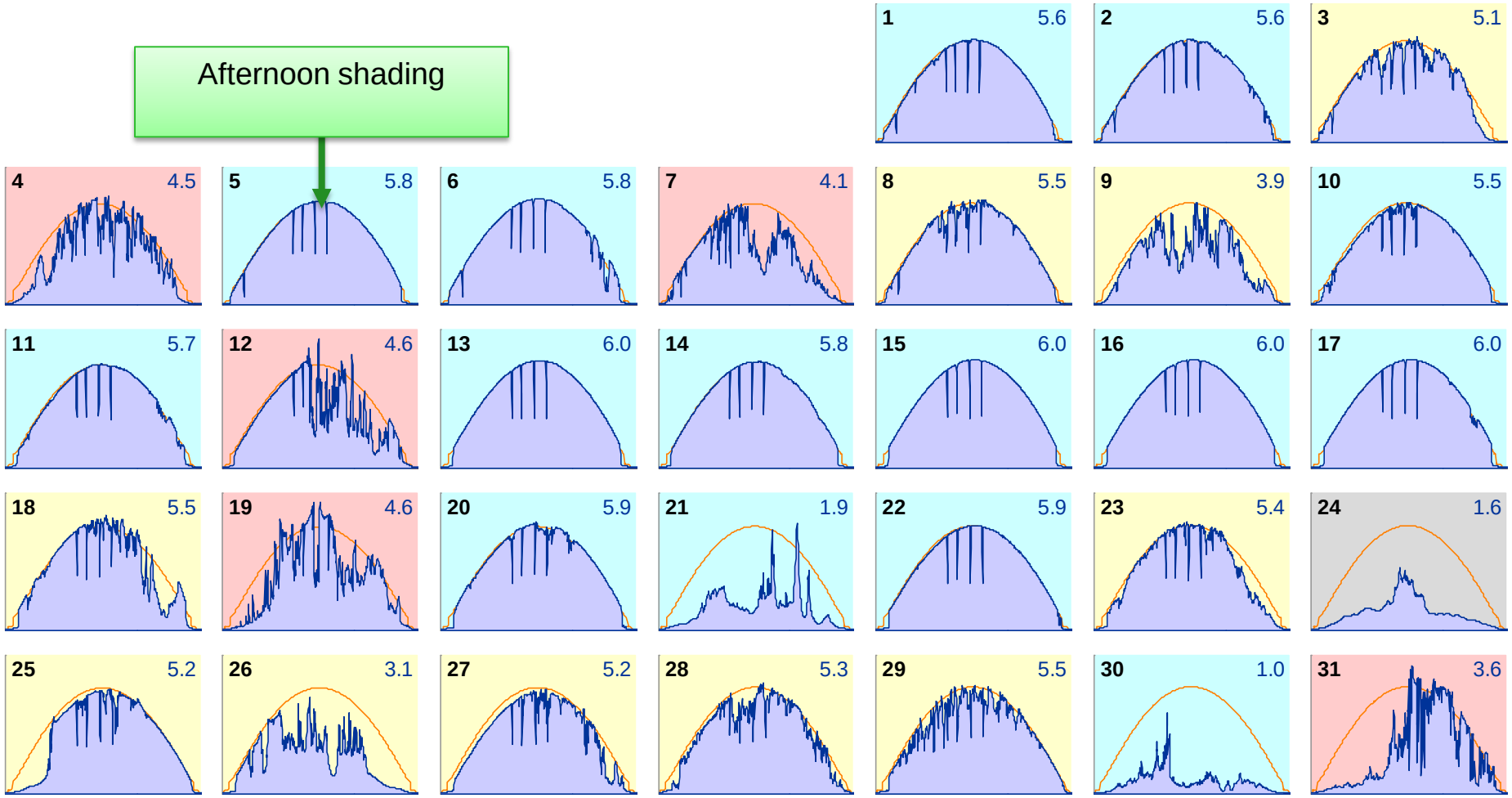
Calendar based on irradiance, 1-min averages

January *

Overcast | Clear | Mild | Moderate | High

* 2014 data used as proxy for 2015 calendar

Afternoon shading



© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

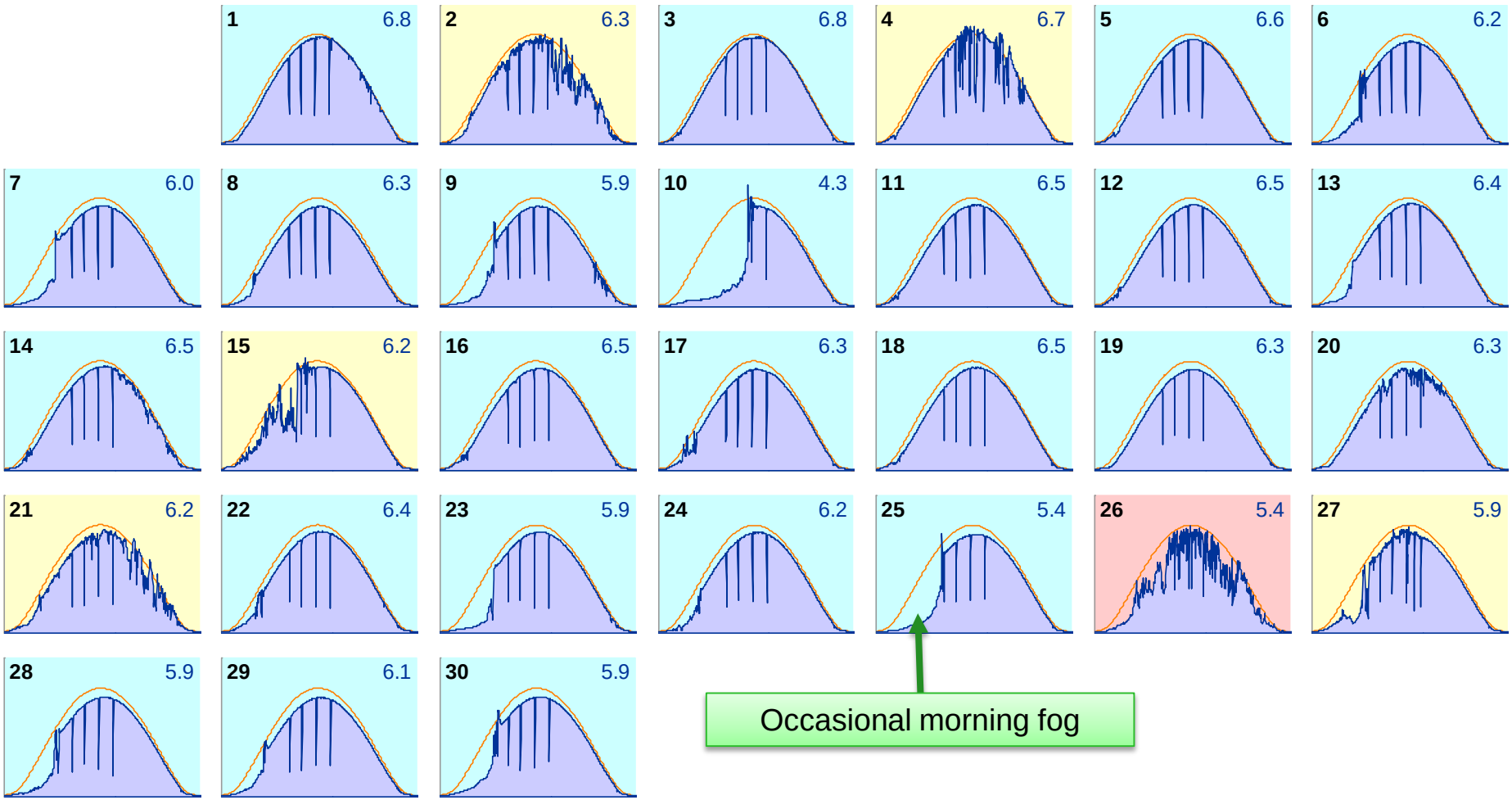
Solar Resource Calendar – Fallbrook (June 2014)

Calendar based on irradiance, 1-min averages

June *

Overcast | Clear | Mild | Moderate | High

* 2014 data used as proxy for 2015 calendar



Occasional morning fog

© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Solar Resource Calendar – Valley Center (January 2014)

Calendar based on irradiance, 1-min averages

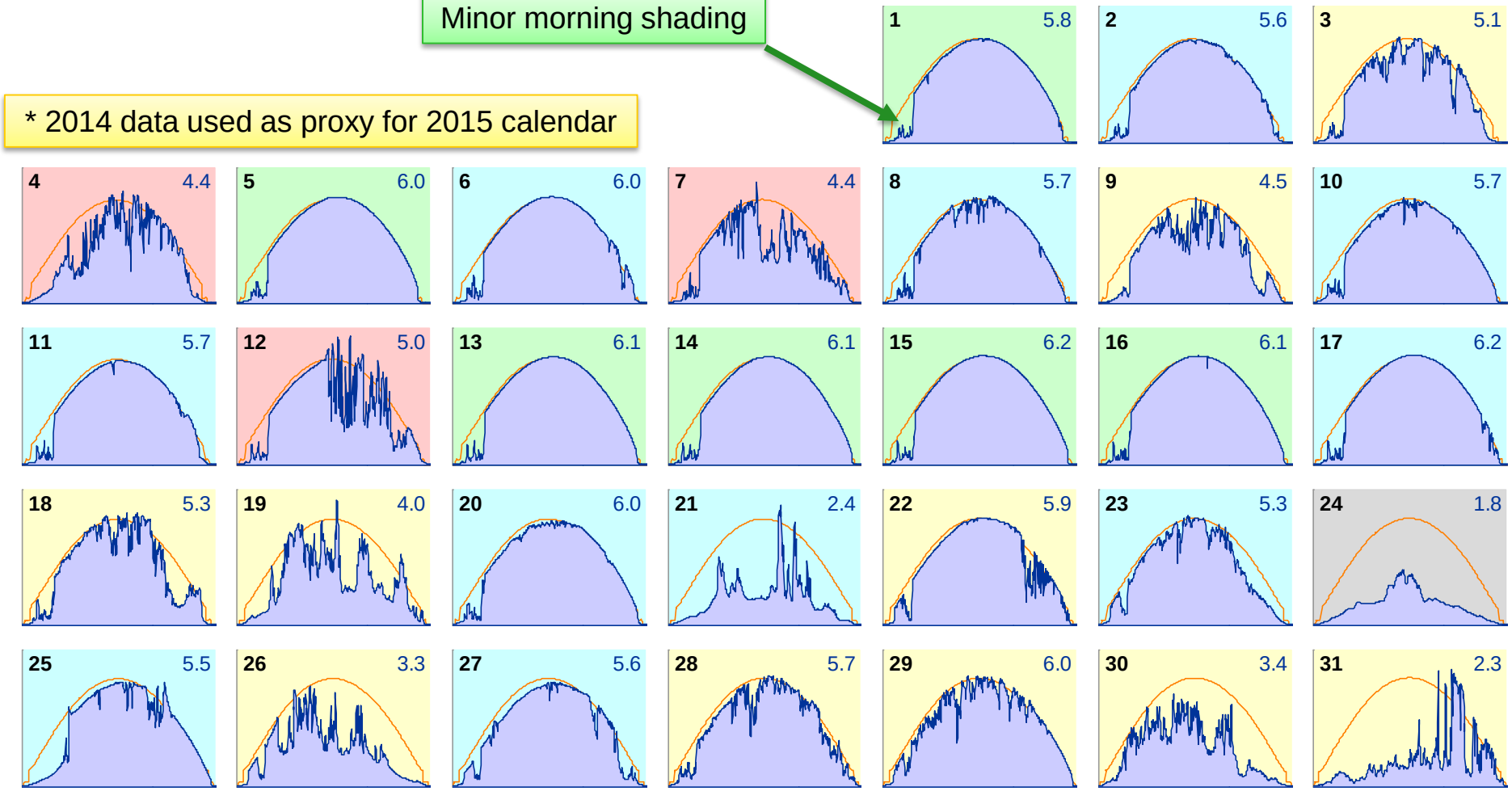
January *

Overcast | Clear | Mild | Moderate | High

Sun | Mon | Tue | Wed | Thu | Fri | Sat

Minor morning shading

* 2014 data used as proxy for 2015 calendar



© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

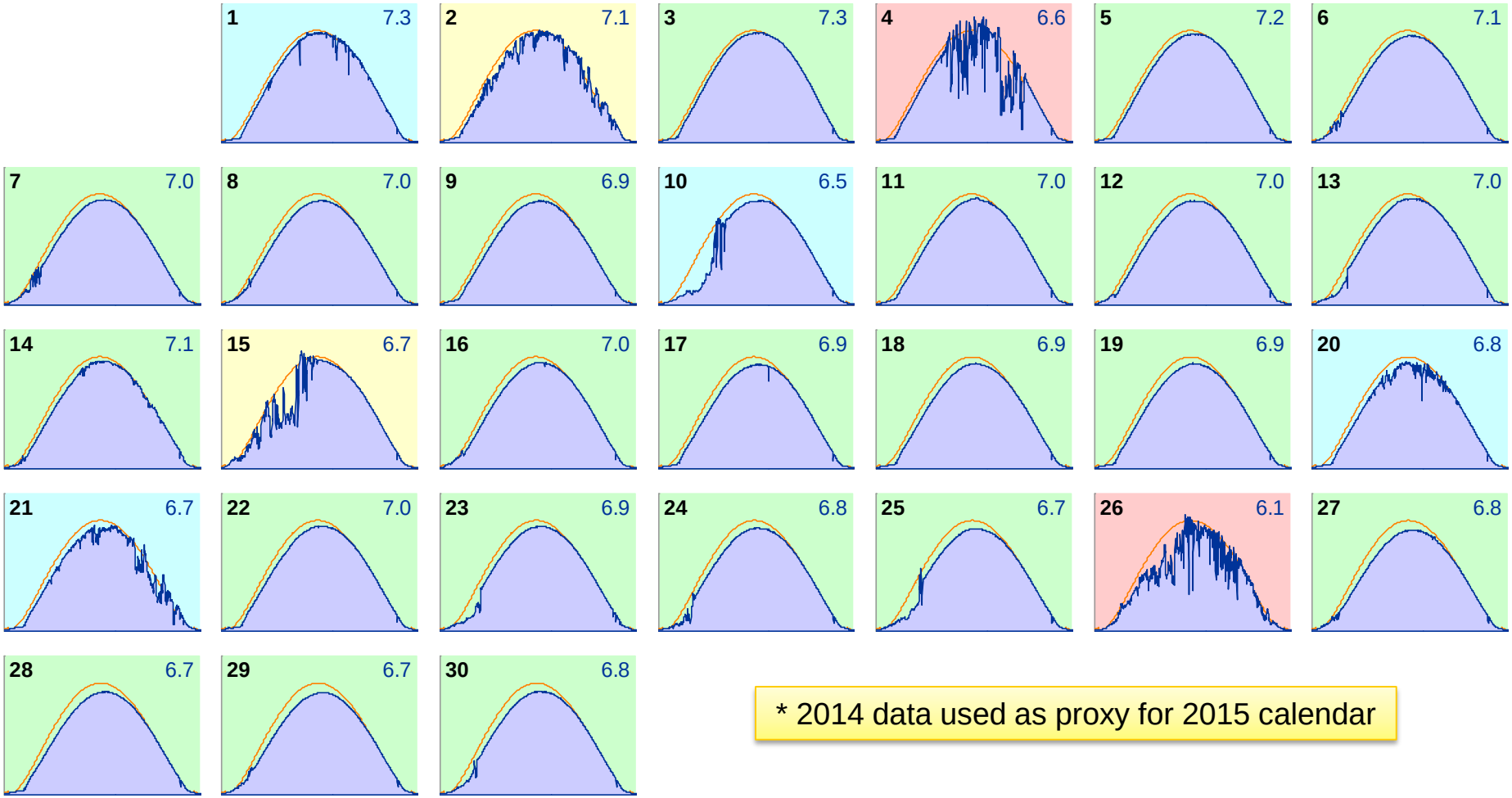
Solar Resource Calendar – Valley Center (June 2014)

Calendar based on irradiance, 1-min averages

June *

Overcast | Clear | Mild | Moderate | High

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1 7.3	2 7.1	3 7.3	4 6.6	5 7.2	6 7.1
7 7.0	8 7.0	9 6.9	10 6.5	11 7.0	12 7.0	13 7.0
14 7.1	15 6.7	16 7.0	17 6.9	18 6.9	19 6.9	20 6.8
21 6.7	22 7.0	23 6.9	24 6.8	25 6.7	26 6.1	27 6.8
28 6.7	29 6.7	30 6.8				



* 2014 data used as proxy for 2015 calendar

© 2015 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

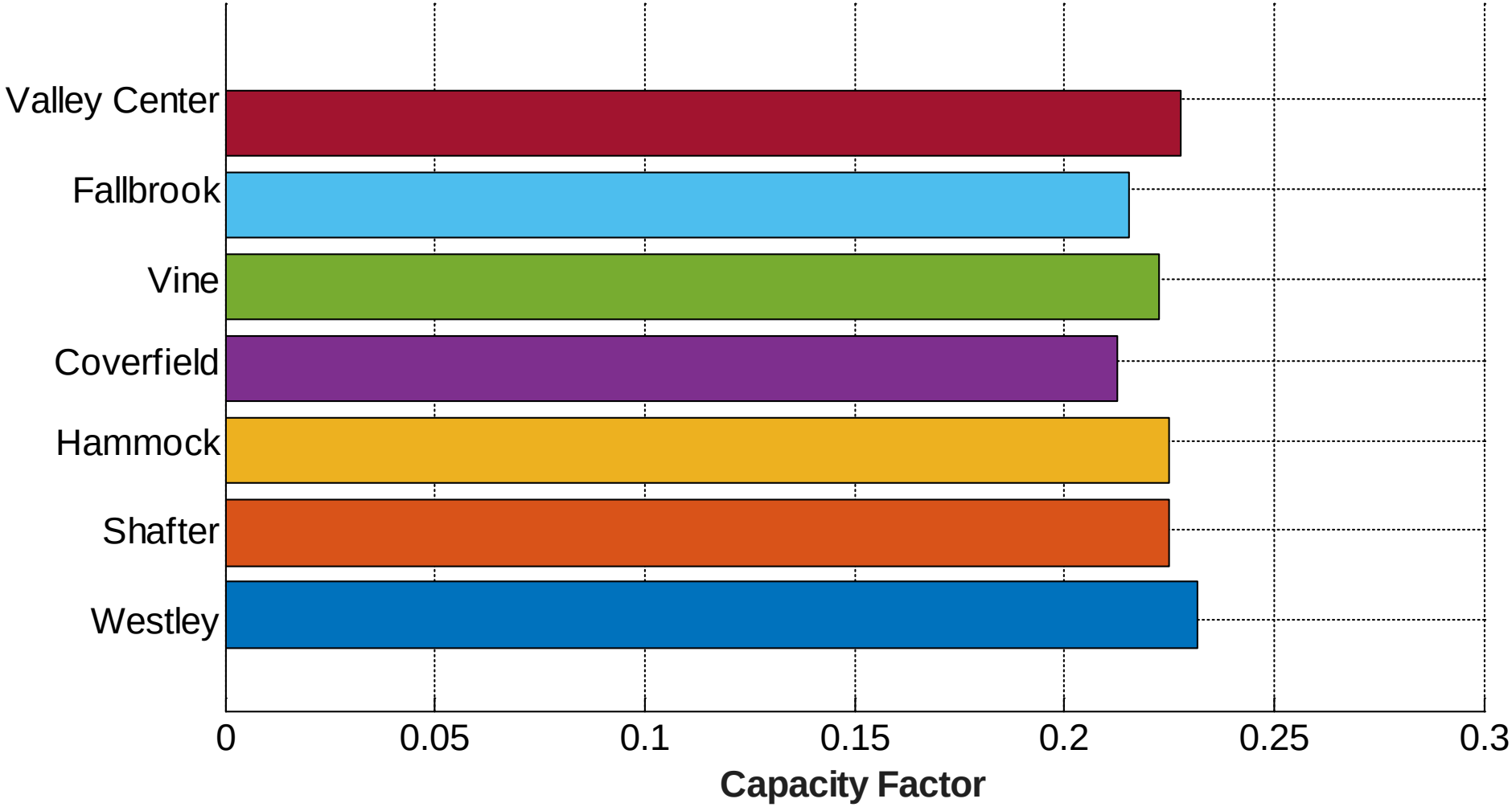
Energy-Based Performance

California Solar Initiative
Screening Distribution Feeders: Alternatives to the 15% Rule
Task 4: Collect High-Resolution PV Data

© 2015 Electric Power Research Institute, Inc. All rights reserved.

Capacity Factor – Jan. to June

Fallbrook and Valley Center data are from 2014; all other sites are from 2015

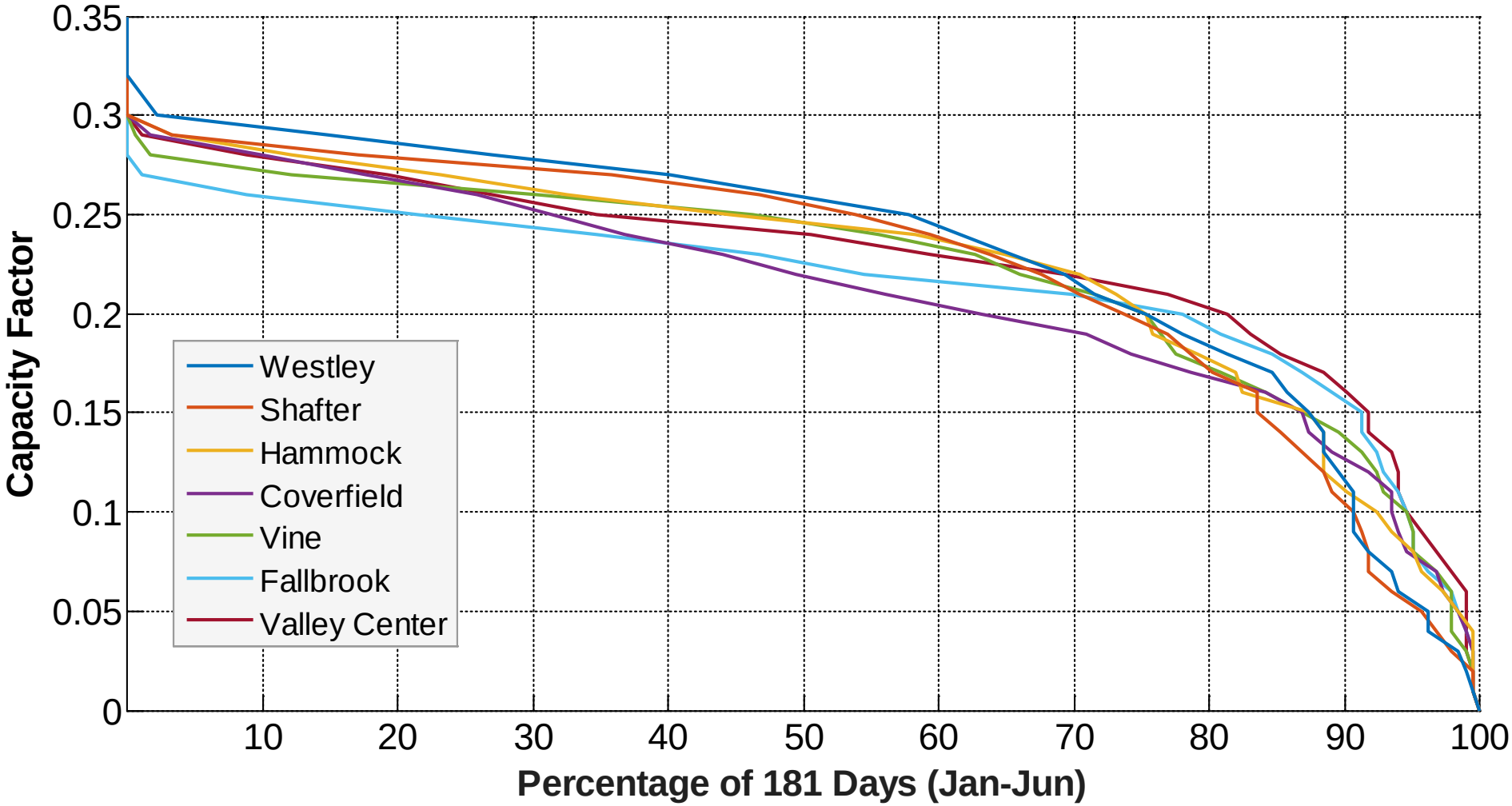


© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Capacity Factor Duration – Jan. to June

Fallbrook and Valley Center data are from 2014; all other sites are from 2015

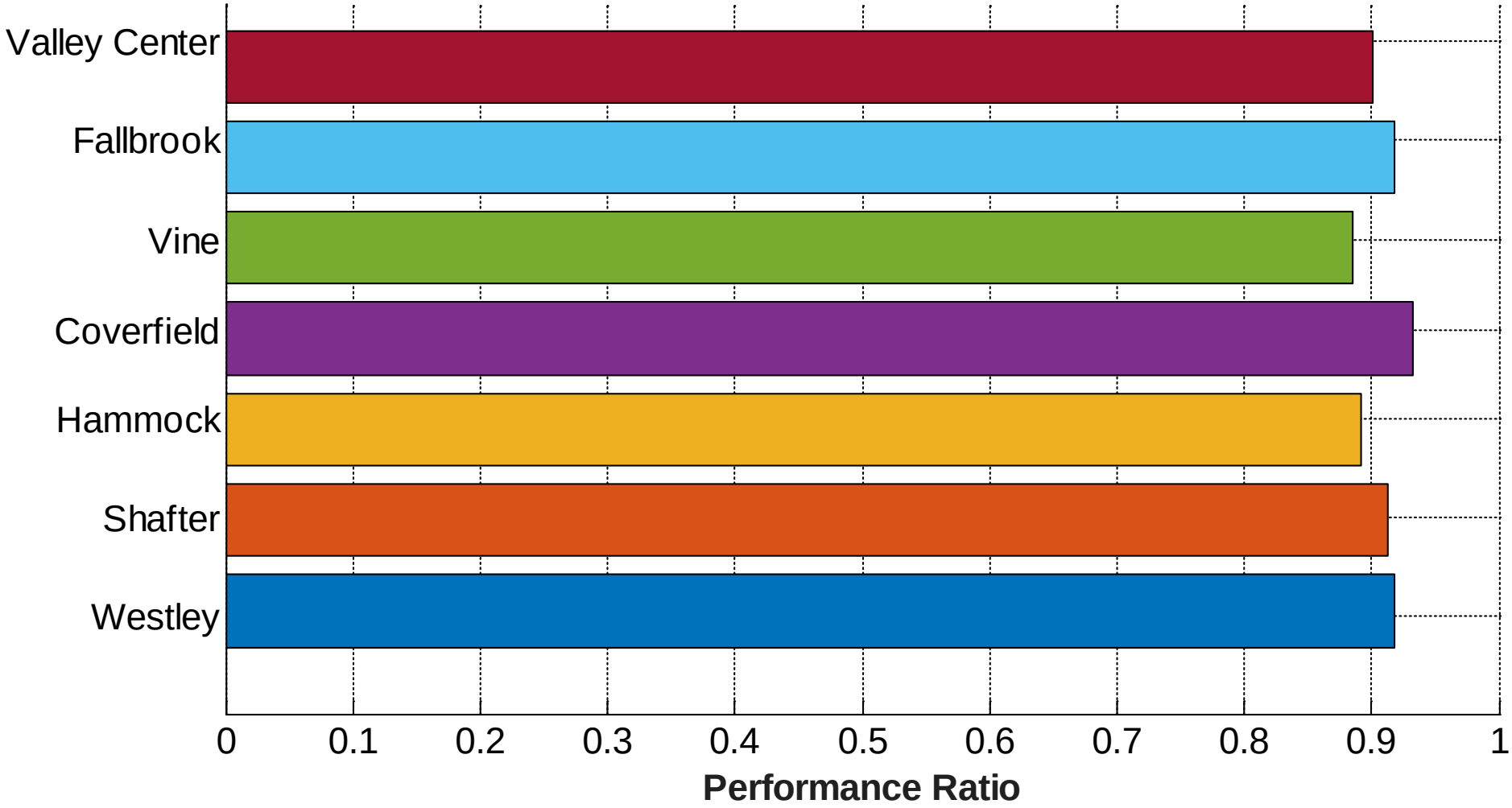


© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Performance Ratio – Jan. to June

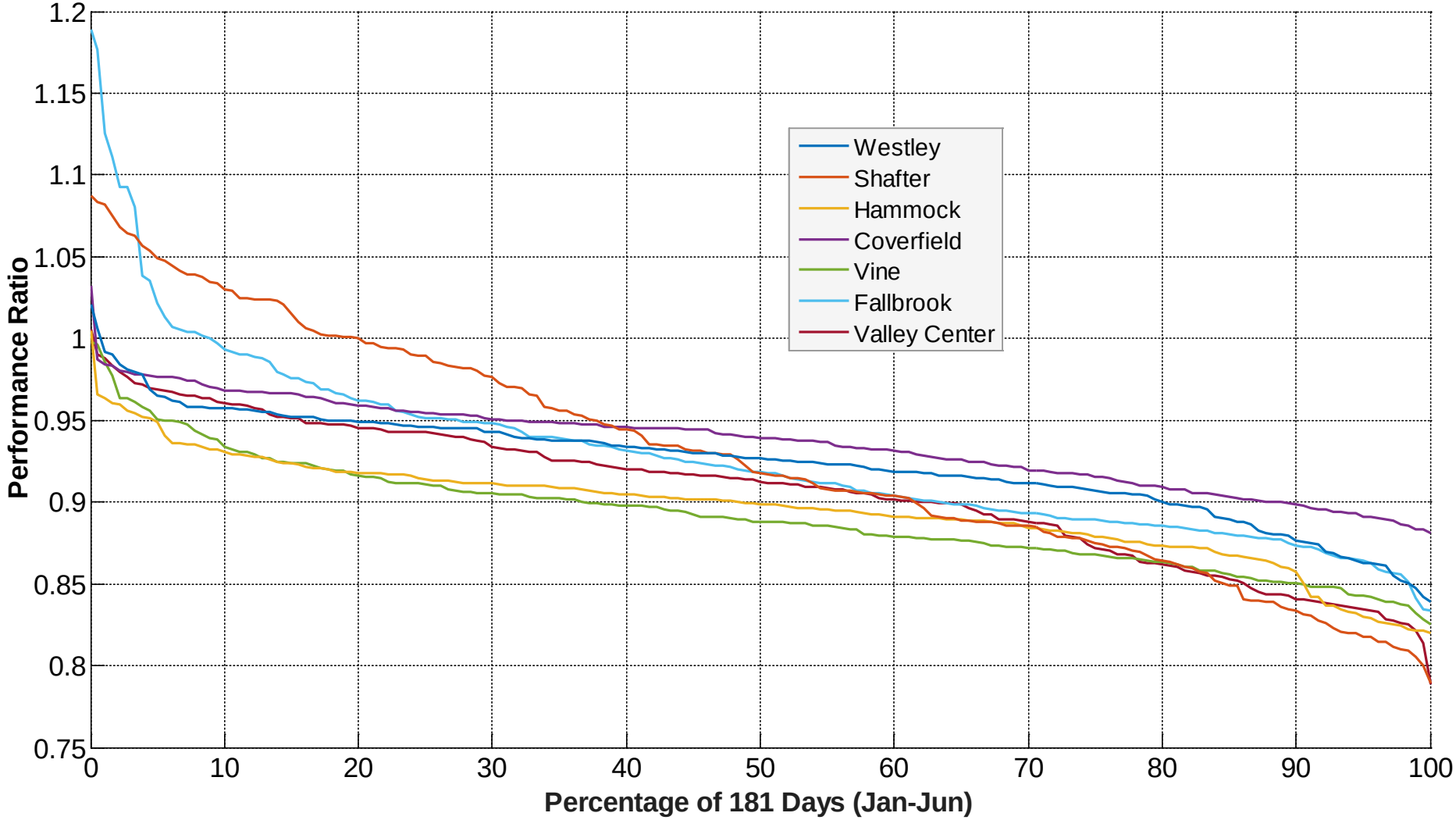
Fallbrook and Valley Center data are from 2014; all other sites are from 2015



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Performance Ratio Duration – Jan. to June

Fallbrook and Valley Center data are from 2014; all other sites are from 2015



© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

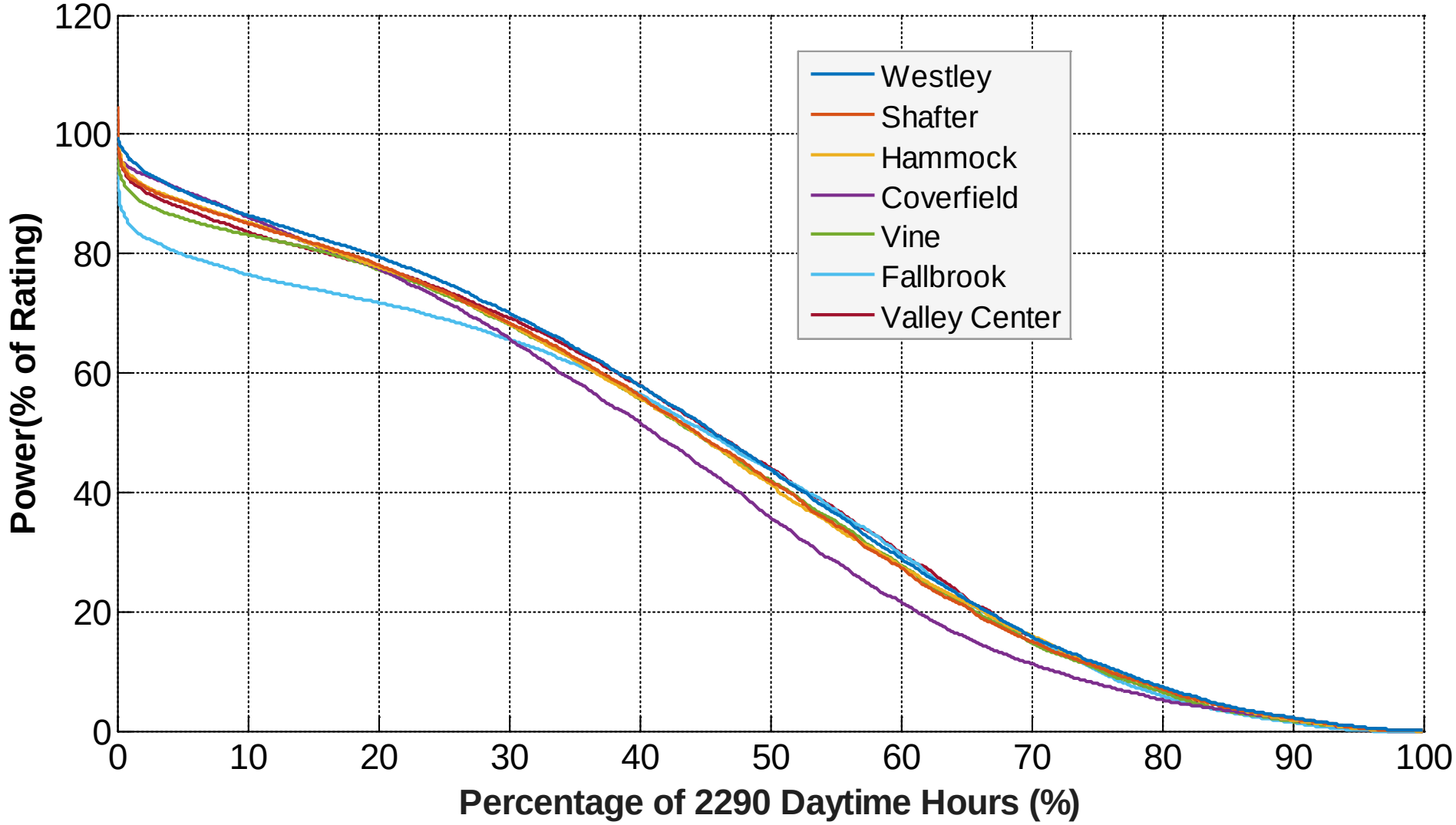
Power Output Characteristics

California Solar Initiative
Screening Distribution Feeders: Alternatives to the 15% Rule
Task 4: Collect High-Resolution PV Data

© 2015 Electric Power Research Institute, Inc. All rights reserved.

Power Duration Curve – Jan. to June

Fallbrook and Valley Center data are from 2014; all other sites are from 2015

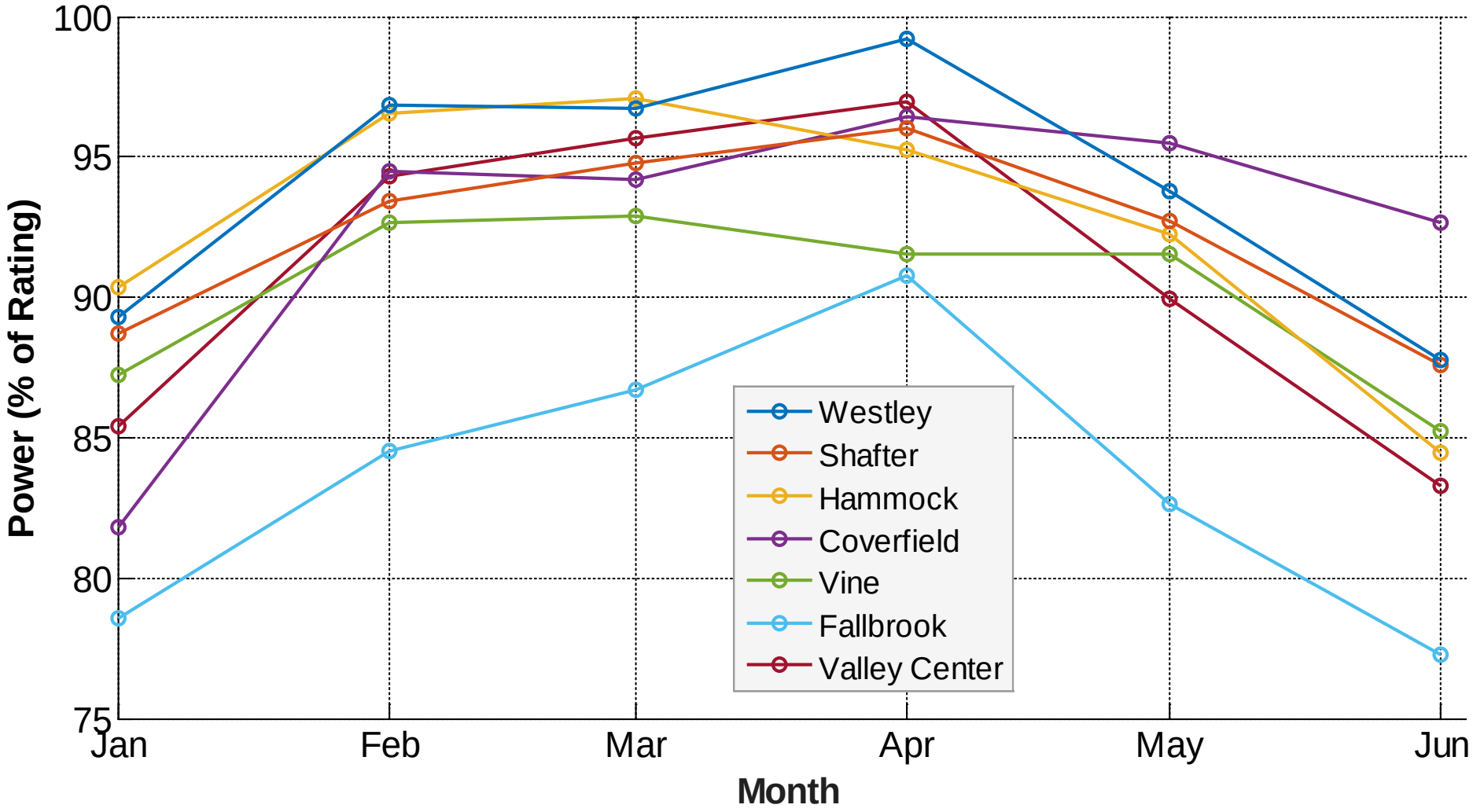


© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Monthly Near-Maximum Powers – Jan. to June

Fallbrook and Valley Center data are from 2014; all other sites are from 2015



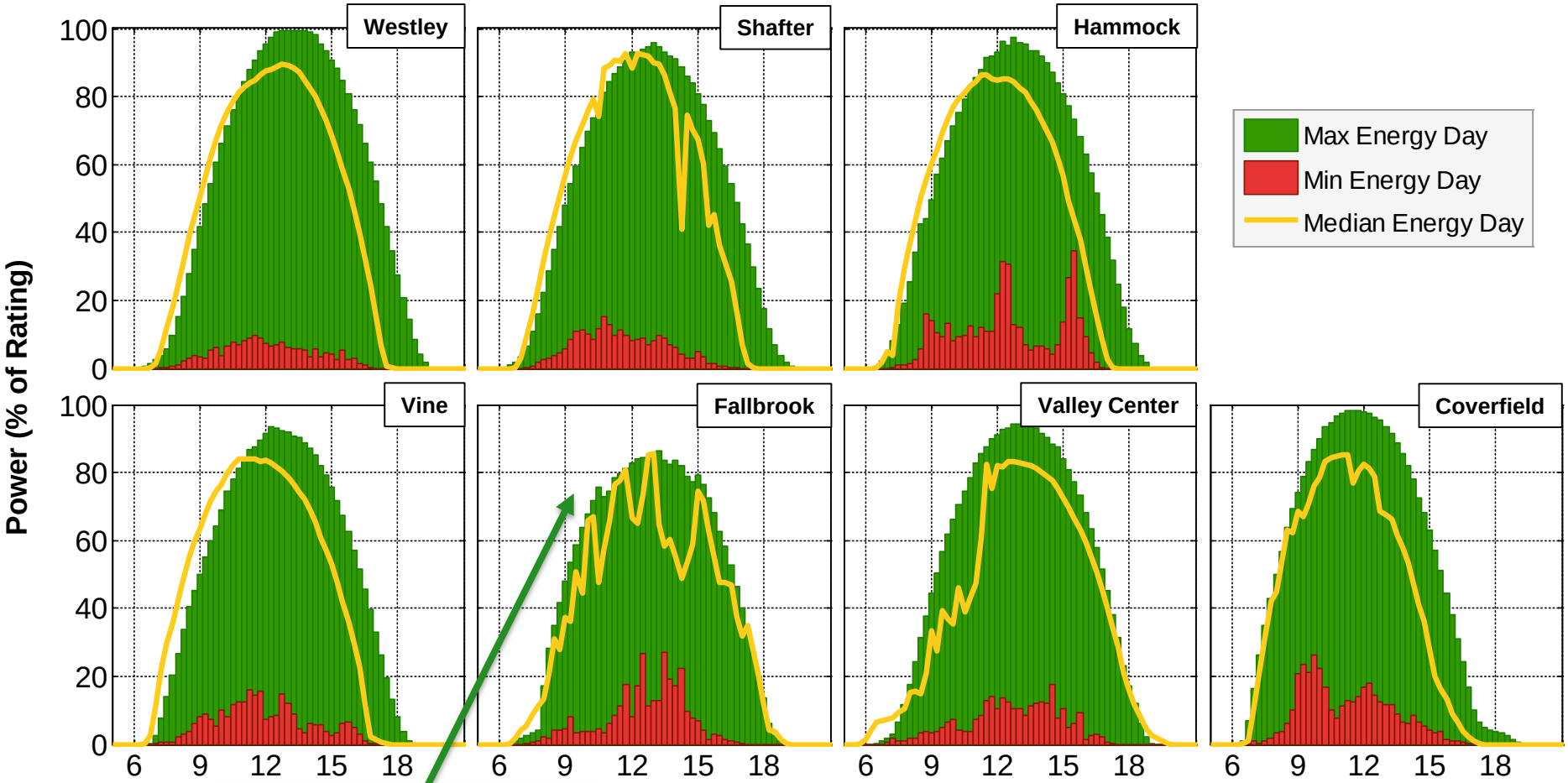
© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Sample Power Output Profiles – Jan. to June

15-minute averages

Fallbrook and Valley Center data are from 2014; all other sites are from 2015



Low max energy caused by line shading

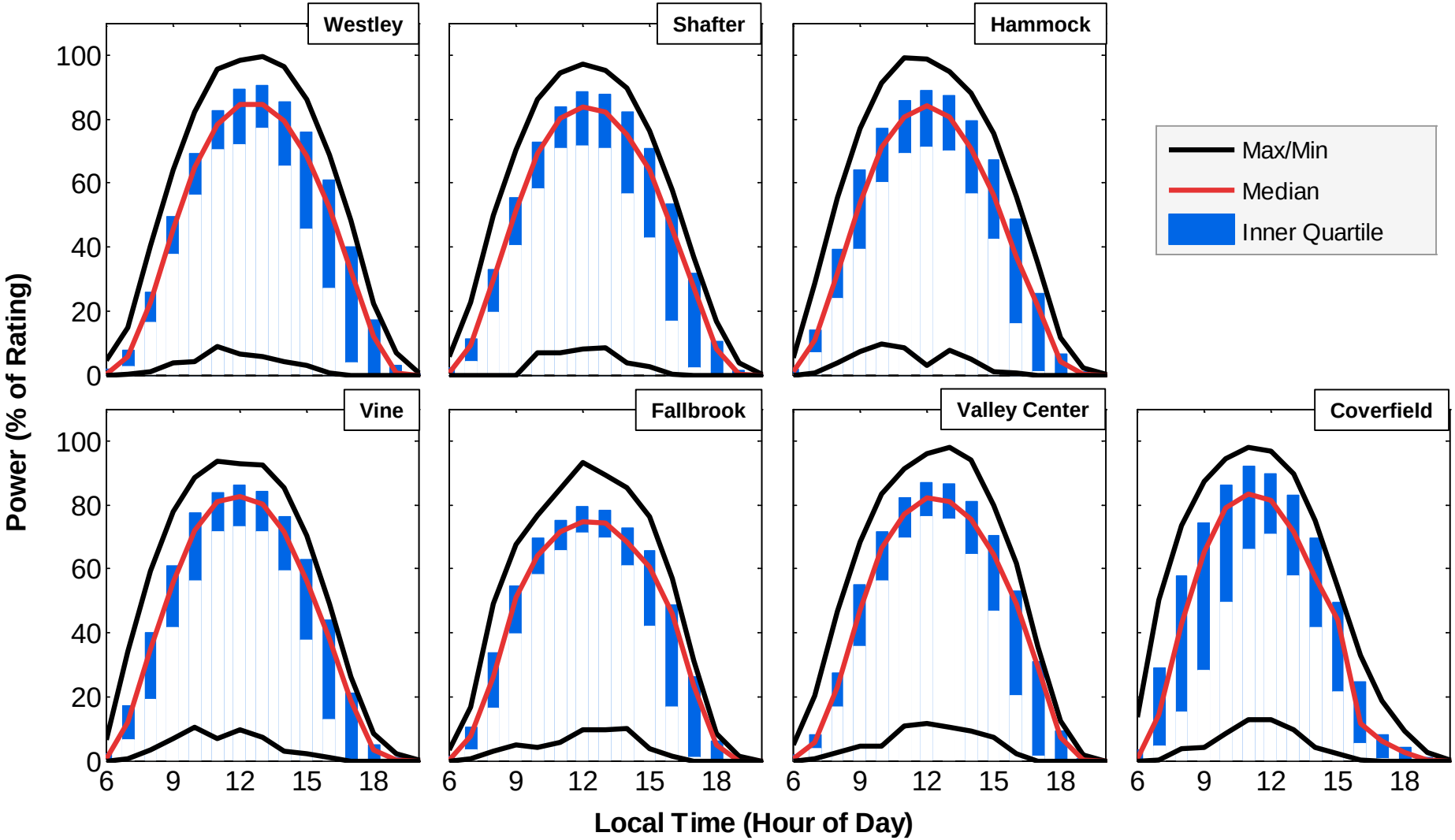
© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Statistical Distribution of Power – Jan. to June

1-Hour Averages

Fallbrook and Valley Center data are from 2014; all other sites are from 2015



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Variability: Establishing Ramp-Rate Datasets

California Solar Initiative
Screening Distribution Feeders: Alternatives to the 15% Rule
Task 4: Collect High-Resolution PV Data

© 2015 Electric Power Research Institute, Inc. All rights reserved.

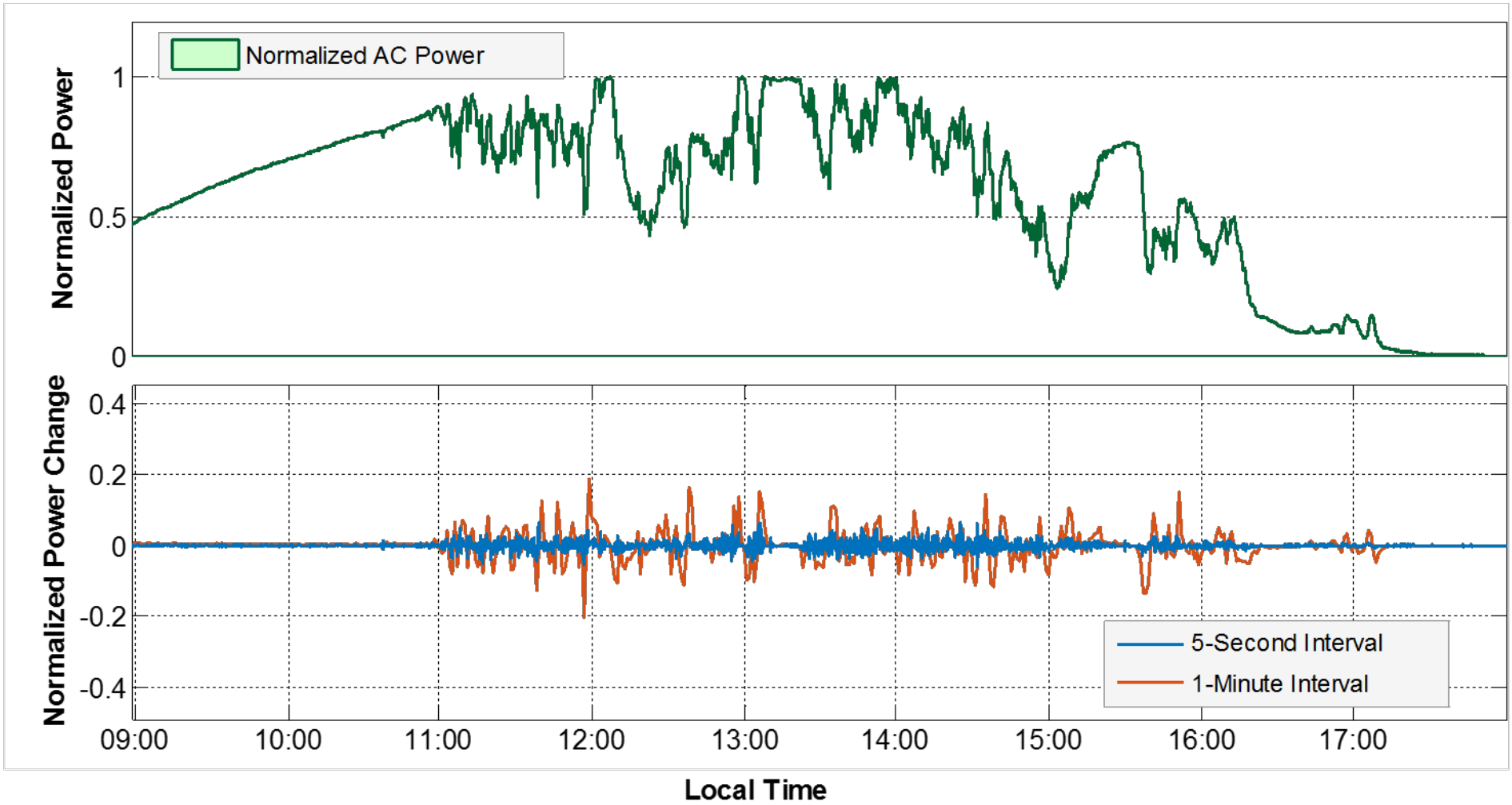
How often do Ramping Events Occur? Based on 2290 Hours

Percentile	Time Interval			
	10 sec	1 min	10 min	1 hr
99.99th	82.4	13.7	1.37	0.229
99.9th	824	137	13.7	2.29
99th	8,244	1,374	137	22.9
95th	41,220	6,870	687	115
90th	82,440	13,740	1,374	229

© 2015 Electric Power Research Institute, Inc. All rights reserved.

Sample One-Day Power Output Profile – Westley

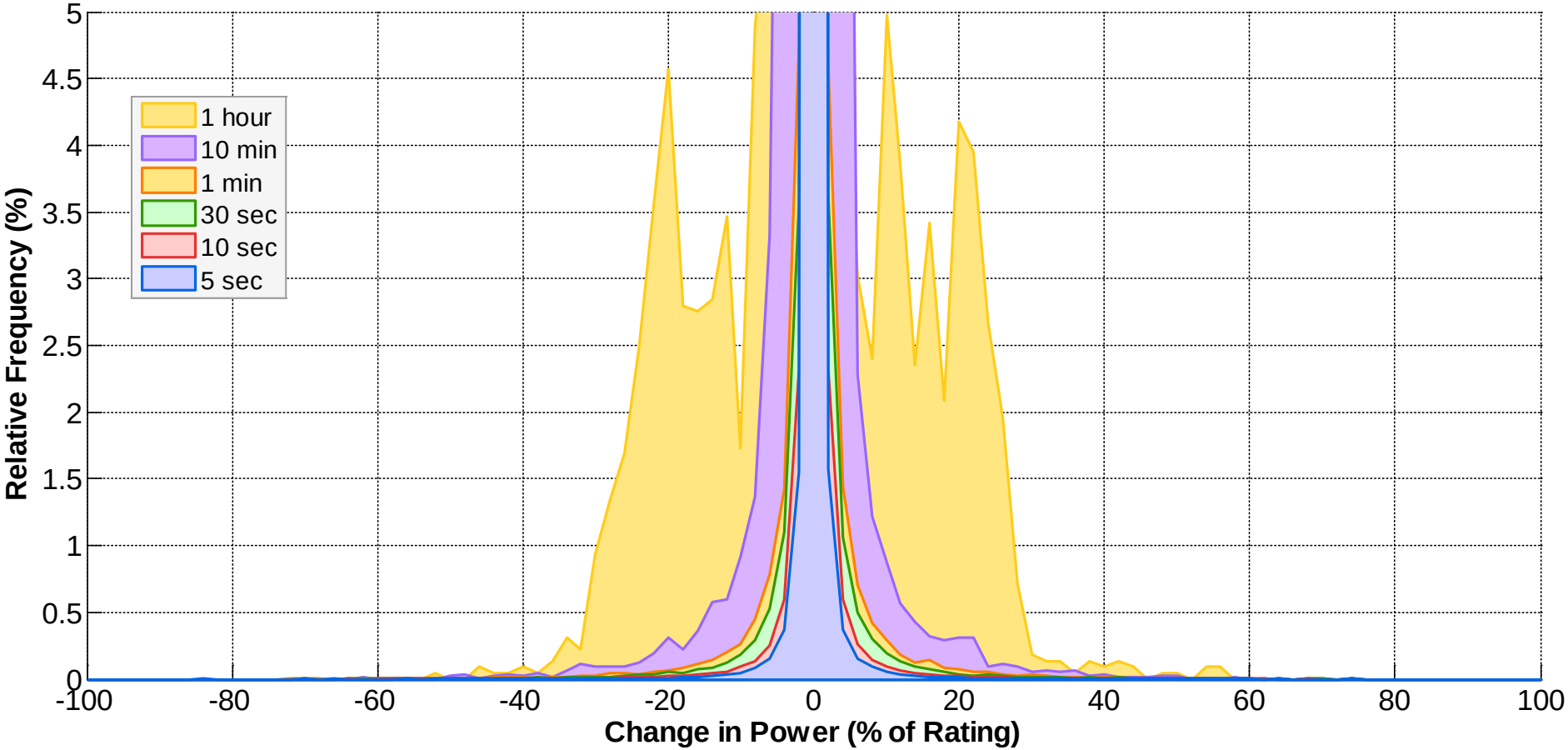
Afternoon Clouds



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Ramp Rate Distribution – Westley

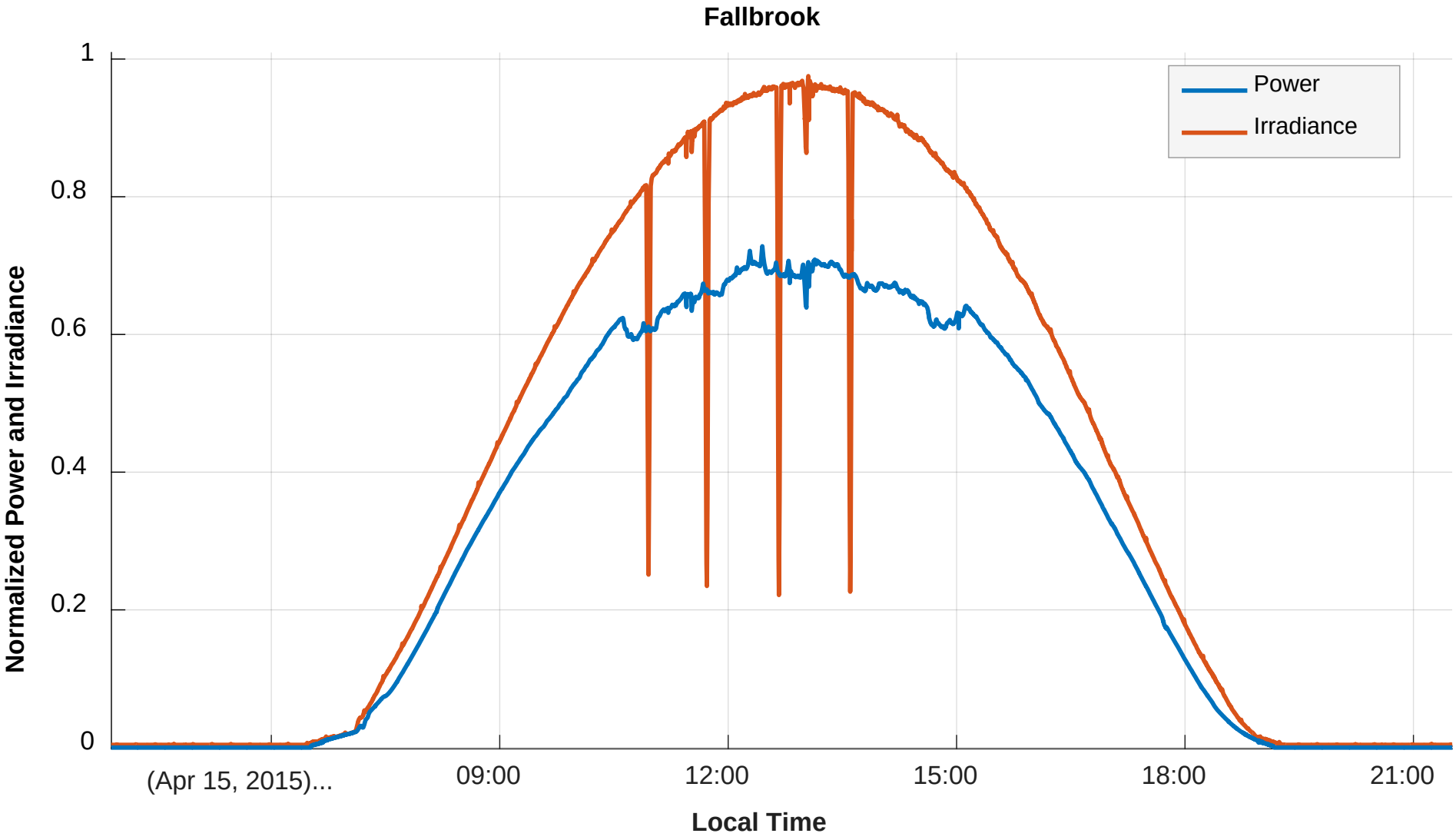
Jan. to June 2015



© 2015 Electric Power Research Institute, Inc. All rights reserved.

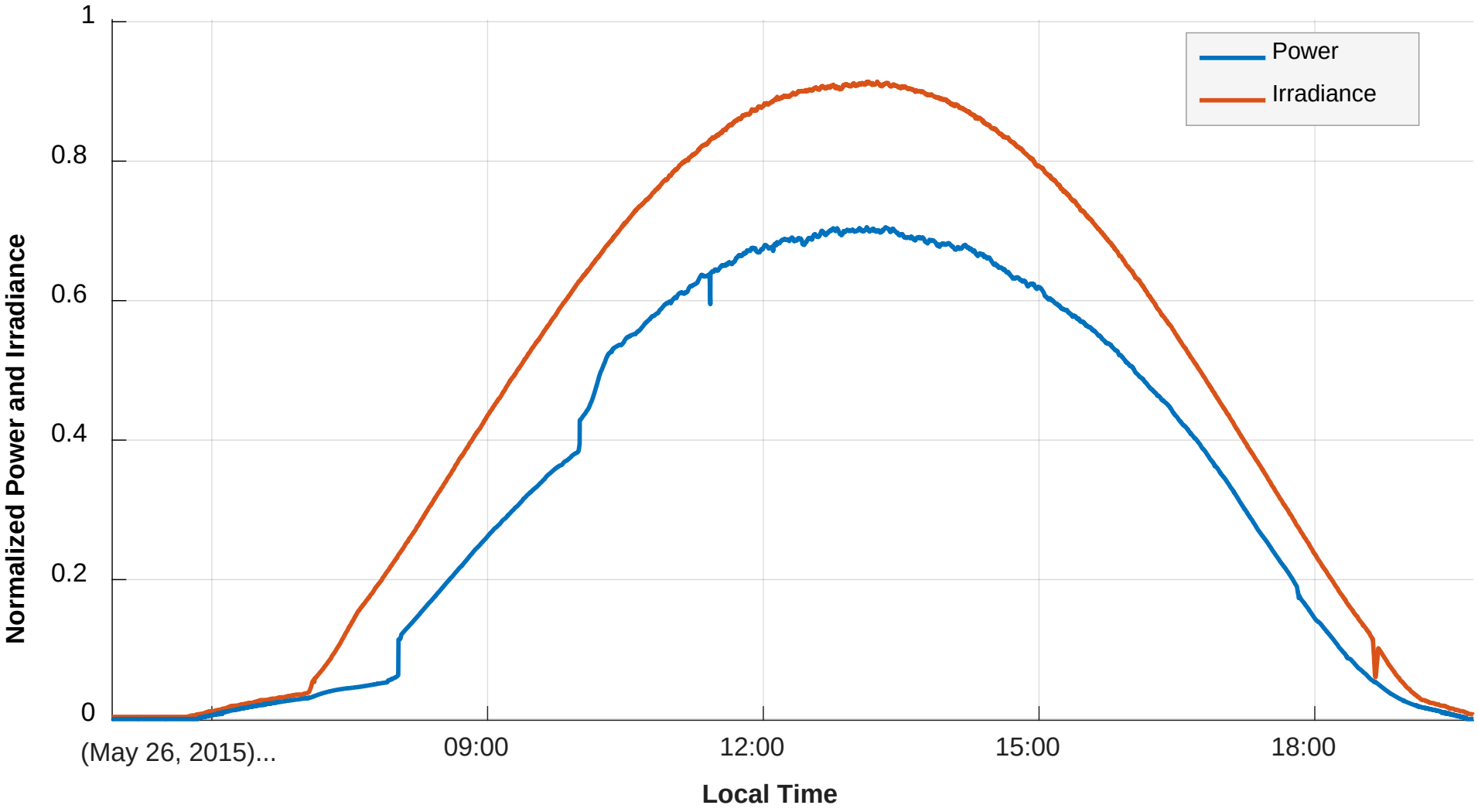
Shading Examples – Fallbrook

Jan. to June 2014



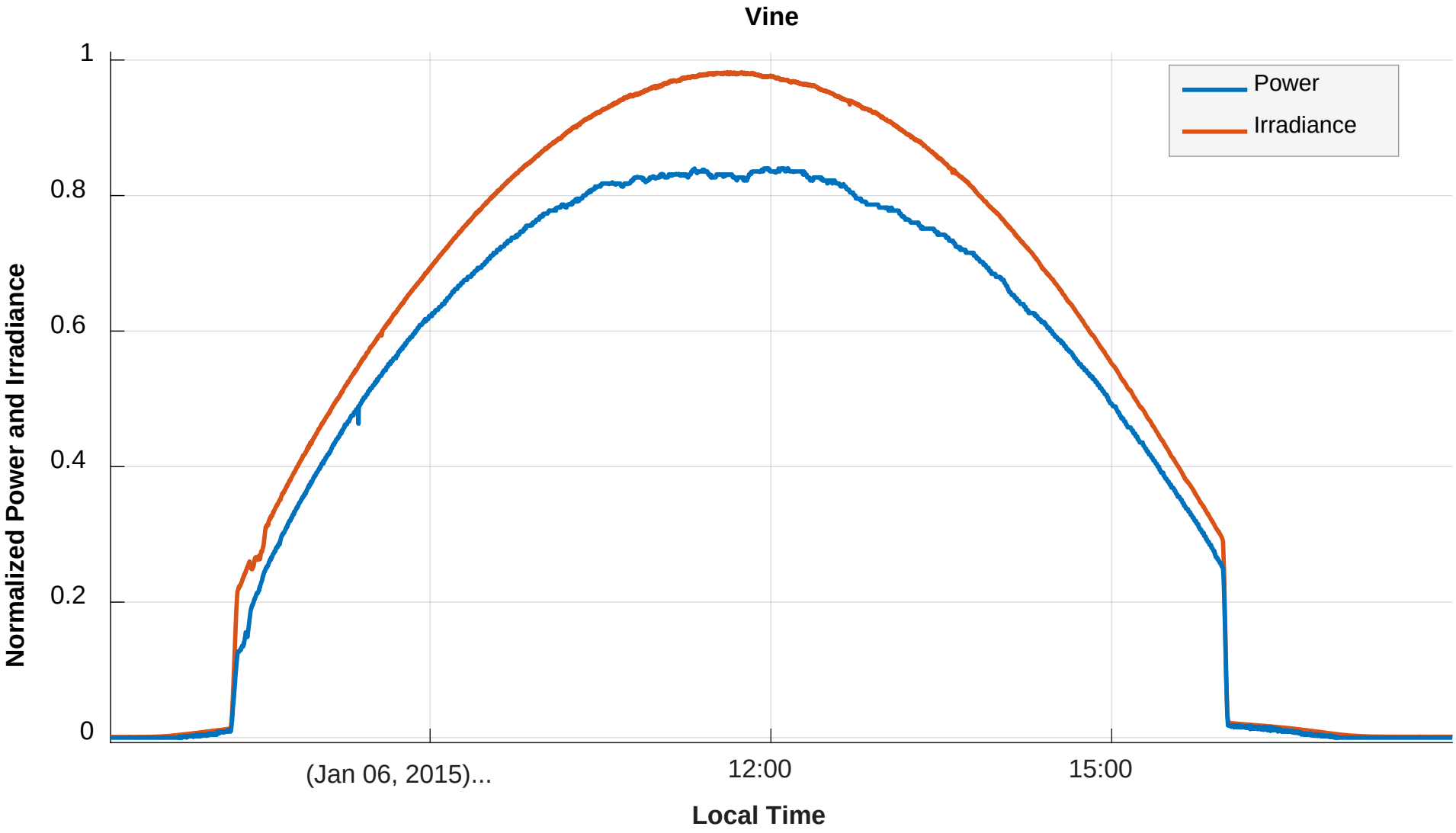
© 2015 Electric Power Research Institute, Inc. All rights reserved.

Shading Examples – Valley Center



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Shading Examples – Vine



© 2015 Electric Power Research Institute, Inc. All rights reserved.

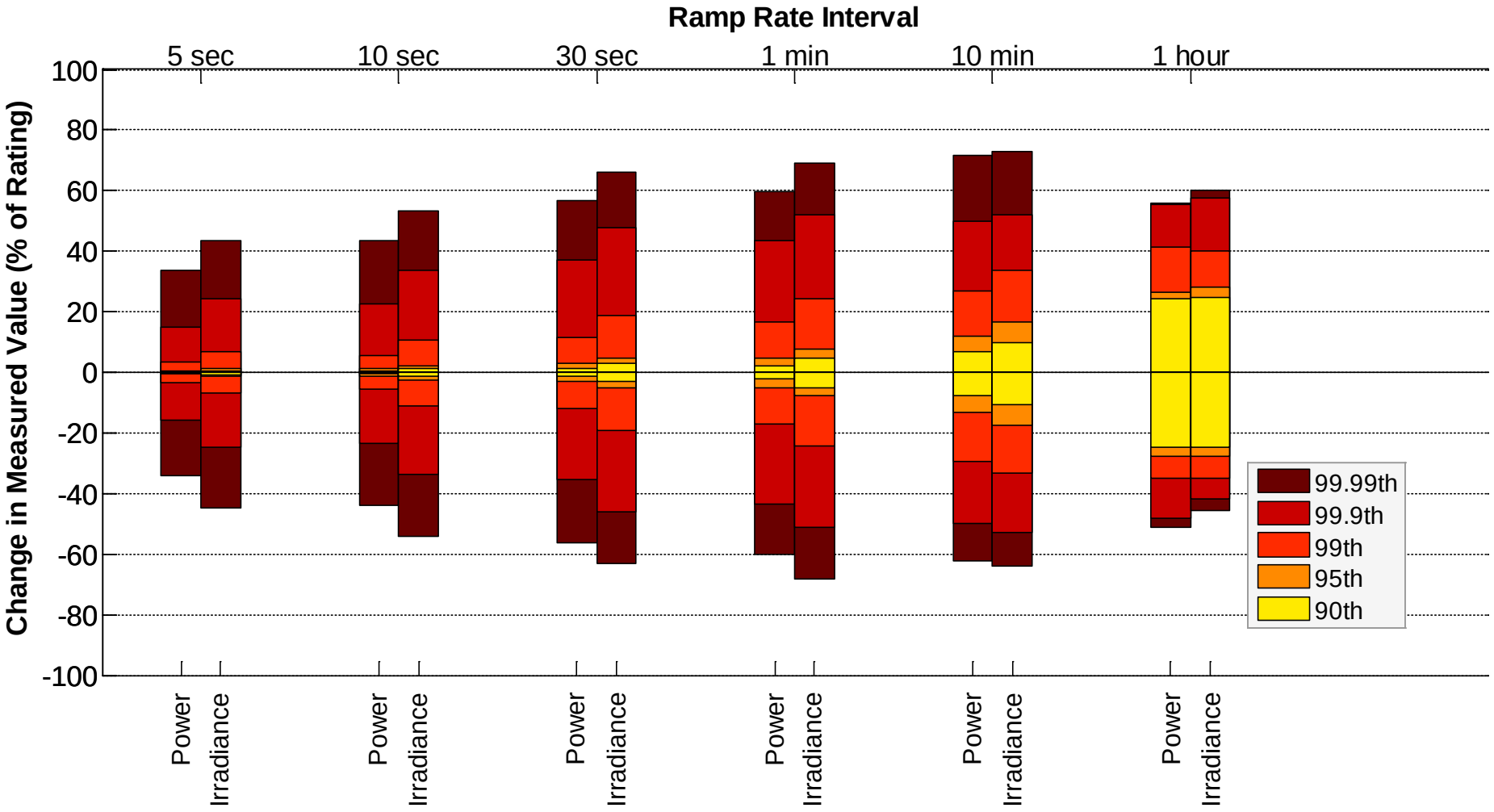
Variability: Ramp-Rates for Individual Sites

California Solar Initiative
Screening Distribution Feeders: Alternatives to the 15% Rule
Task 4: Collect High-Resolution PV Data

© 2015 Electric Power Research Institute, Inc. All rights reserved.

Ramp Rate Percentiles – Westley

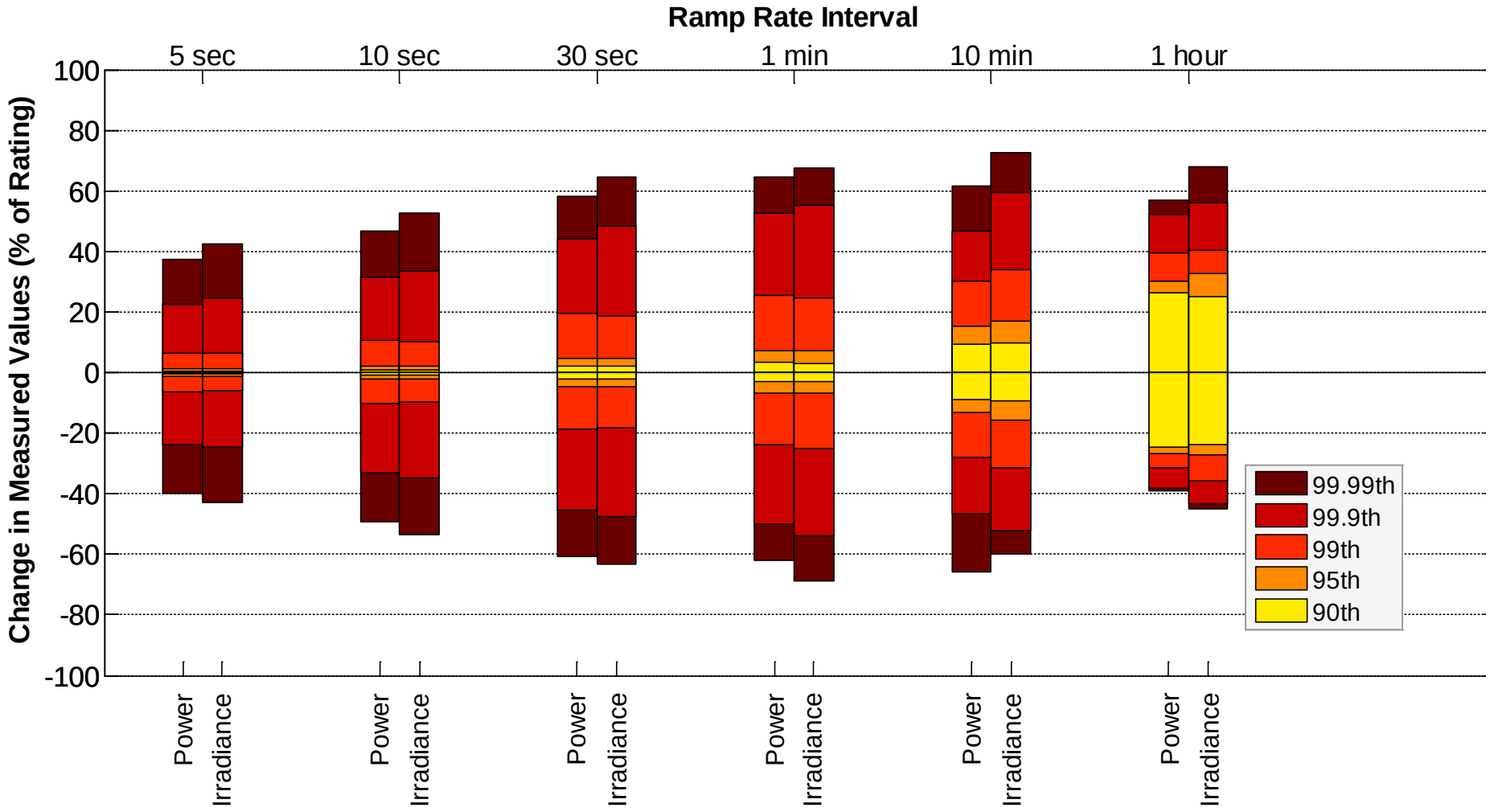
Jan. to June 2015



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Ramp Rate Percentiles – Fallbrook

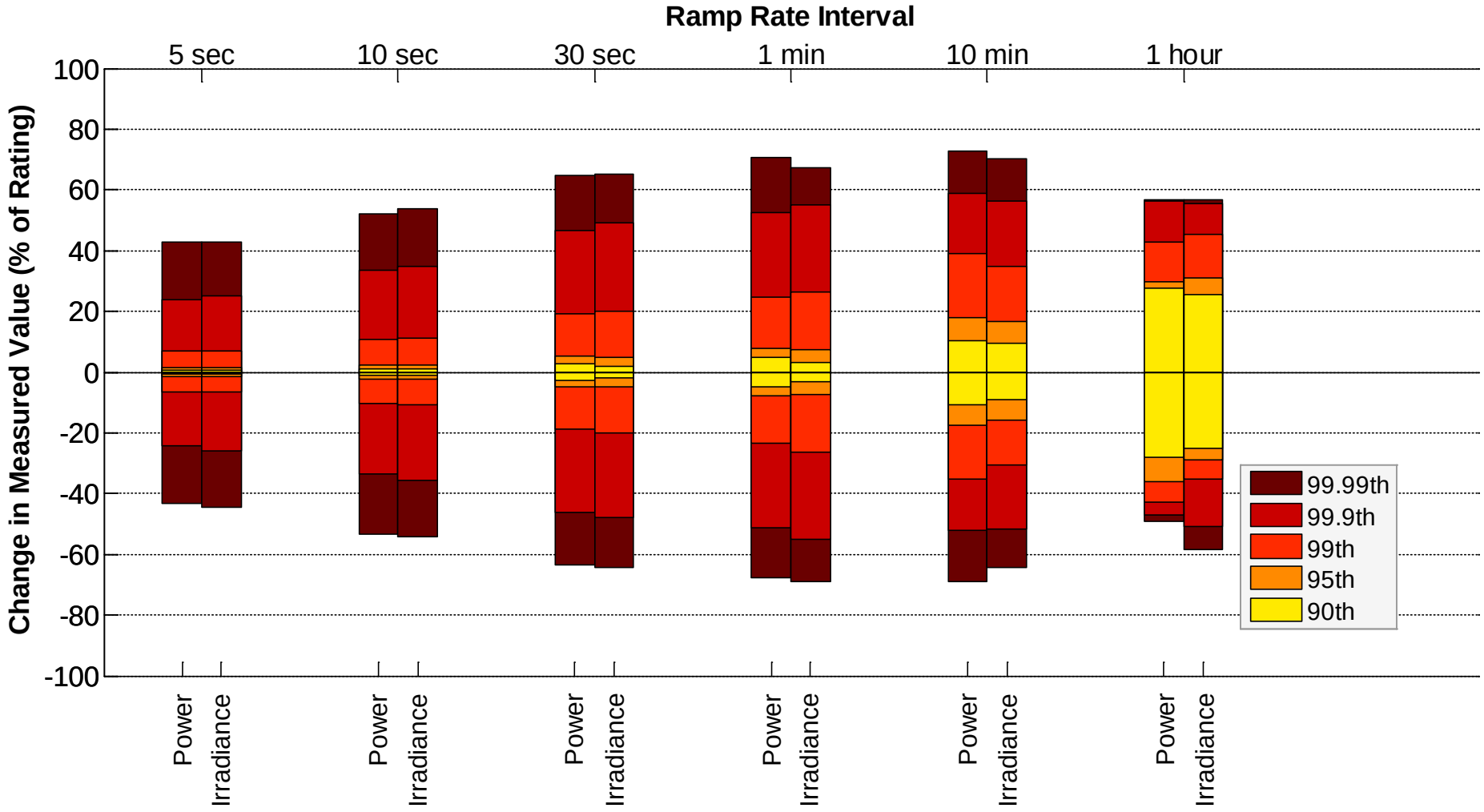
Jan. to June 2014



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Ramp Rate Percentiles – Valley Center

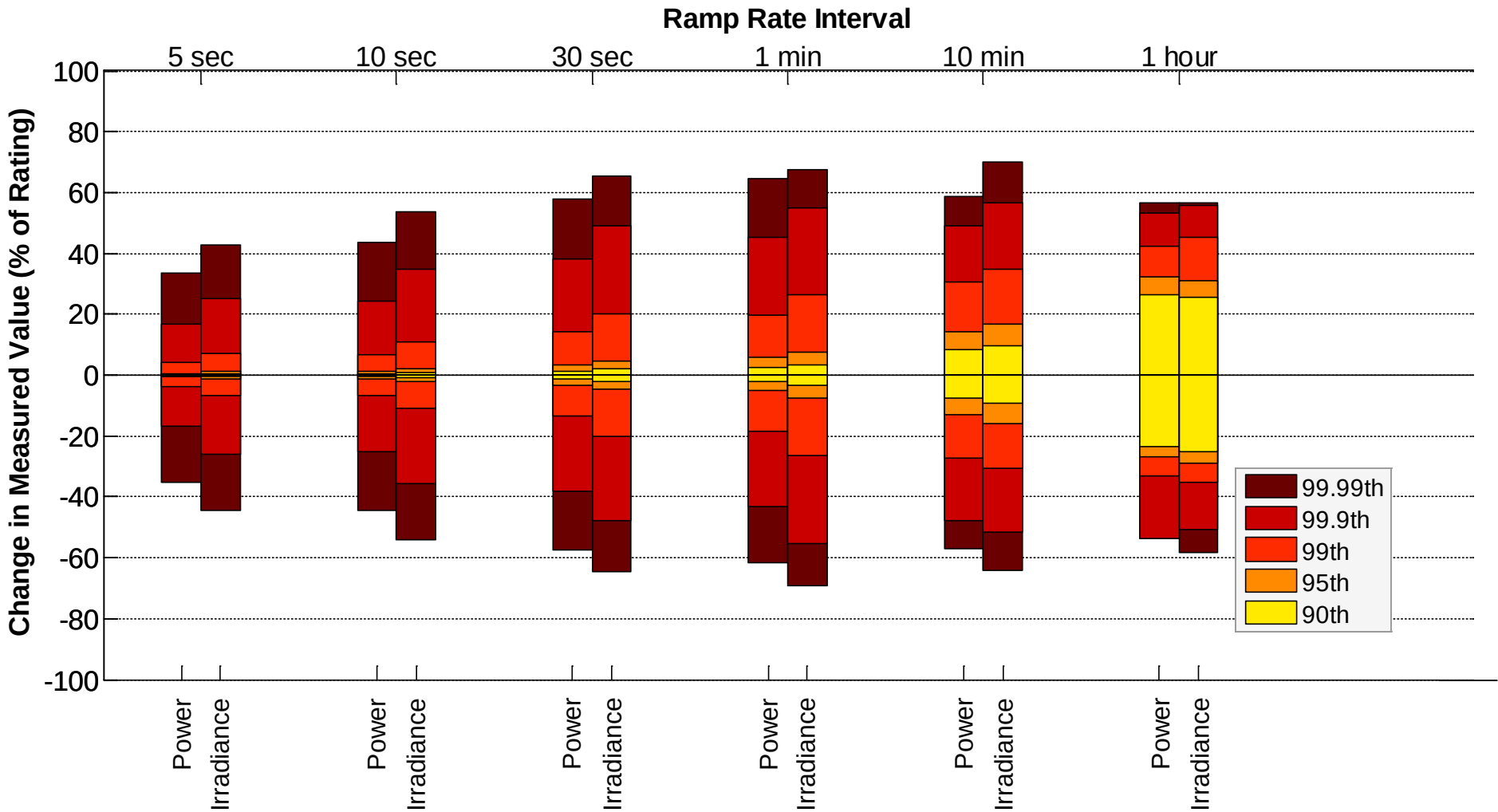
Jan. to June 2014



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Ramp Rate Percentiles – Vine

Jan. to June 2015



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Variability: Ramp-Rates for Site Clusters

California Solar Initiative
Screening Distribution Feeders: Alternatives to the 15% Rule
Task 4: Collect High-Resolution PV Data

© 2015 Electric Power Research Institute, Inc. All rights reserved.

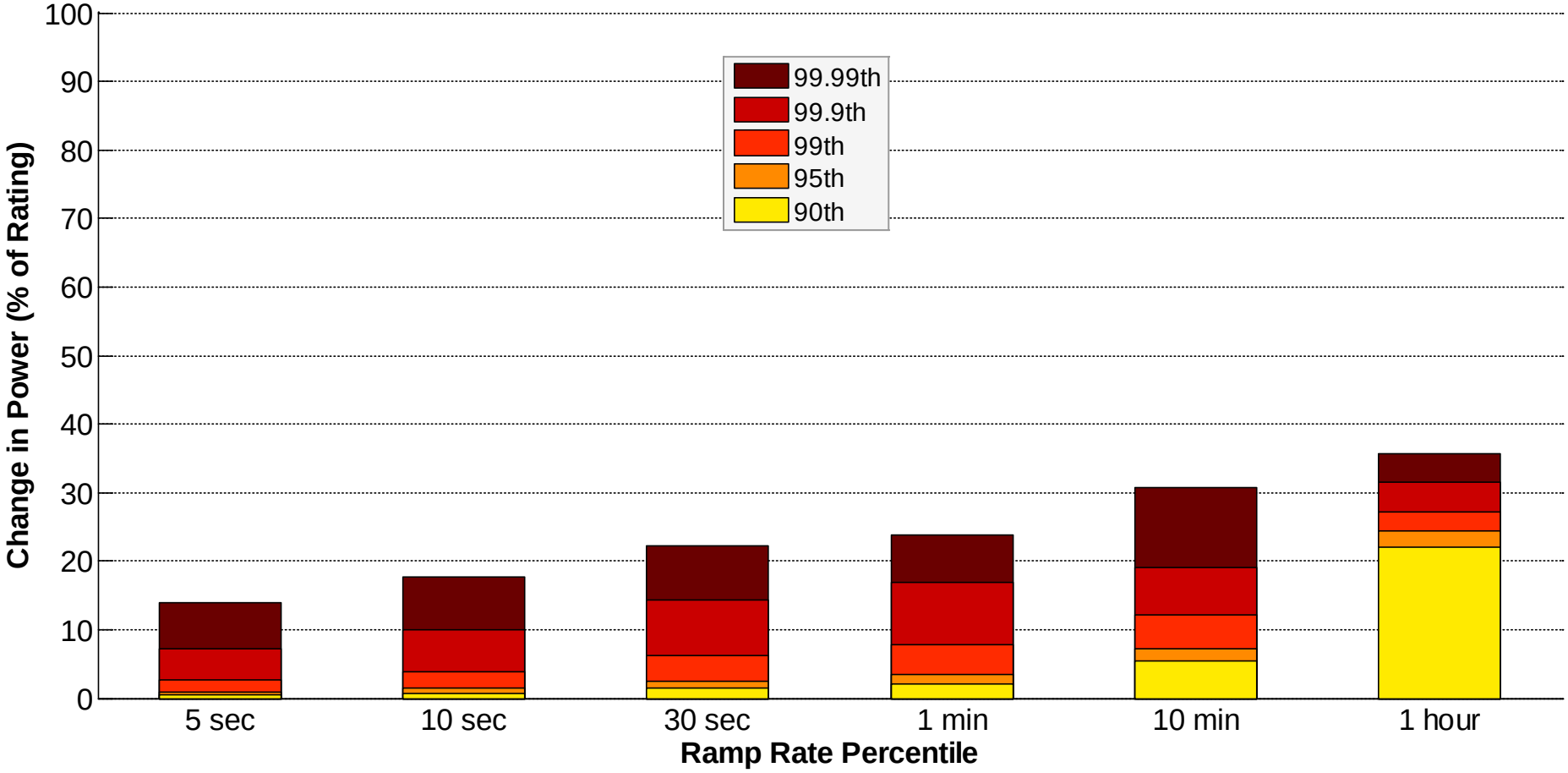
Final Data Set Clusters

	Statewide Cluster	Regional Cluster	Feeder Cluster
Westley	CA	-	-
Shafter	CA	-	-
Coverfield	CA	Los Angeles	-
Oak Glen	CA	Los Angeles	-
Hammock	CA	Los Angeles	-
Vine	CA	Los Angeles	-
Ramona #5	-	San Diego	Ramona
Ramona #10	-	San Diego	Ramona
Ramona #11	-	San Diego	Ramona
Ramona #12	-	San Diego	Ramona
Valley Center #1	-	San Diego	Valley Center
Valley Center #2	-	San Diego	Valley Center
Valley Center #8	-	San Diego	Valley Center
Valley Center #13	-	San Diego	Valley Center

© 2015 Electric Power Research Institute, Inc. All rights reserved.

Ramp Rate Percentiles – California Cluster

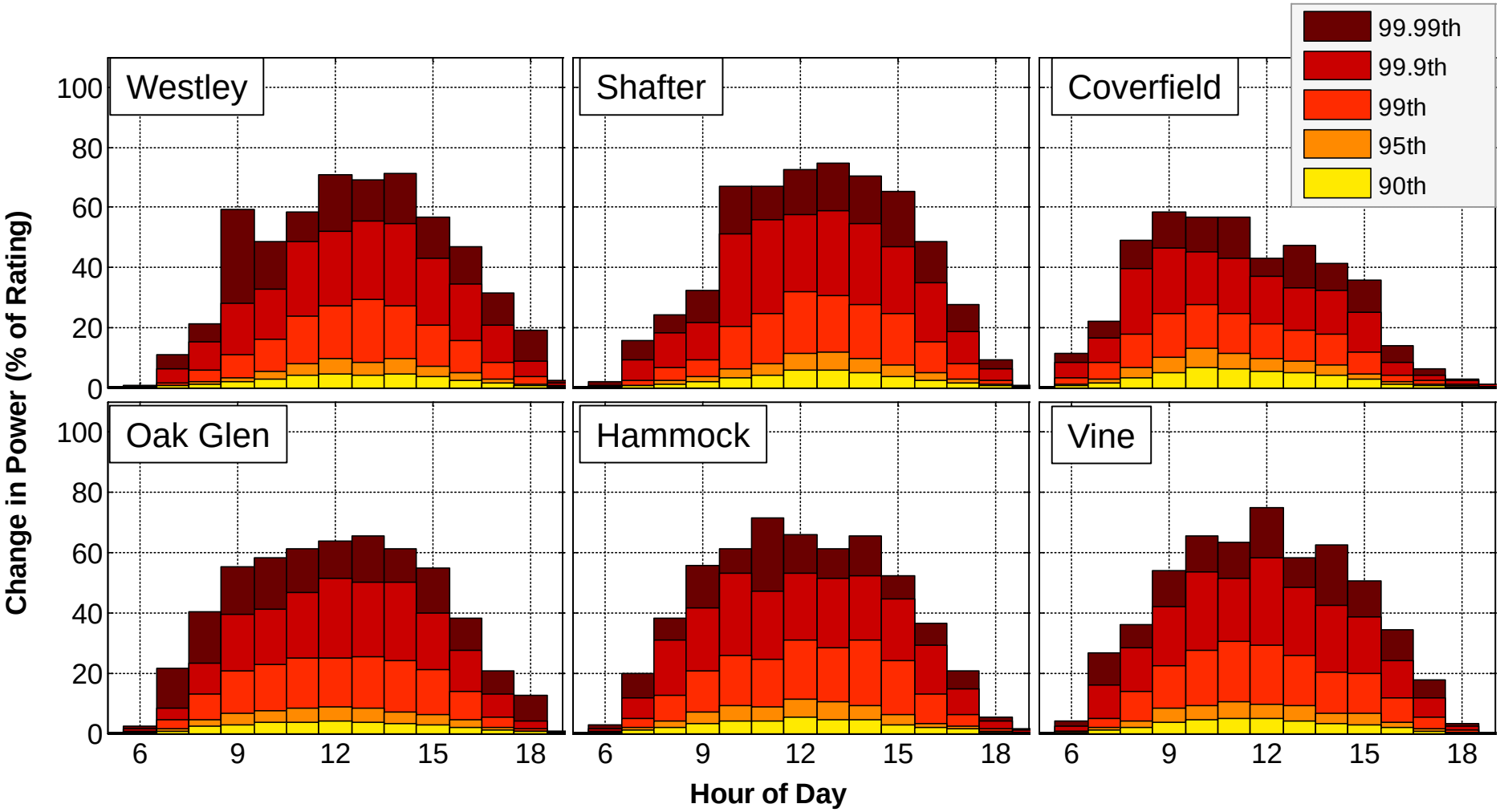
Jan. to June 2015



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Changes in Power vs. Time of Day – California Cluster

Jan. to June 2015, 1-min intervals



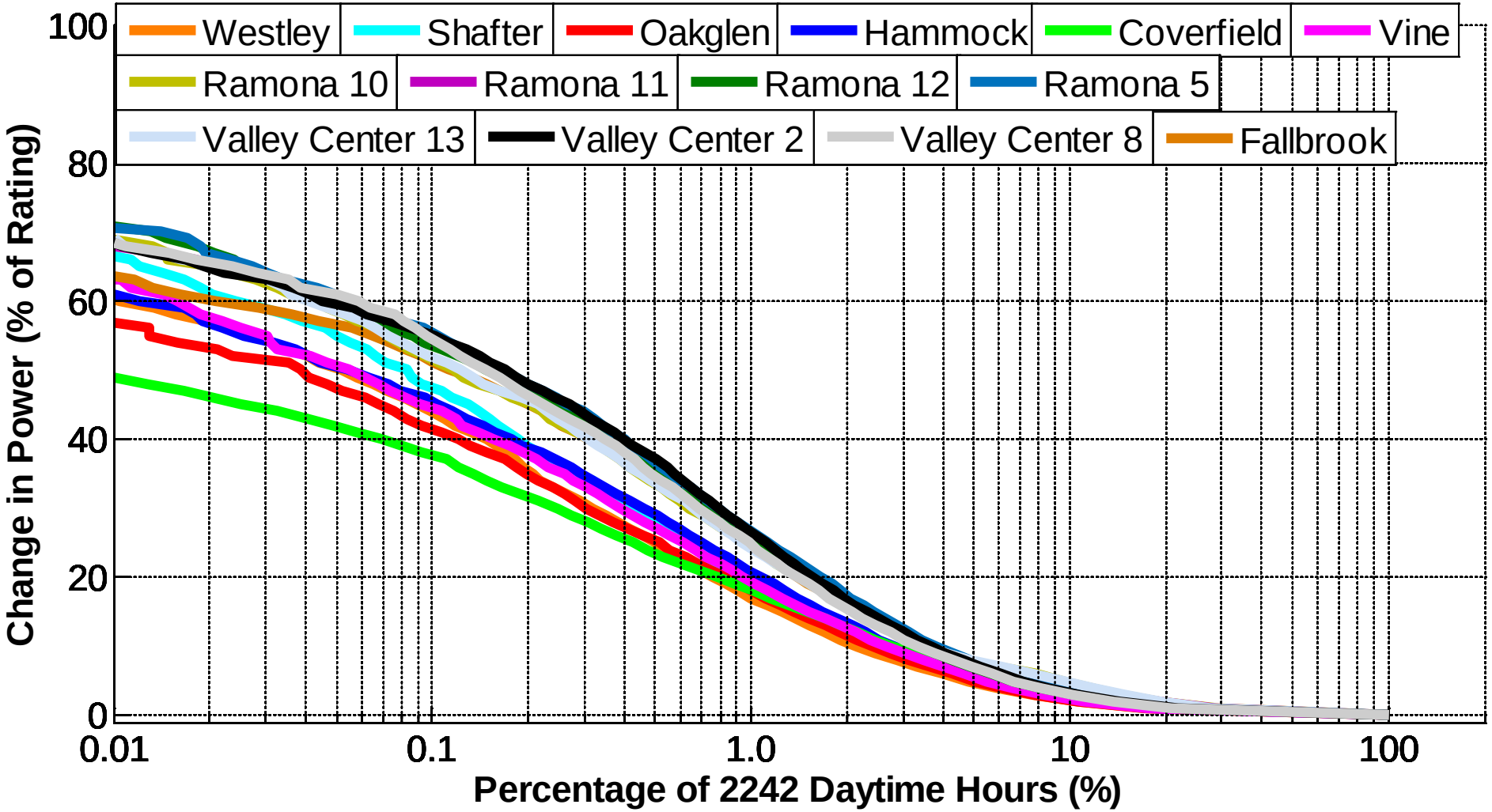
© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Ramp Rate Duration Profile – California Cluster

Jan. to June, 1-min intervals

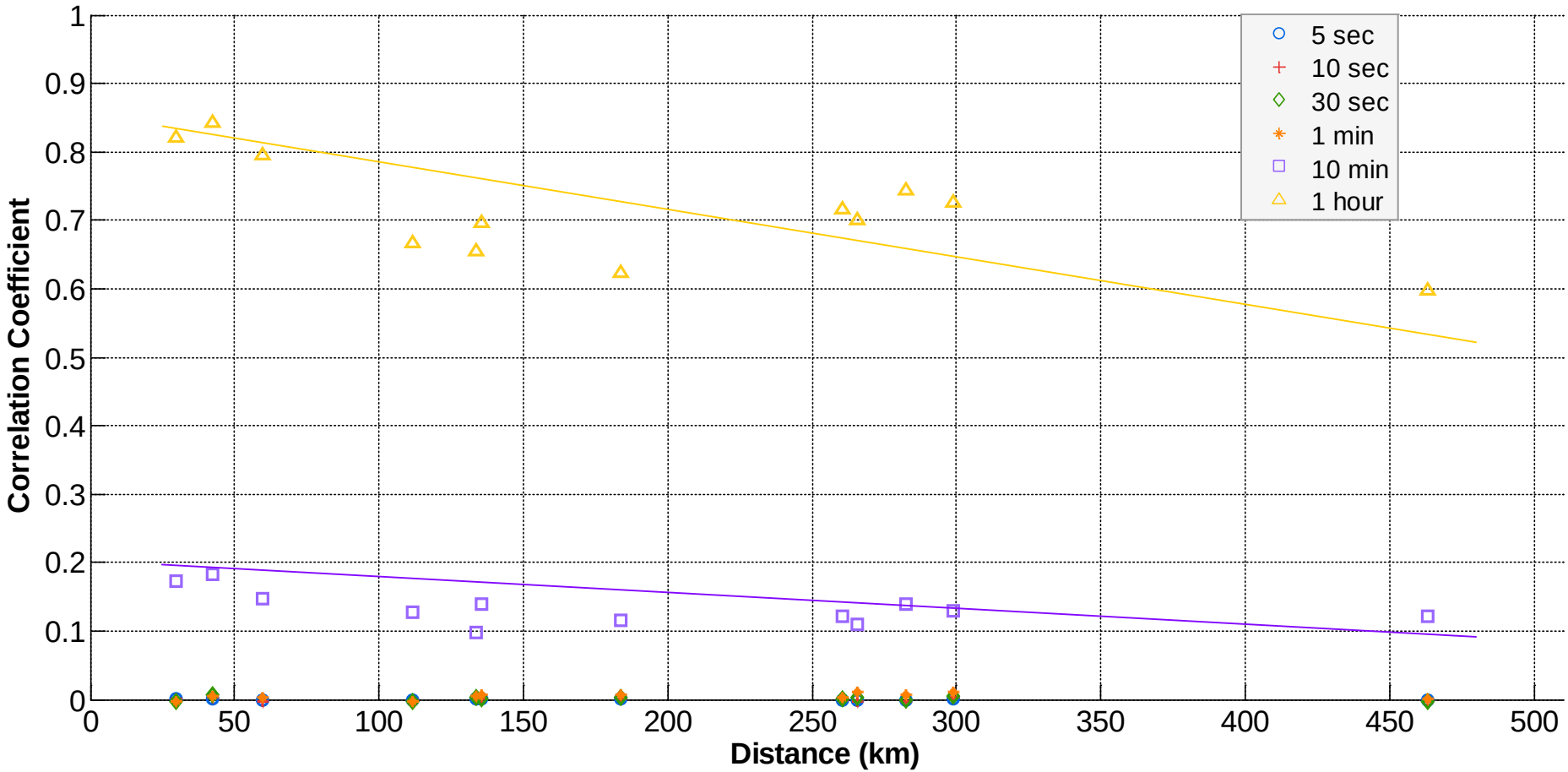
Fallbrook and Valley Center data are from 2014; all other sites are from 2015



© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Correlation of Irradiance Changes over Distances – California Cluster

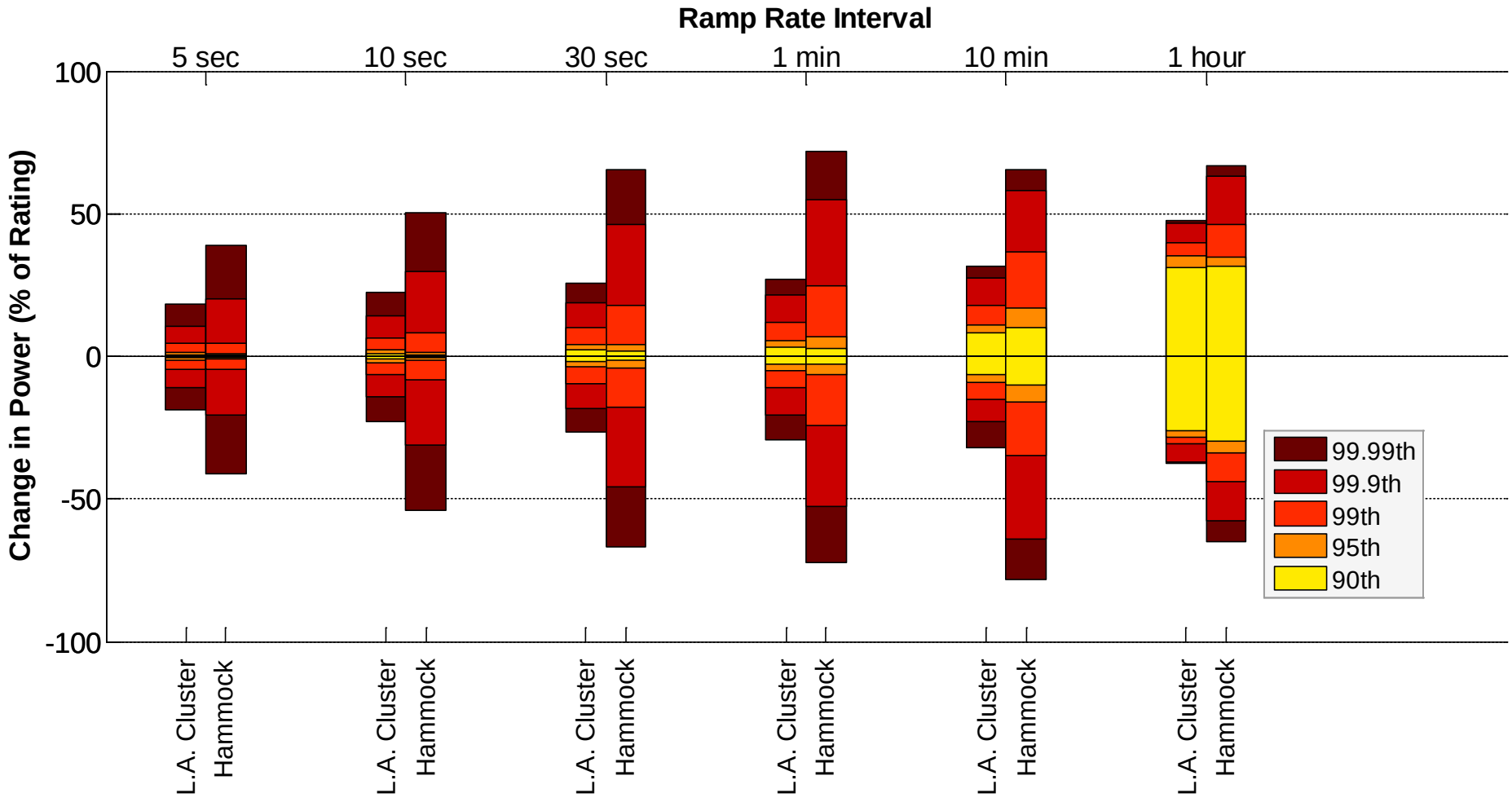


© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Ramp Rate Percentiles – Los Angeles Cluster

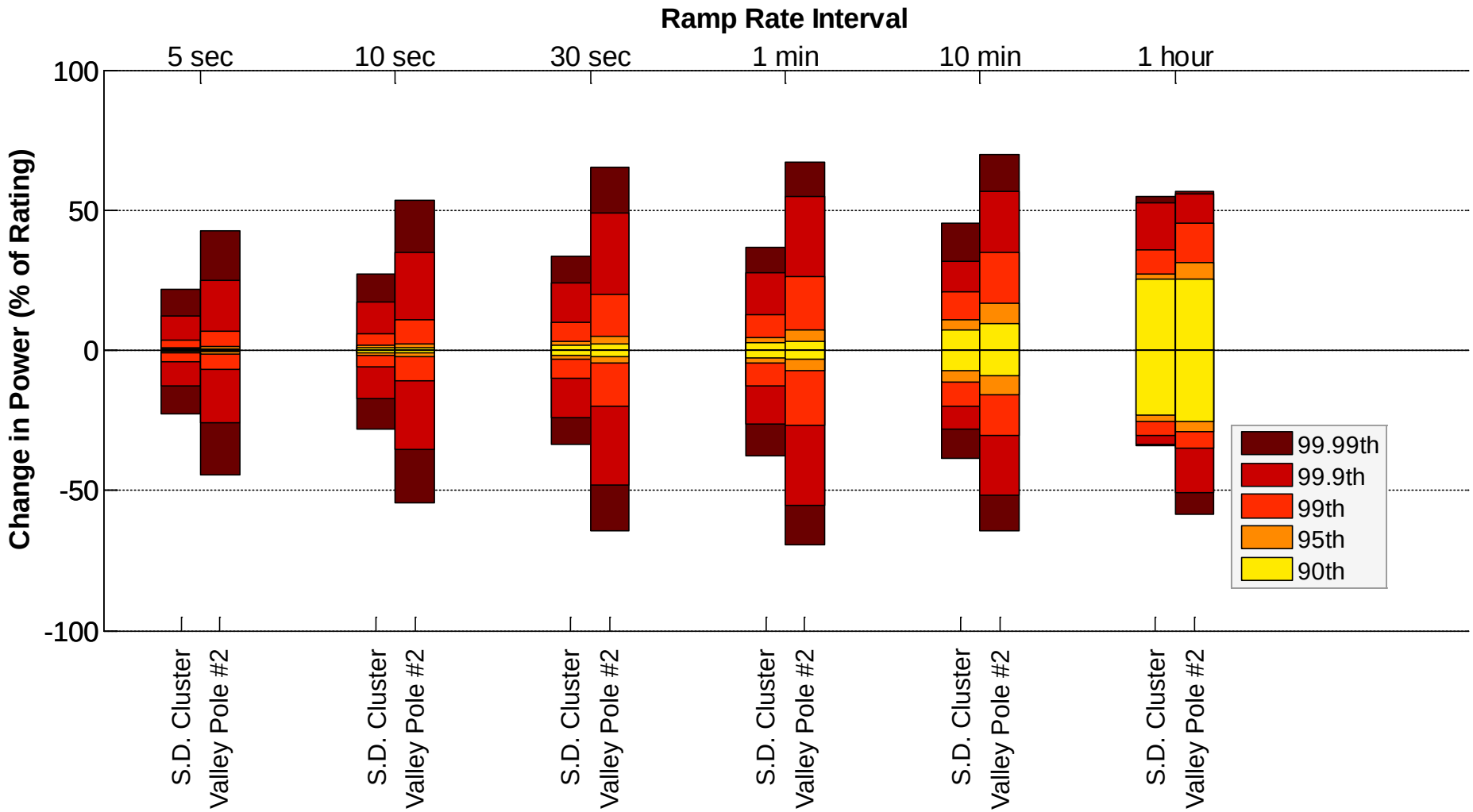
Jan. to June 2015



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Ramp Rate Percentiles – San Diego Cluster

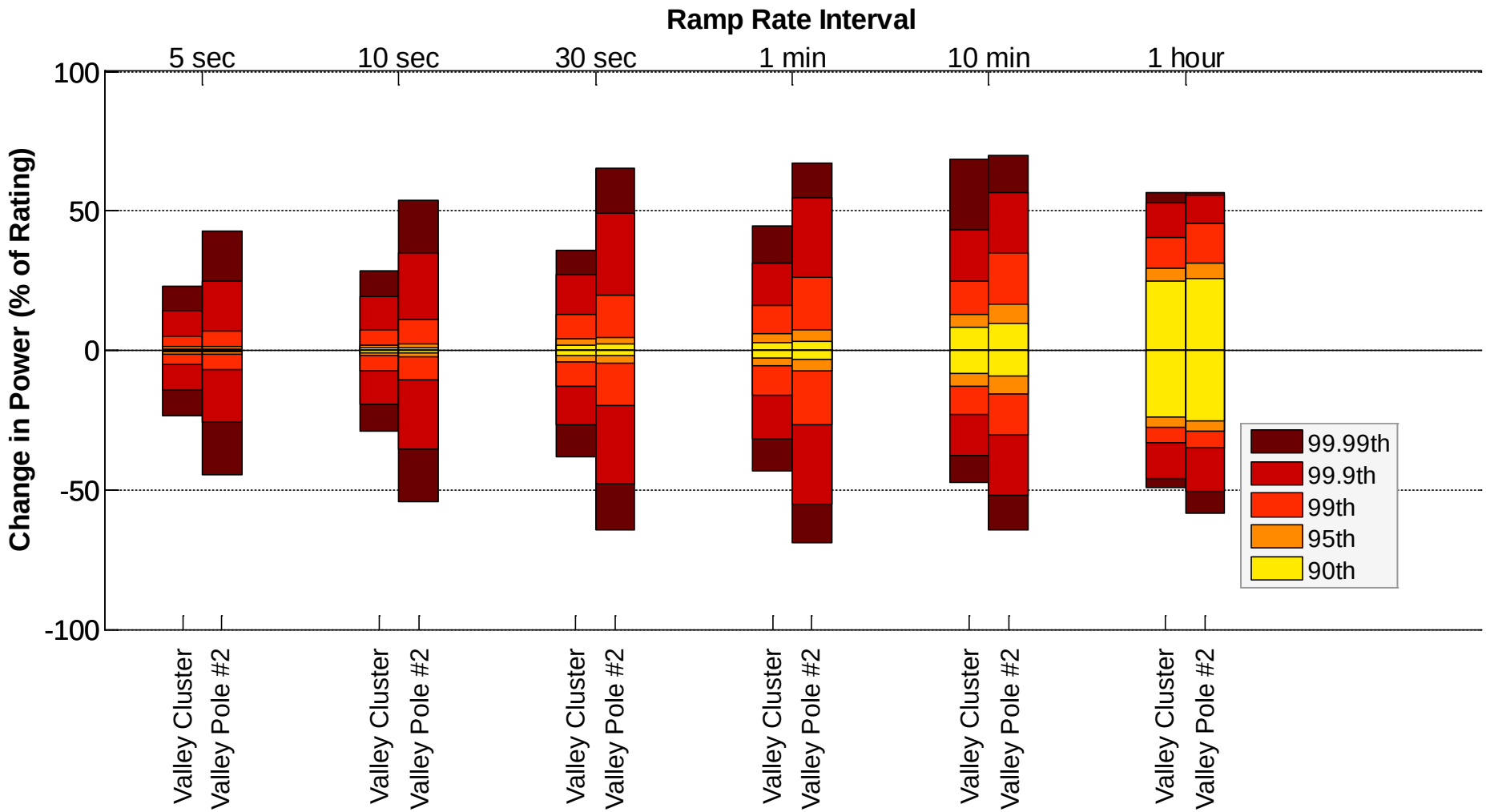
Jan. to June 2014



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Ramp Rate Percentiles – Valley Center Feeder

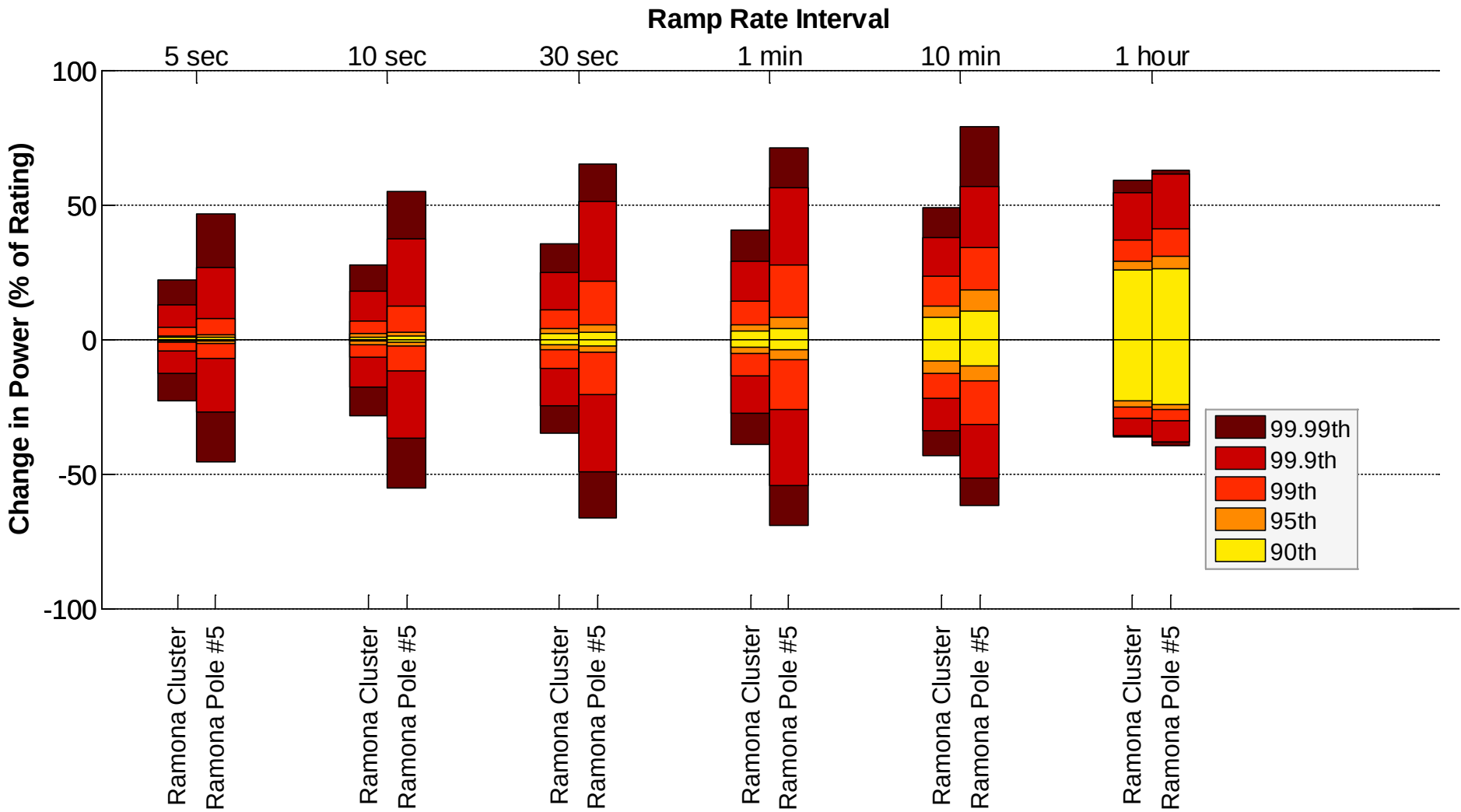
Jan. to June 2014



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Ramp Rate Percentiles – Ramona Feeder

Jan. to June 2014



© 2015 Electric Power Research Institute, Inc. All rights reserved.

Together…Shaping the Future of Electricity

© 2015 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE