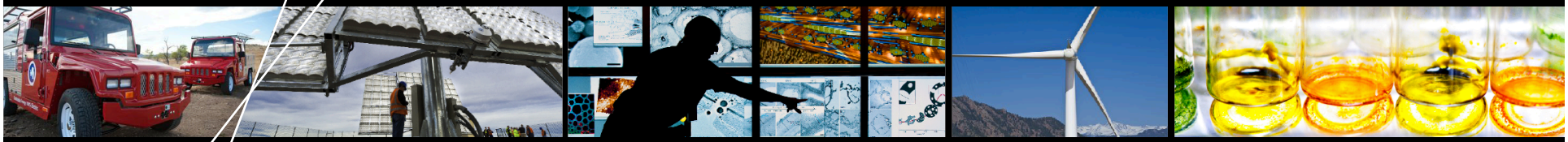
Statistical Overview of Variable Generation Data - Update



WWSIS Phase 2 TRC
November 28, 2012

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

What's New

- **5 minute wind, solar and load data completed**
- **Wind and solar forecasts**
- **CSP dispatch profiles from production simulation**

The Scenarios

- **Four Scenarios**
  - TEPPC – TEPPC 2020 based
    - Approximately 13% penetration
    - 9.5% Wind/3.5% Solar
  - High Solar – 33% Penetration
    - 25% Solar/8% Wind
  - High-Mix – 33% Penetration
    - 16.5% Solar/16.5% Wind
  - High Wind – 33% Penetration
    - 8% Solar/25% Wind

Scenario Definitions

- **3 Classes of PV (60% of solar)**
  - Rooftop (40% PV)
  - Population located utility scale (20% PV)
  - Best resource located utility scale (40% PV)
- **CSP – All has 6 hours of storage (40% of solar)**
- **ReEDS analysis run for wind and solar to make a first cut at regional allocations**
- **Solar plants developed to meet the targets based on ReEDS allocations**
- **Wind is selected from WWSIS wind dataset by best resource based on ReEDS allocations**
- **Other renewables (Biomass, Geothermal etc.) not included in penetration targets**

‘As Built’ Scenario Energy Penetration

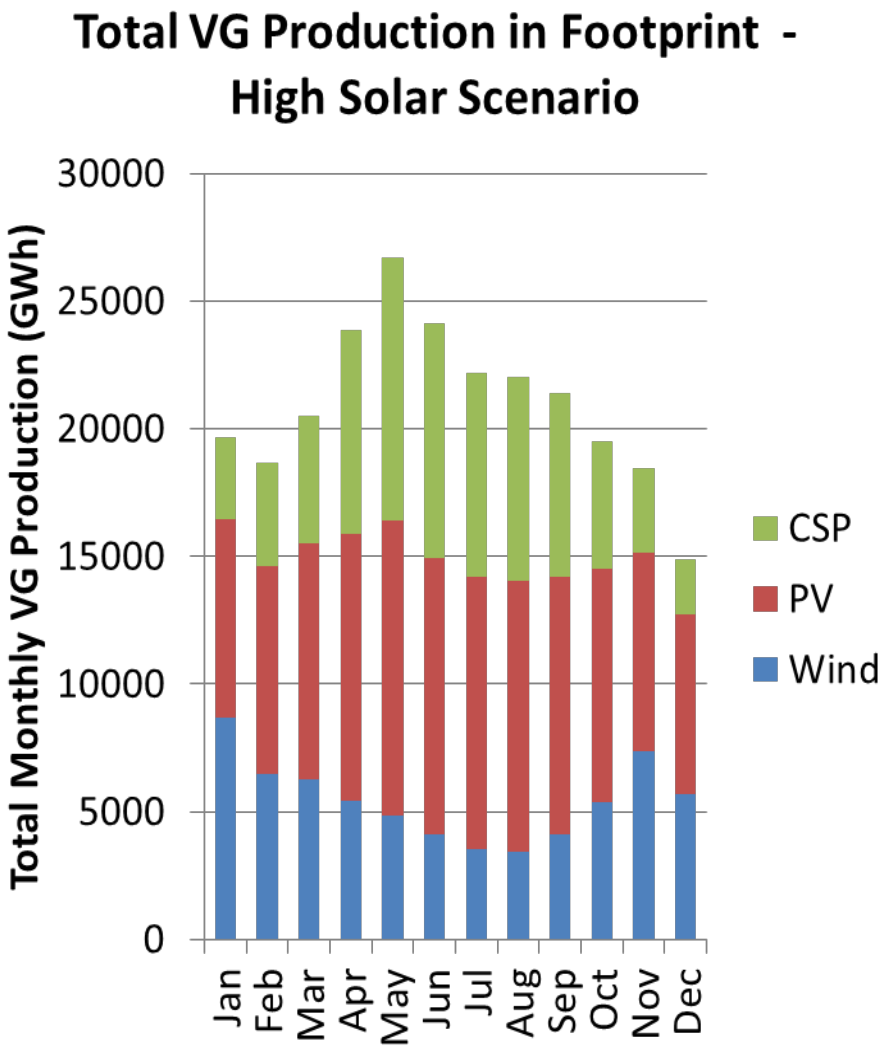
- **Several factors effected the final penetration levels seen in the simulations**

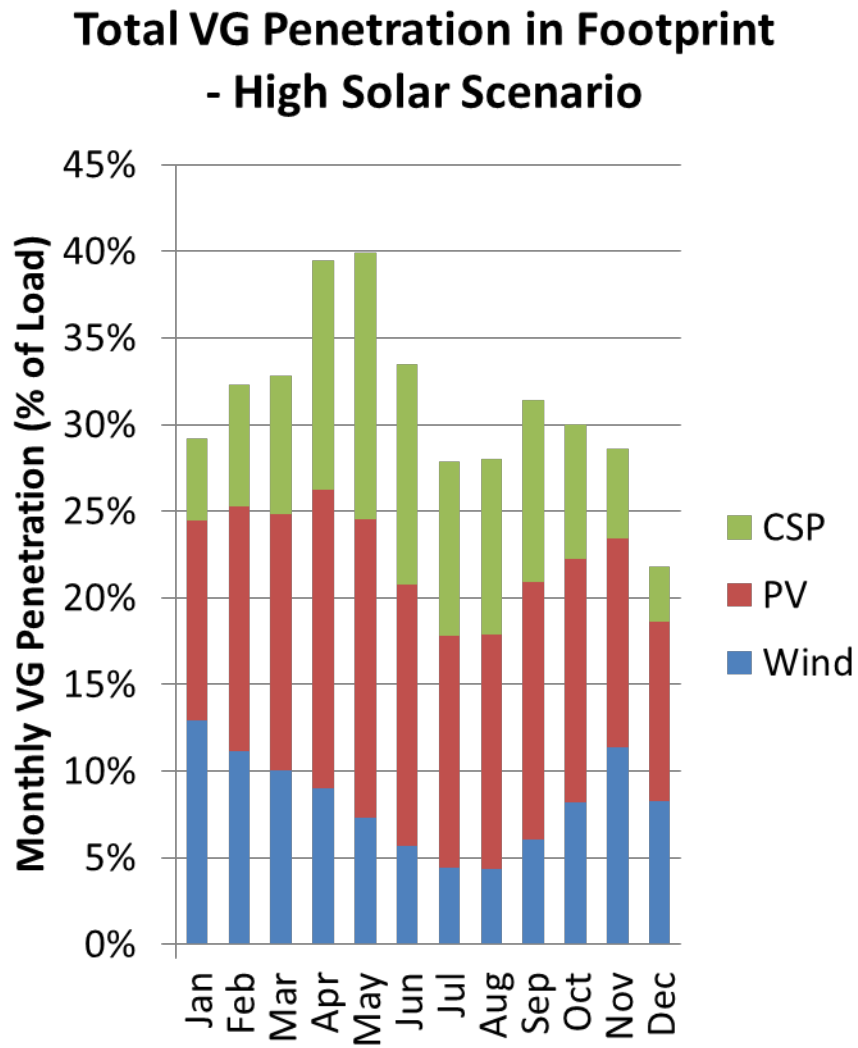
	High-Solar		High-Mix		High-Wind	
FacilityType	Energy (GWh)	Penetration	Energy (GWh)	Penetration	Energy (GWh)	Penetration
Rooftop	30,120	4%	26,436	3%	14,689	2%
Pop Util PV	33,841	4%	18,306	2%	7,252	1%
Best Res PV	48,218	6%	29,266	4%	14,140	2%
CSP	76,072	10%	49,956	6%	23,915	3%
Total Solar	188,251	24%	123,964	16%	59,996	8%
Wind	65,729	8%	134,706	17%	203,375	26%
Total VG	253,979	32%	258,669	33%	263,371	34%

Capacity Factor

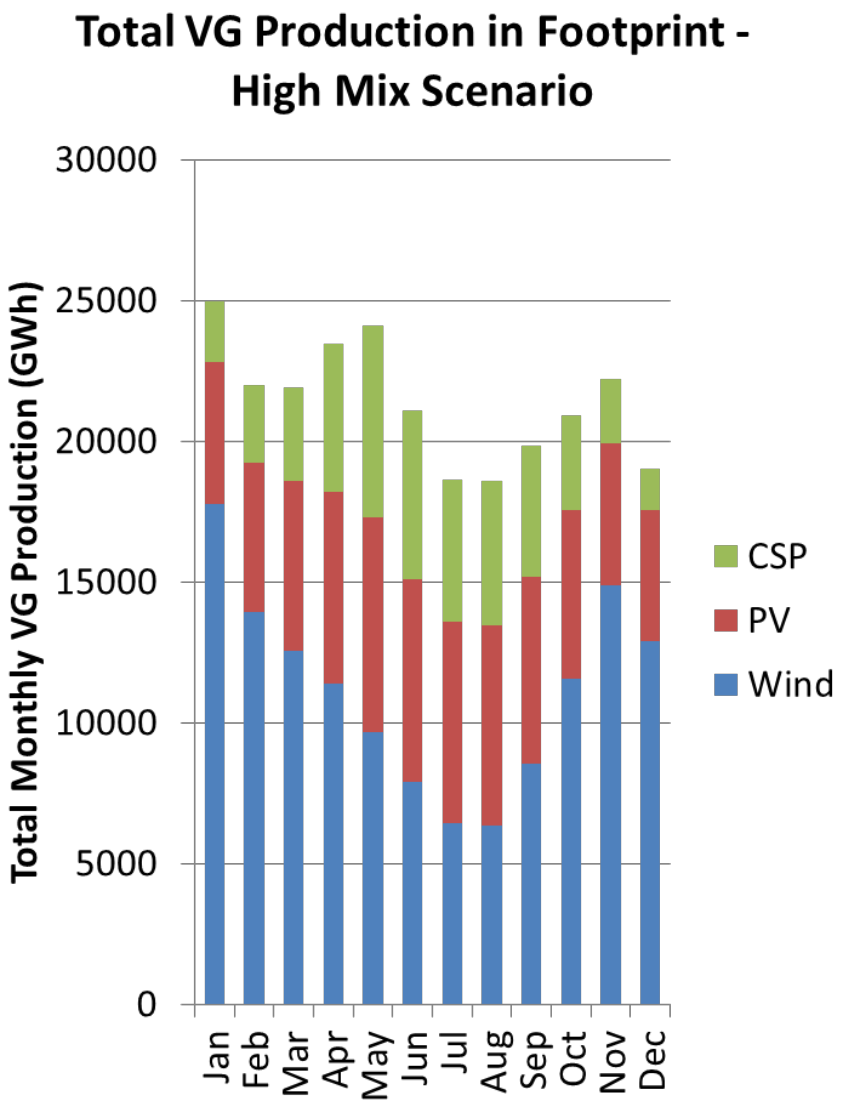
	High-Solar		High-Mix		High-Wind	
FacilityType	Nameplate (MW)	CF	Nameplate (MW)	CF	Nameplate (MW)	CF
Rooftop	19,543	18%	17,145	18%	9,635	17%
Pop Util PV	18,016	21%	9,263	23%	3,714	22%
Best Res PV	24,739	22%	14,242	23%	6,933	23%
CSP	21,526	40%	13,997	41%	6,536	42%
Total Solar	83,825	26%	54,647	26%	26,817	26%
Wind	23,357	32%	43,778	35%	66,150	35%
Total VG	191,006	26%	153,071	29%	119,784	31%

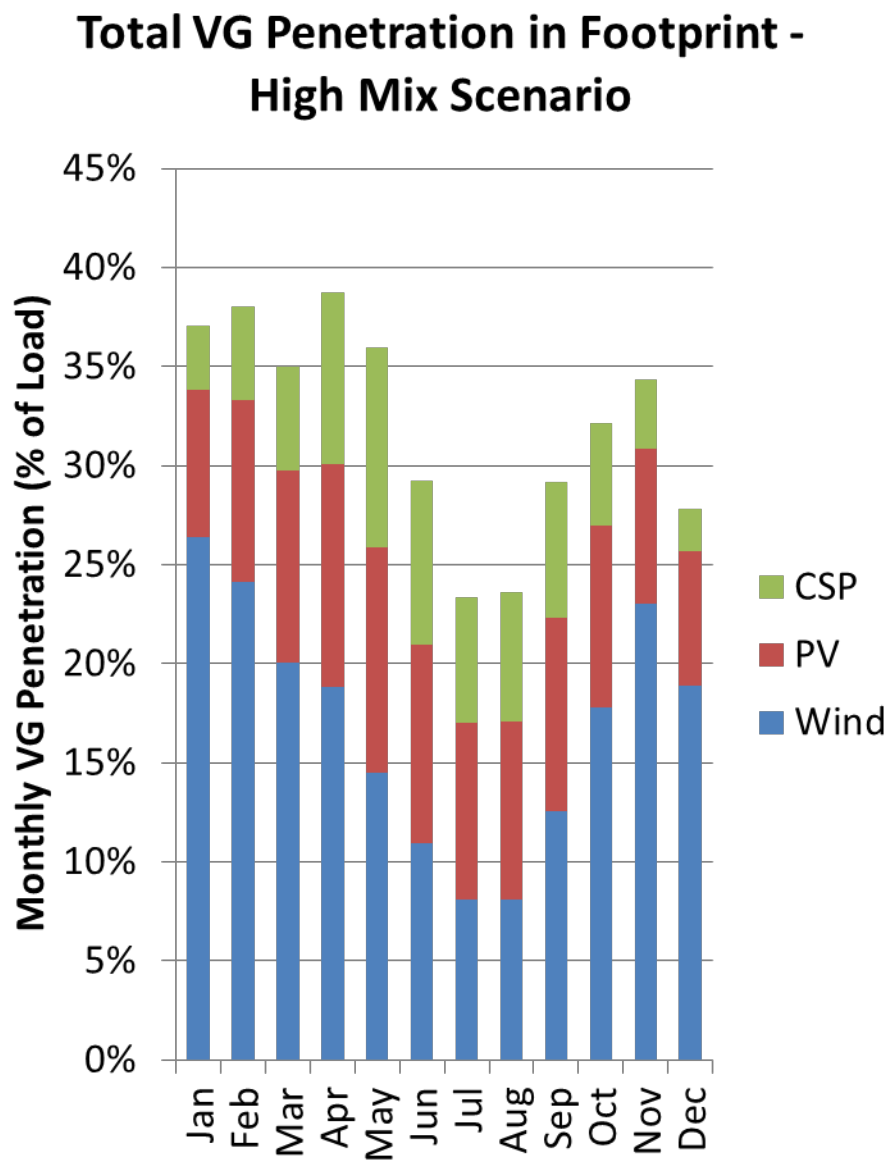
Monthly Energy… High-Solar Scenario



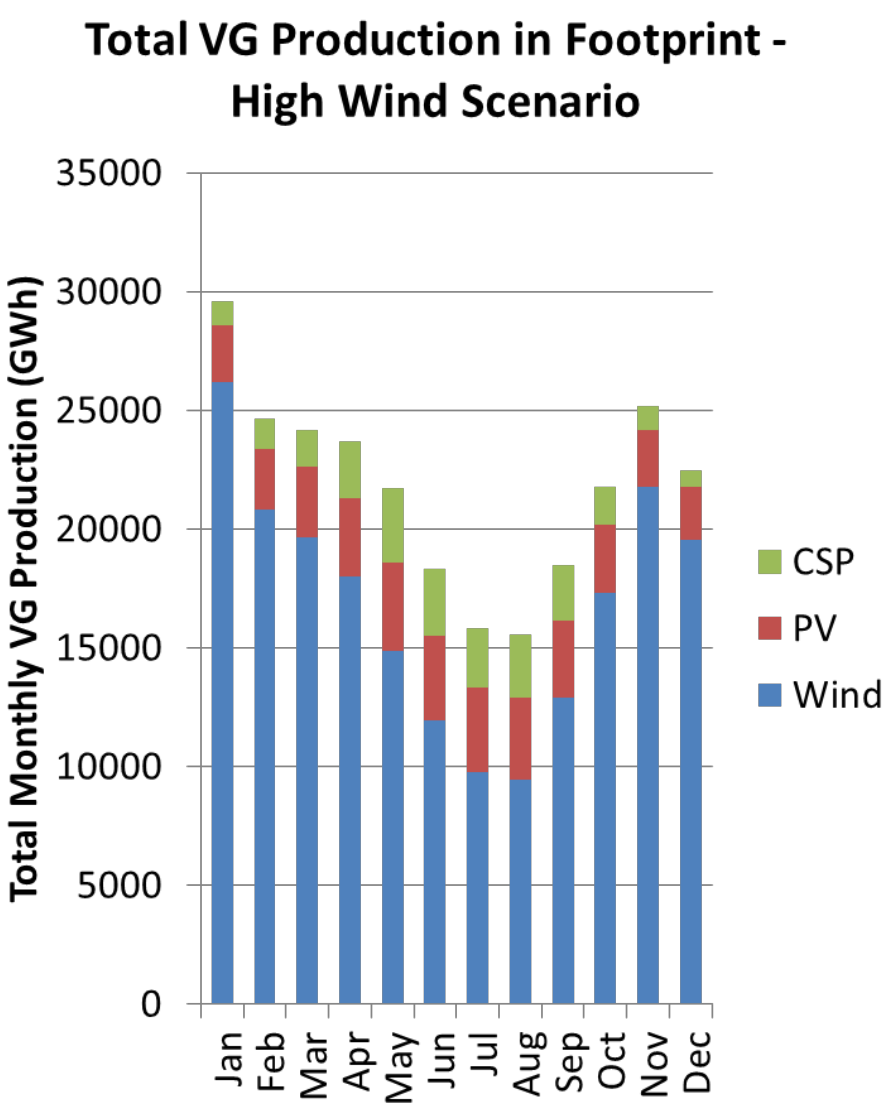


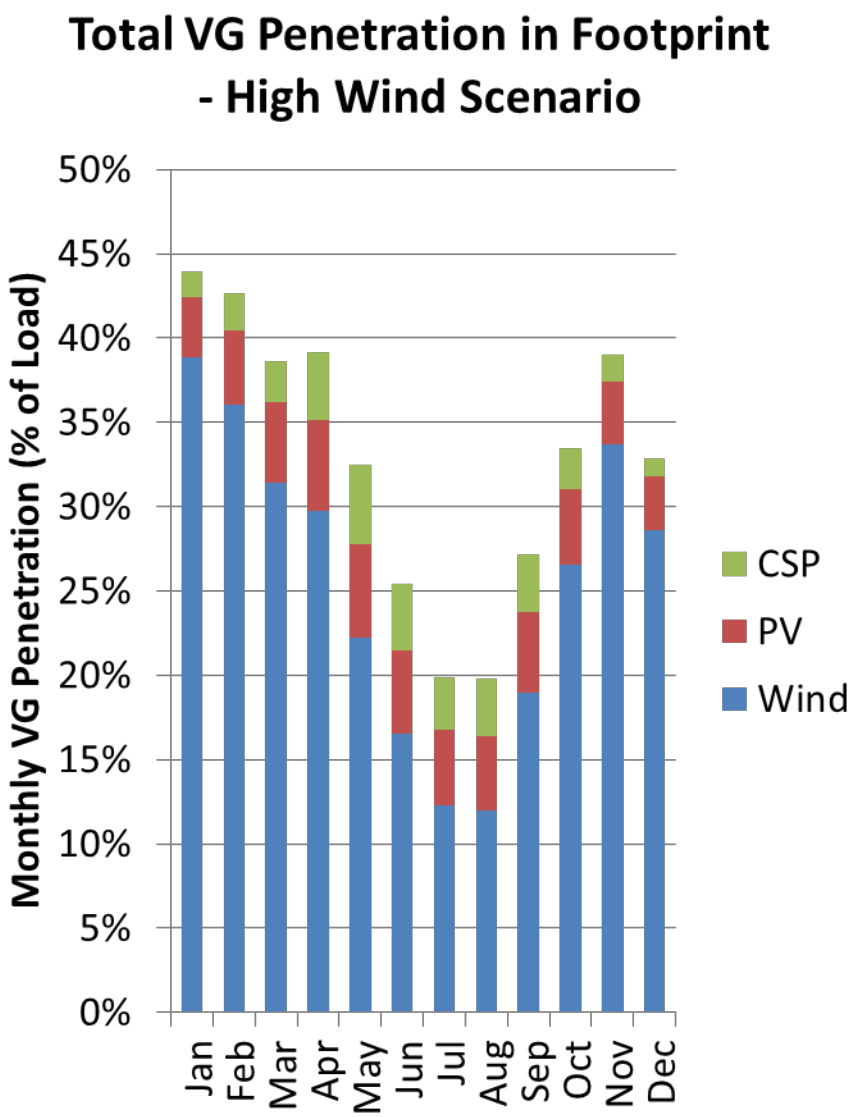
… High-Mix Scenario



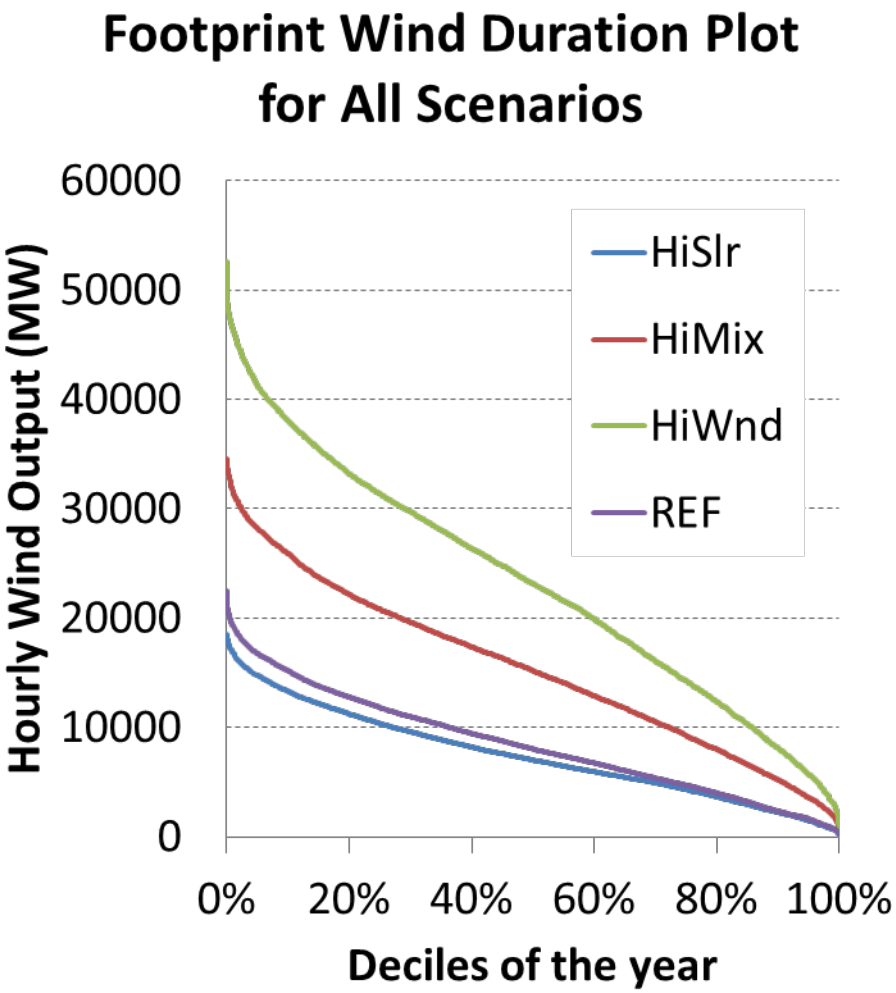


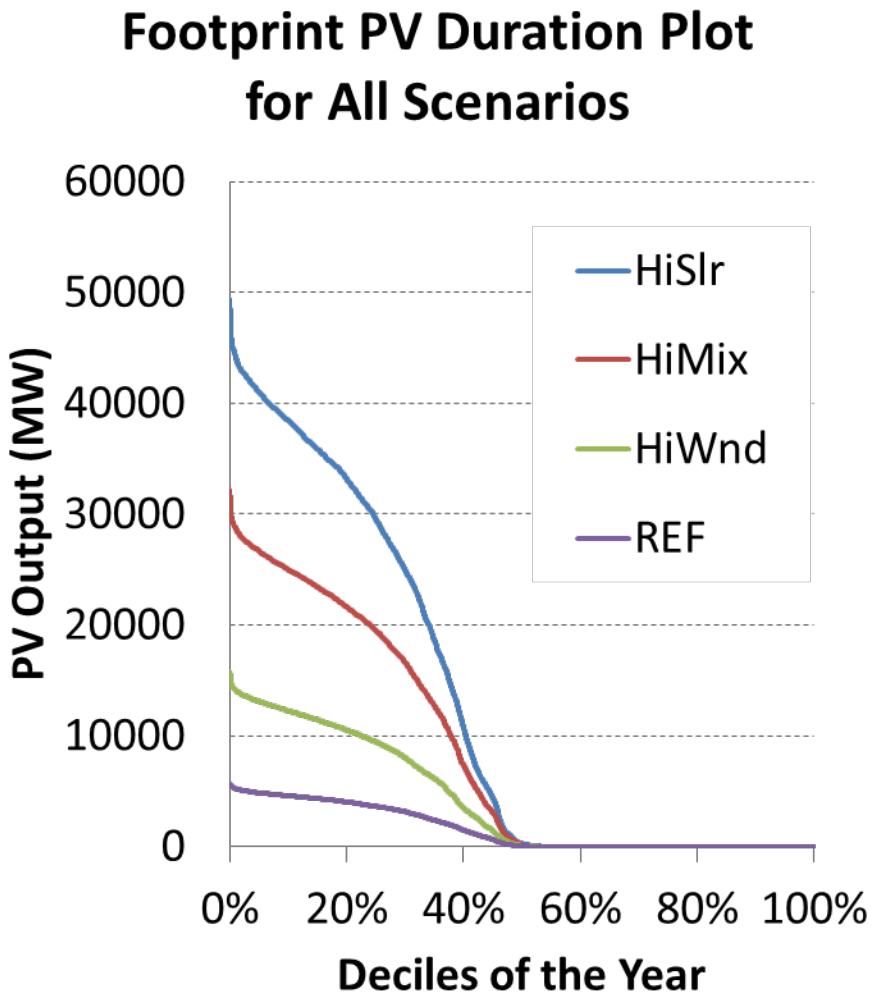
… High-Wind Scenario



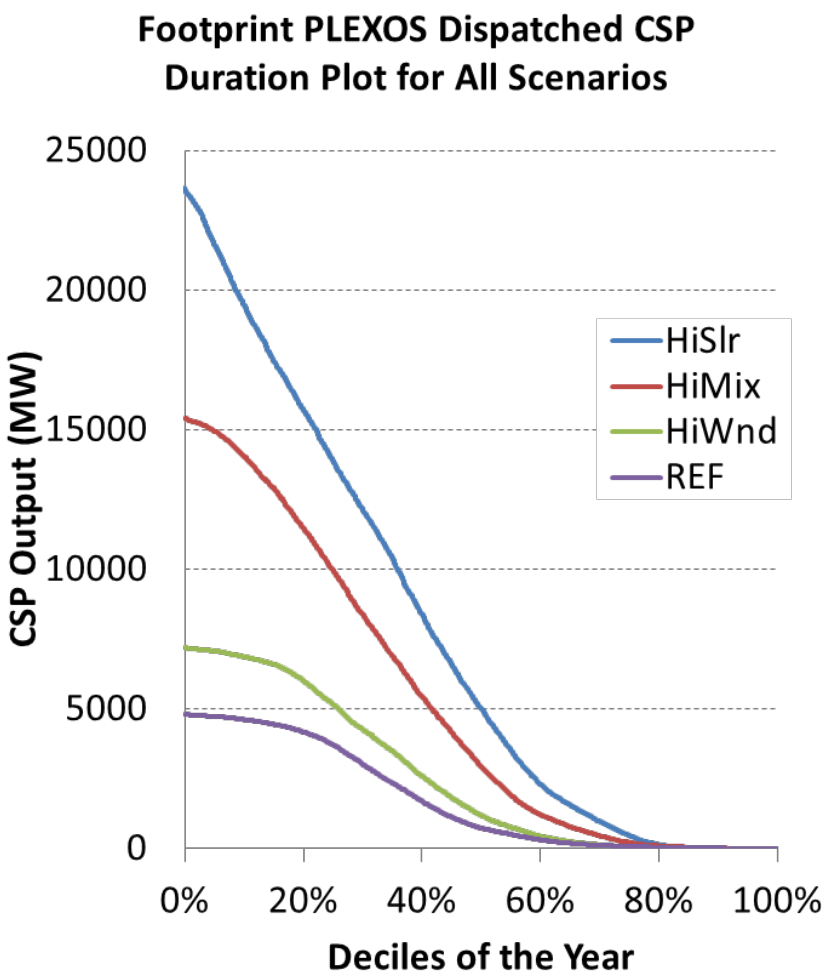


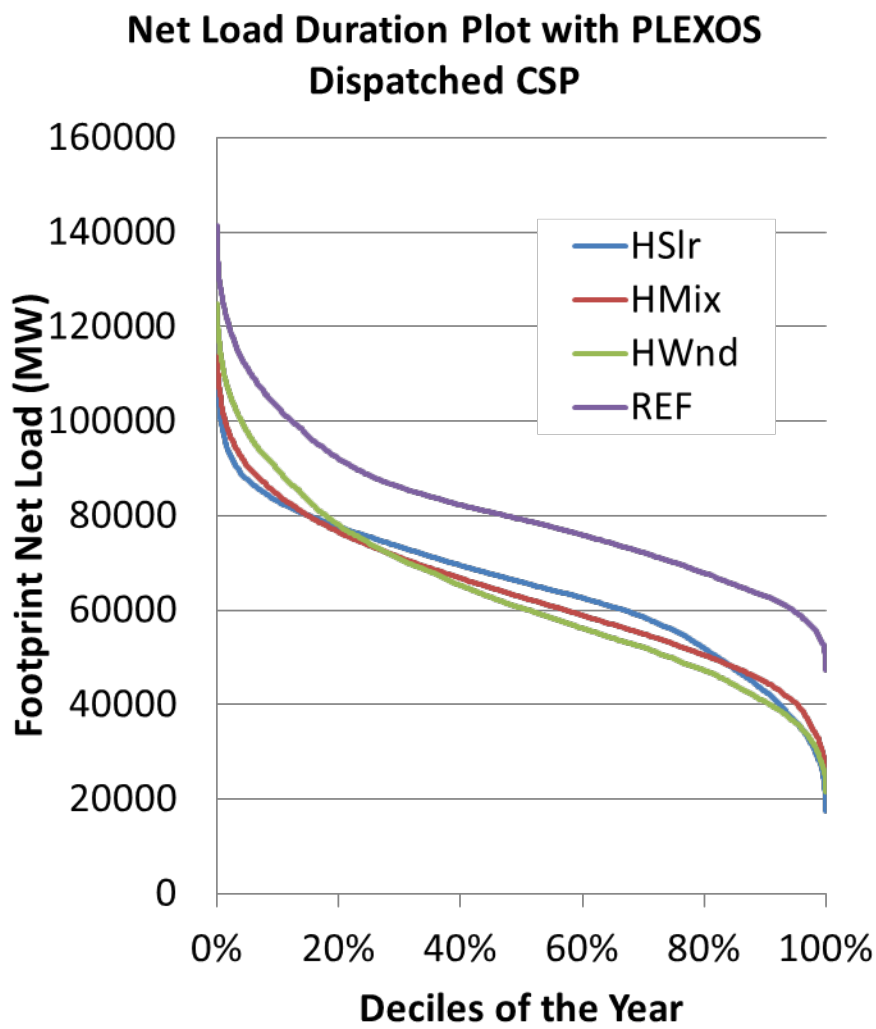
Duration Curves for Wind and PV



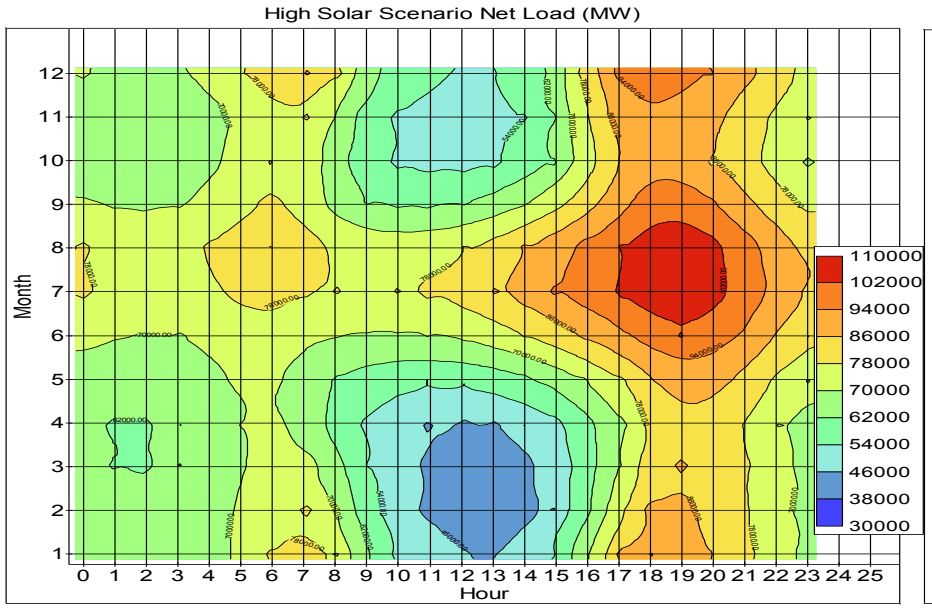


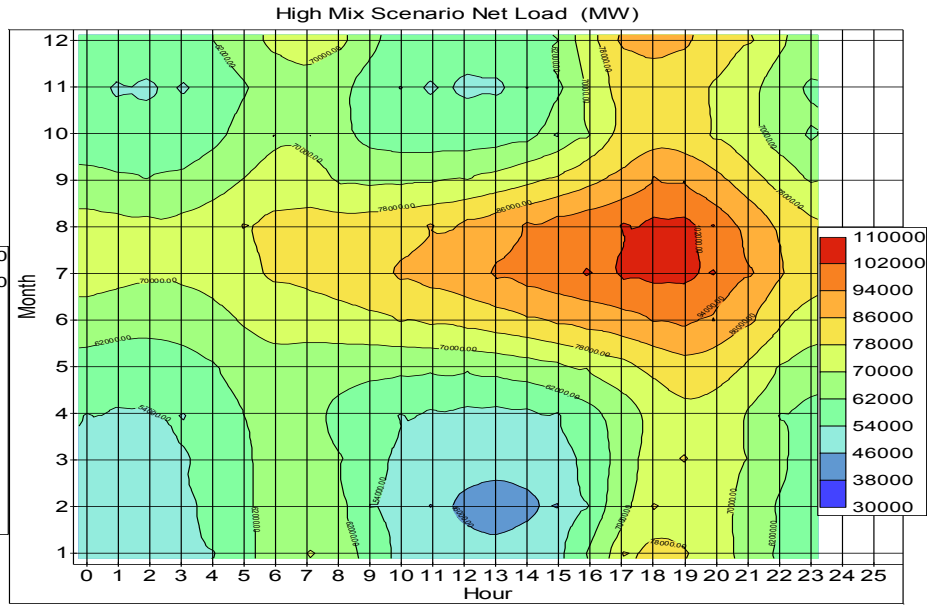
… Dispatched CSP and Net Load

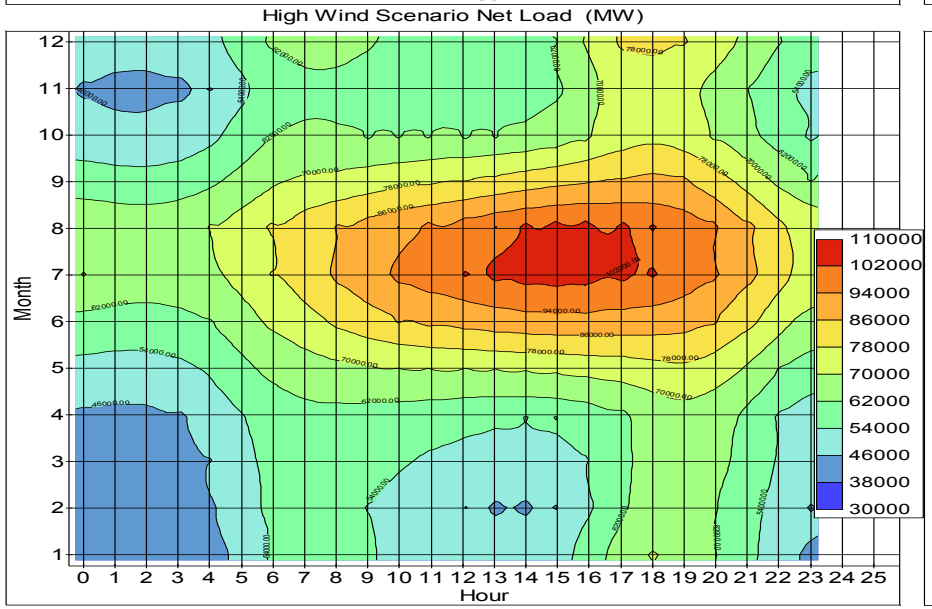


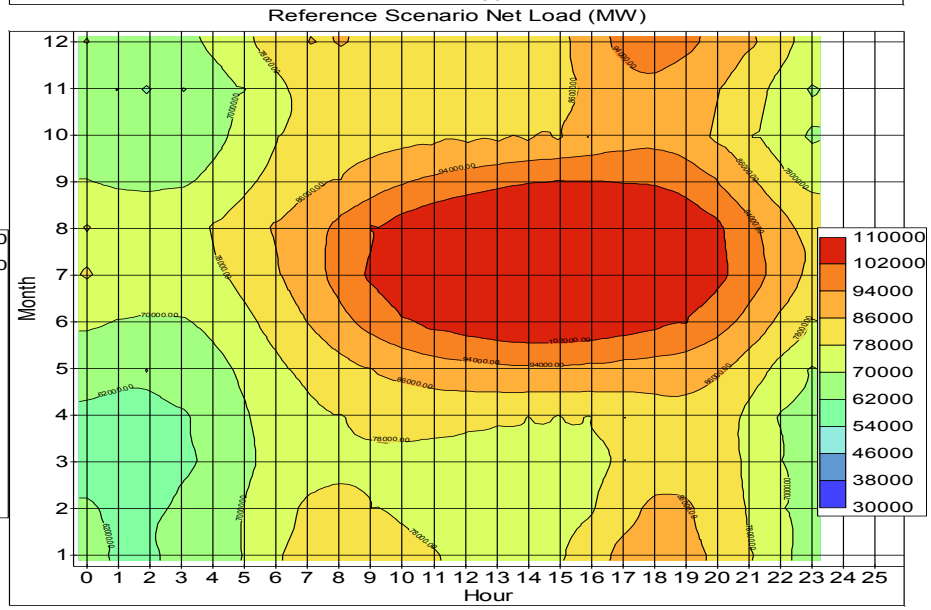


Net Load Timing - Monthly Average Values

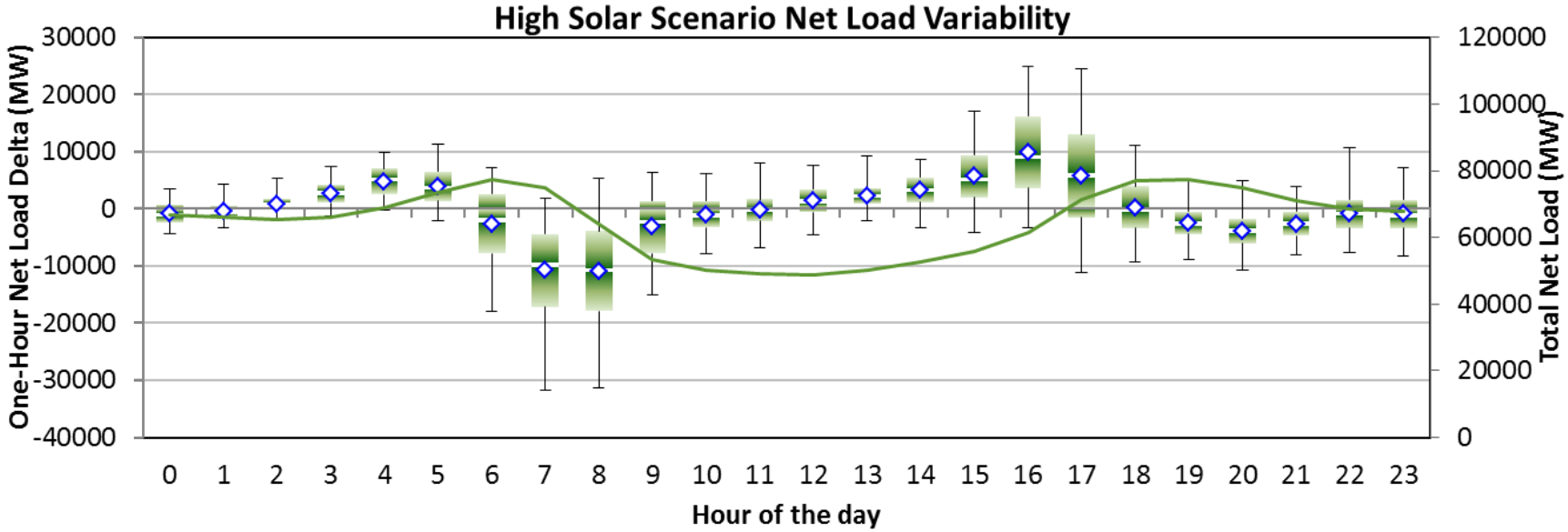


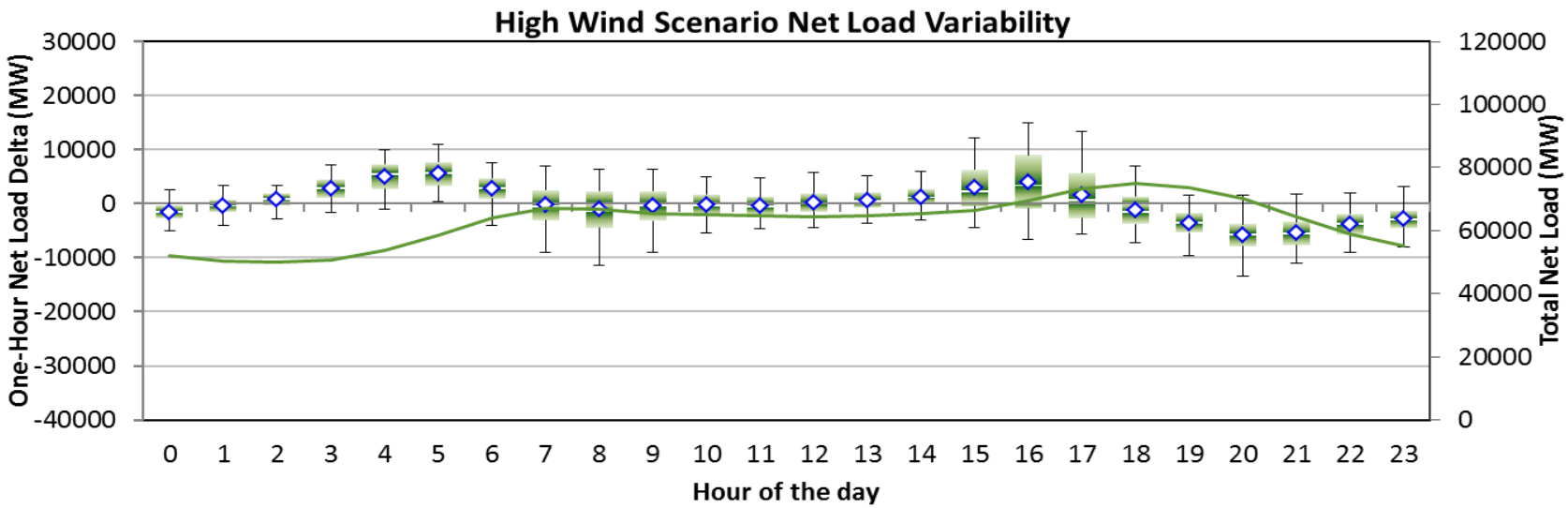






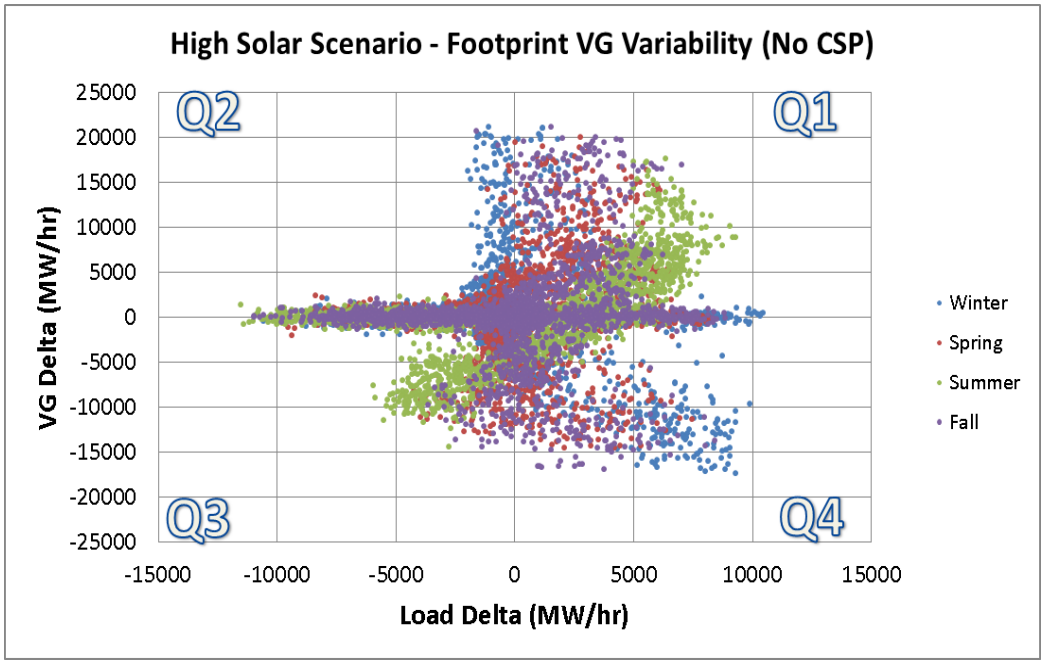
Diurnal Variability with CSP



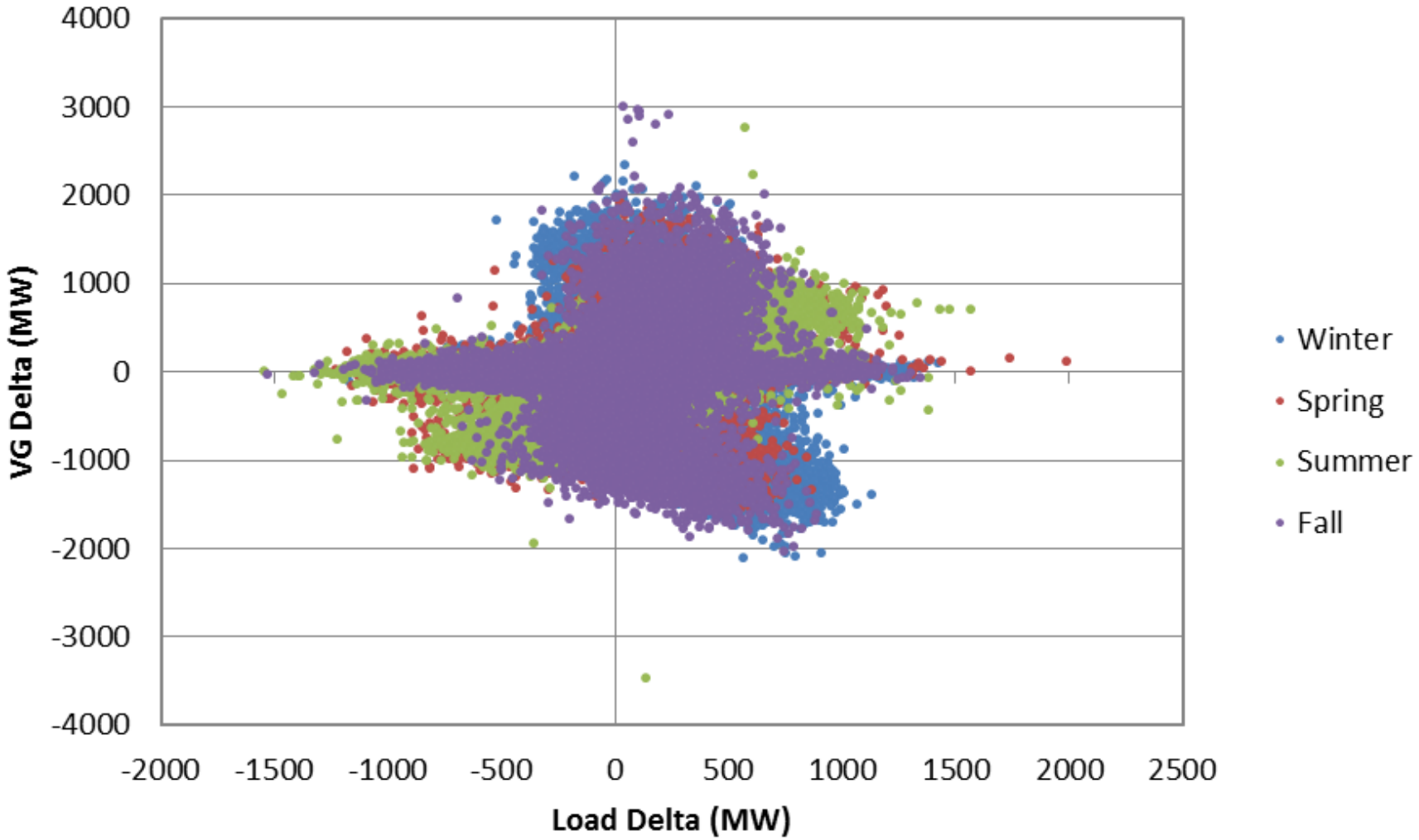


Seasonal Variability

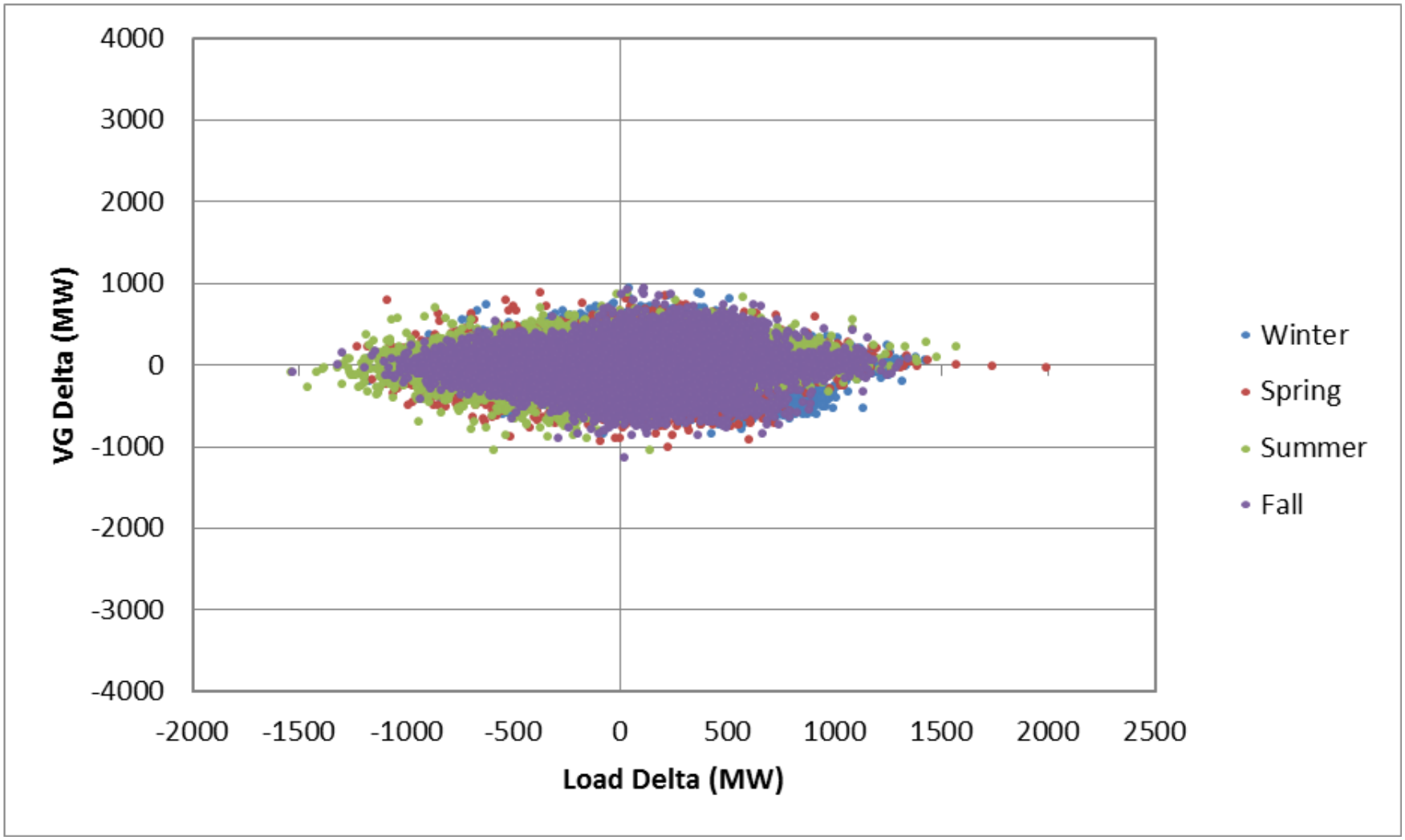
- **Plot of hourly load change vs. variable generation change**
- **Four quadrants**
  - Q1 Load and VG up-ramps
  - Q2 Load down, VG up, net load falls
  - Q3 Load and VG down
  - Q4 Load up, VG down, net load rises



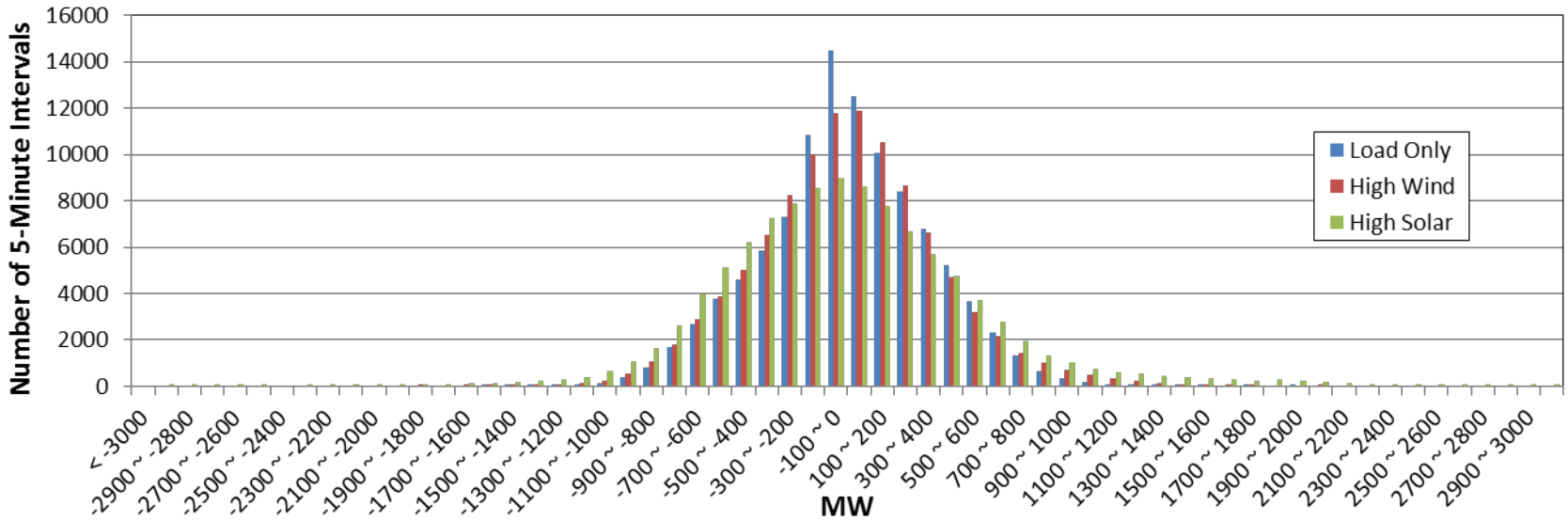
High-Solar 5-Minute VG Changes

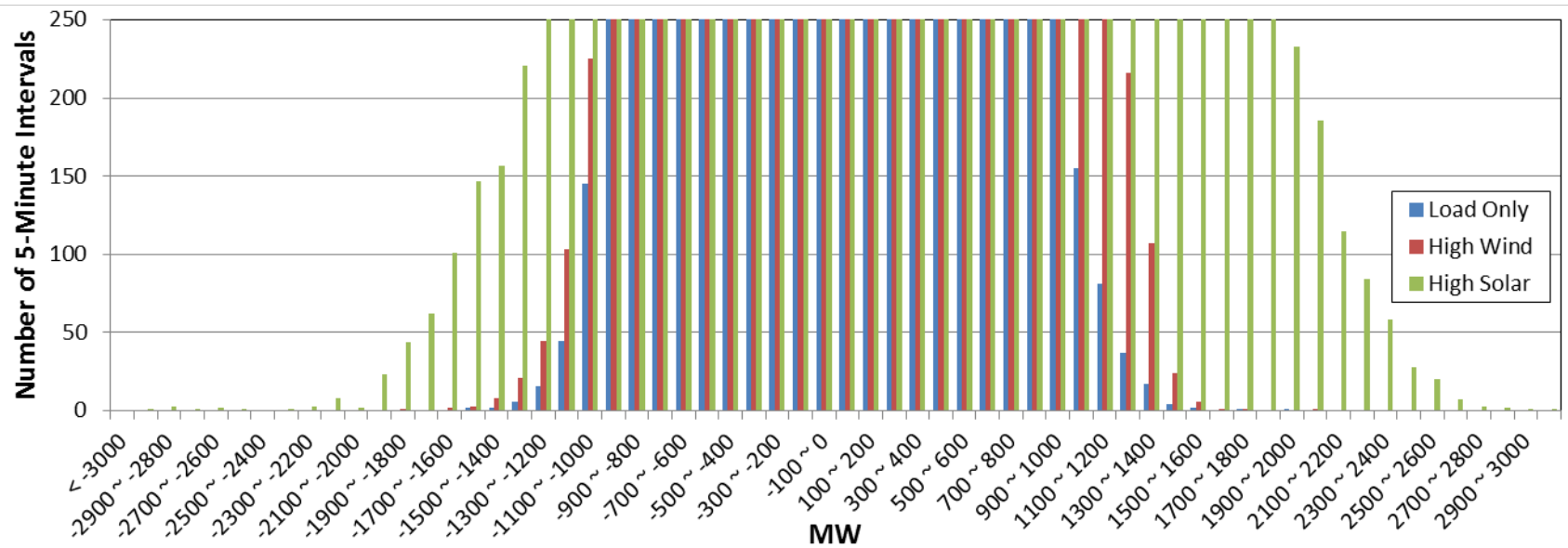


High-Wind 5-Minute VG Changes



Distribution of 5-Minute Net Load Changes

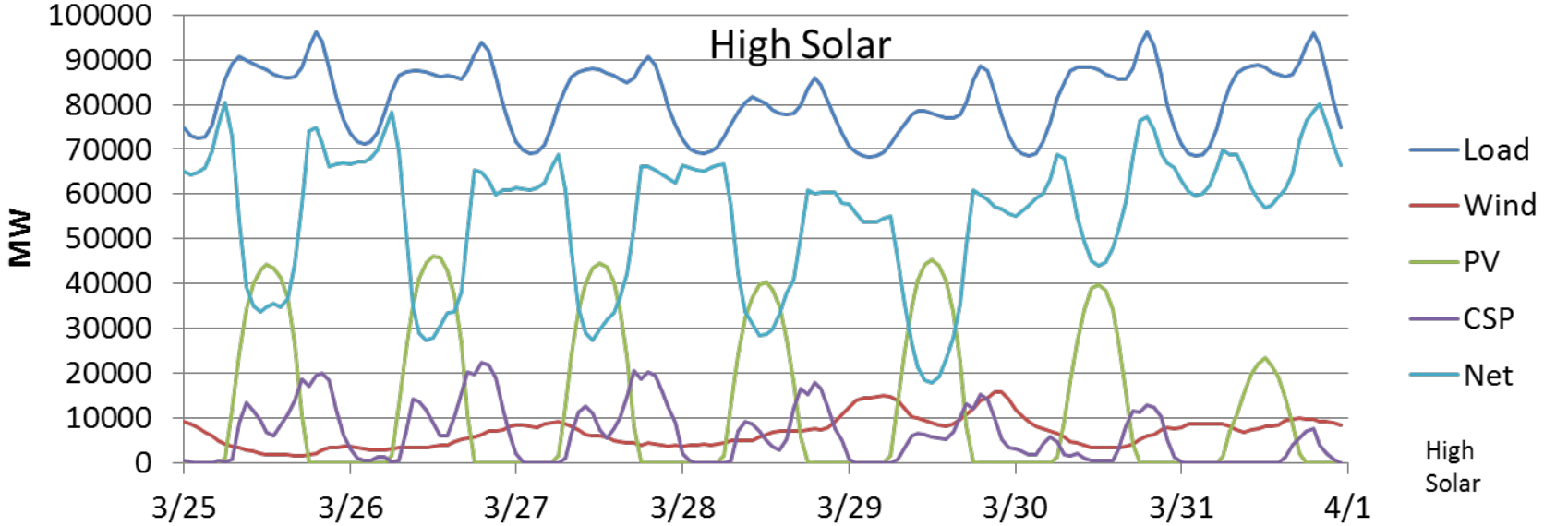


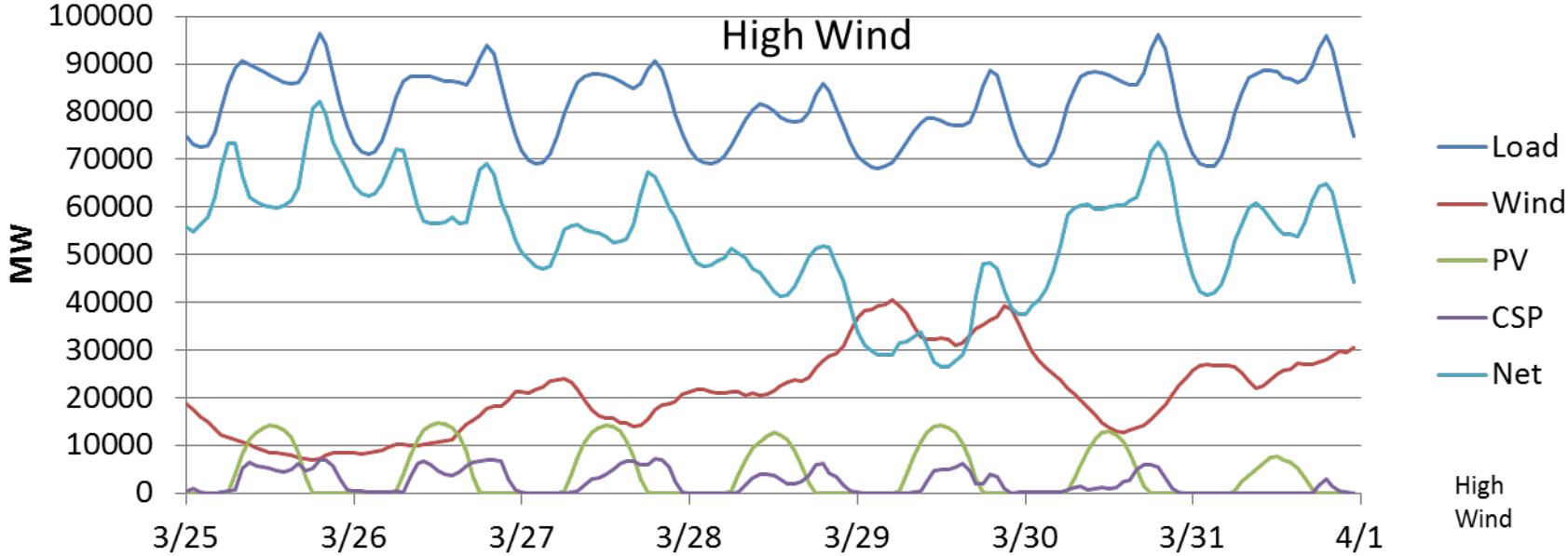


1-hour and 5-Minute Net Load Change Statistics

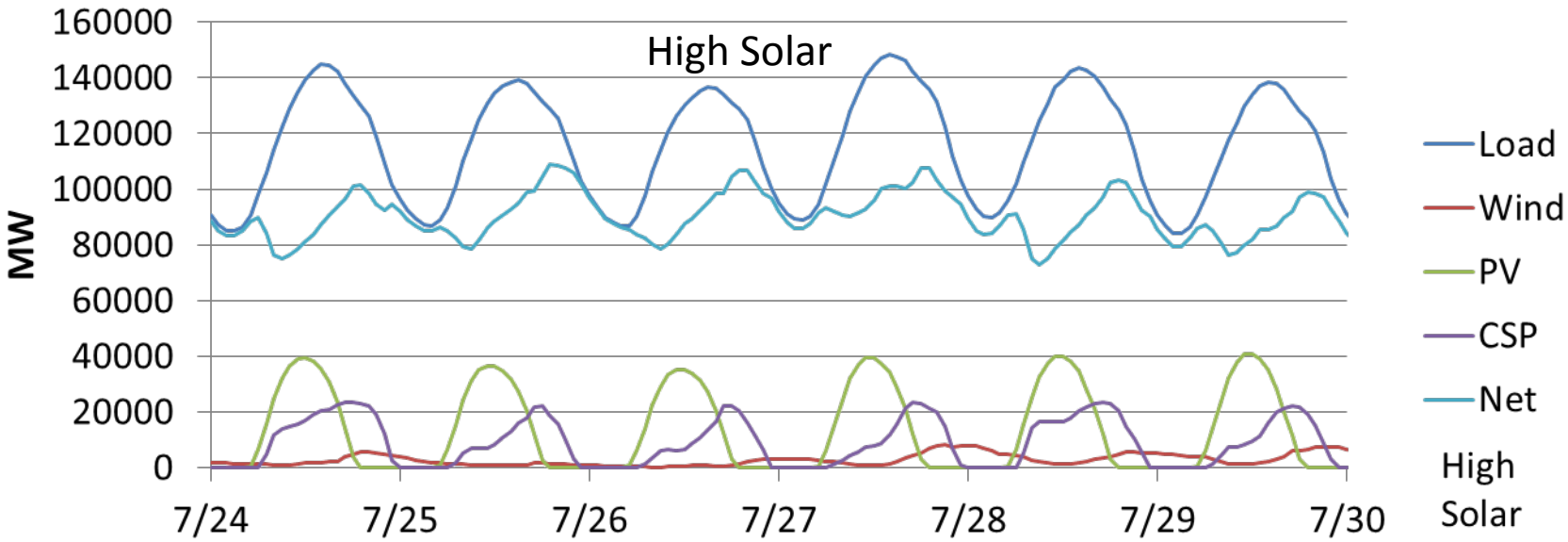
	1 Hour	5 Minute
Sigma (MW)		
Load-alone	3929	358
TEPPC Scenario	3983	366
High-Solar Scenario	6279	548
High-Mix Scenario	4954	447
High-Wind Scenario	4189	390
Max Neg Delta (MW)		
Load-alone	-11534	-1541
TEPPC Scenario	-12827	-1551
High-Solar Scenrio	-22257	-2966
High-Mix Scenario	-15661	-2015
High-Wind Scenario	-13478	-1879
Max Pos Delta (MW)		
Load-alone	10451	1991
TEPPC Scenario	11194	2001
High-Solar Scenrio	26671	3611
High-Mix Scenario	20391	2355
High-Wind Scenario	14166	2020
No. Drops < 3 * Load Sigma		
Load-alone	0	97
TEPPC Scenario	1	137
High-Solar Scenrio	222	1596
High-Mix Scenario	31	431
High-Wind Scenario	6	219
No. Rises > 3* Load Sigma		
Load-alone	0	174
TEPPC Scenario	0	209
High-Solar Scenrio	371	3973
High-Mix Scenario	217	2340
High-Wind Scenario	39	791

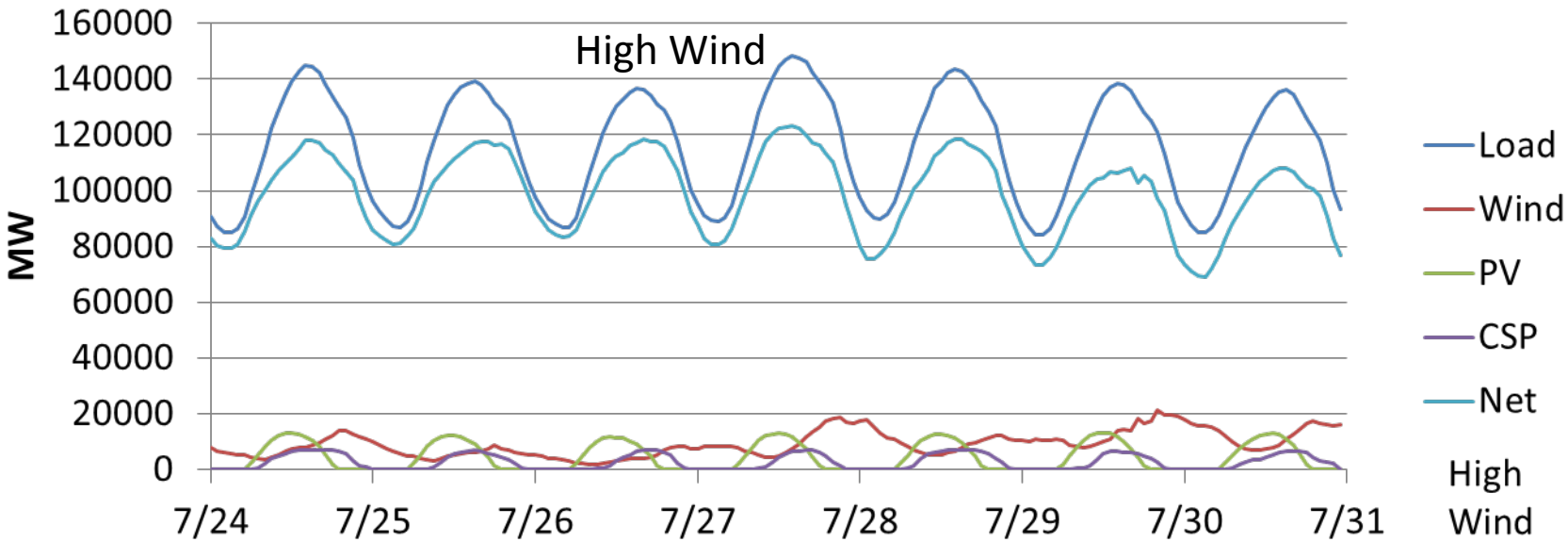
Typical Profiles – A Week in March



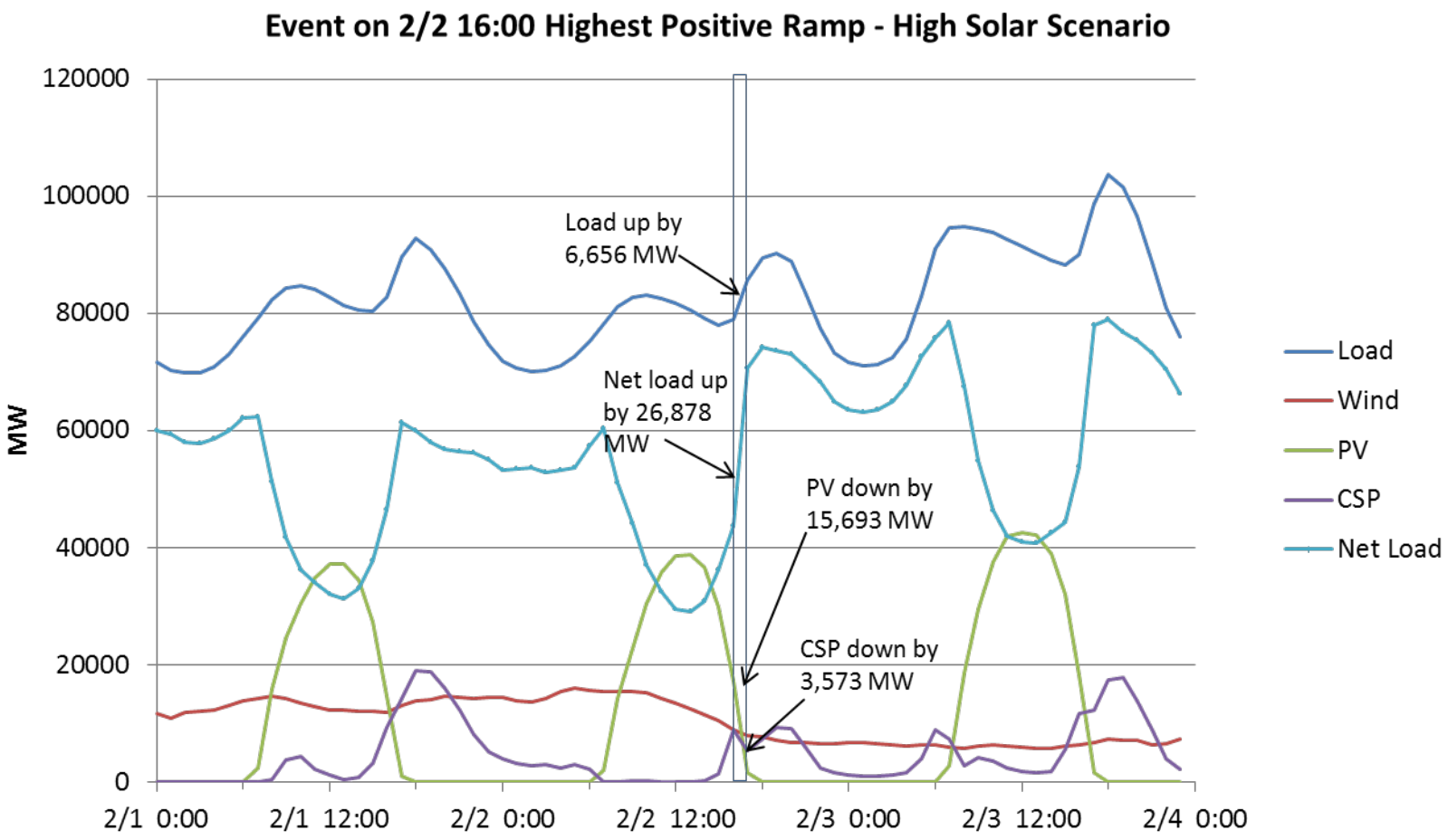


… and a Week In July

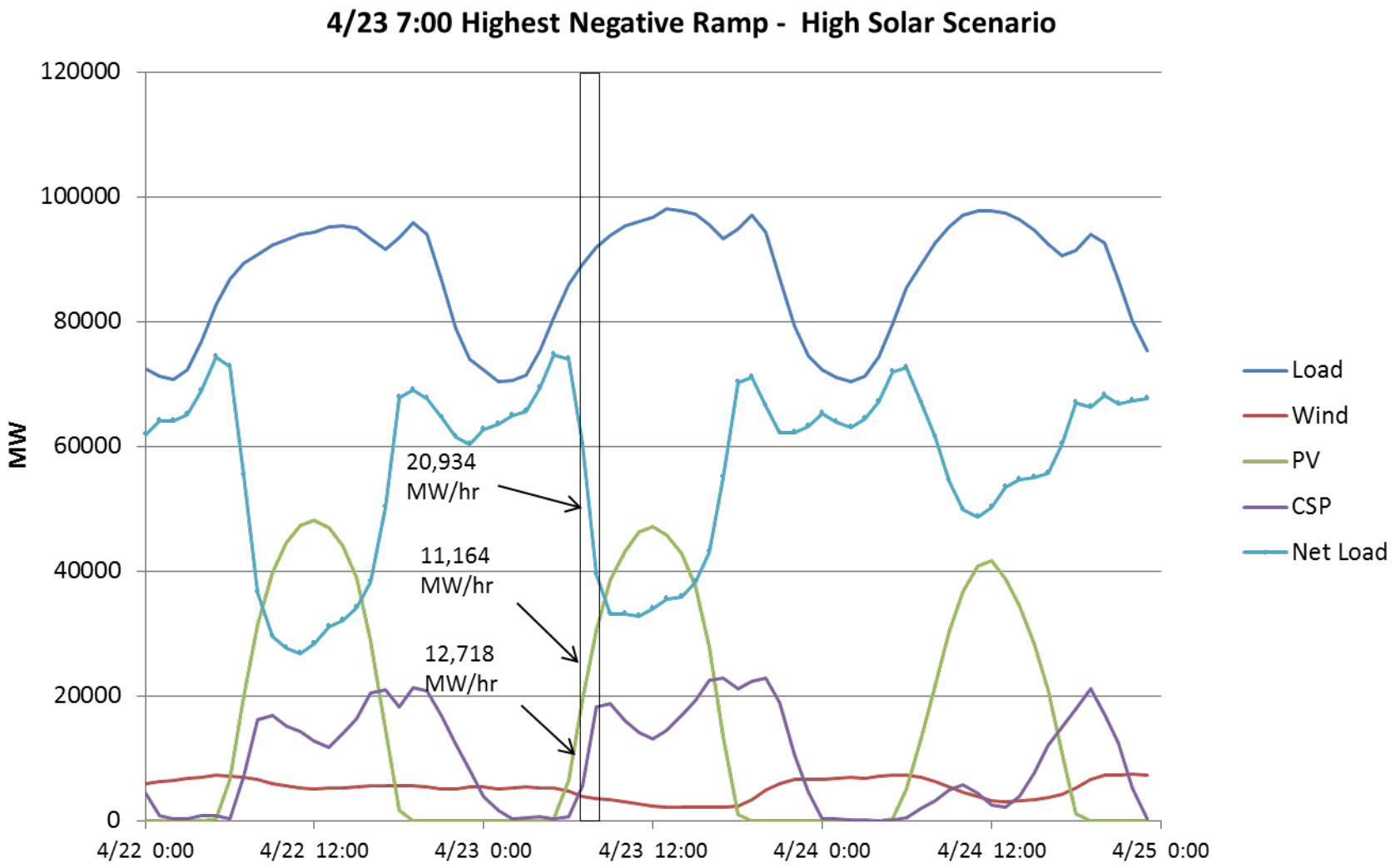




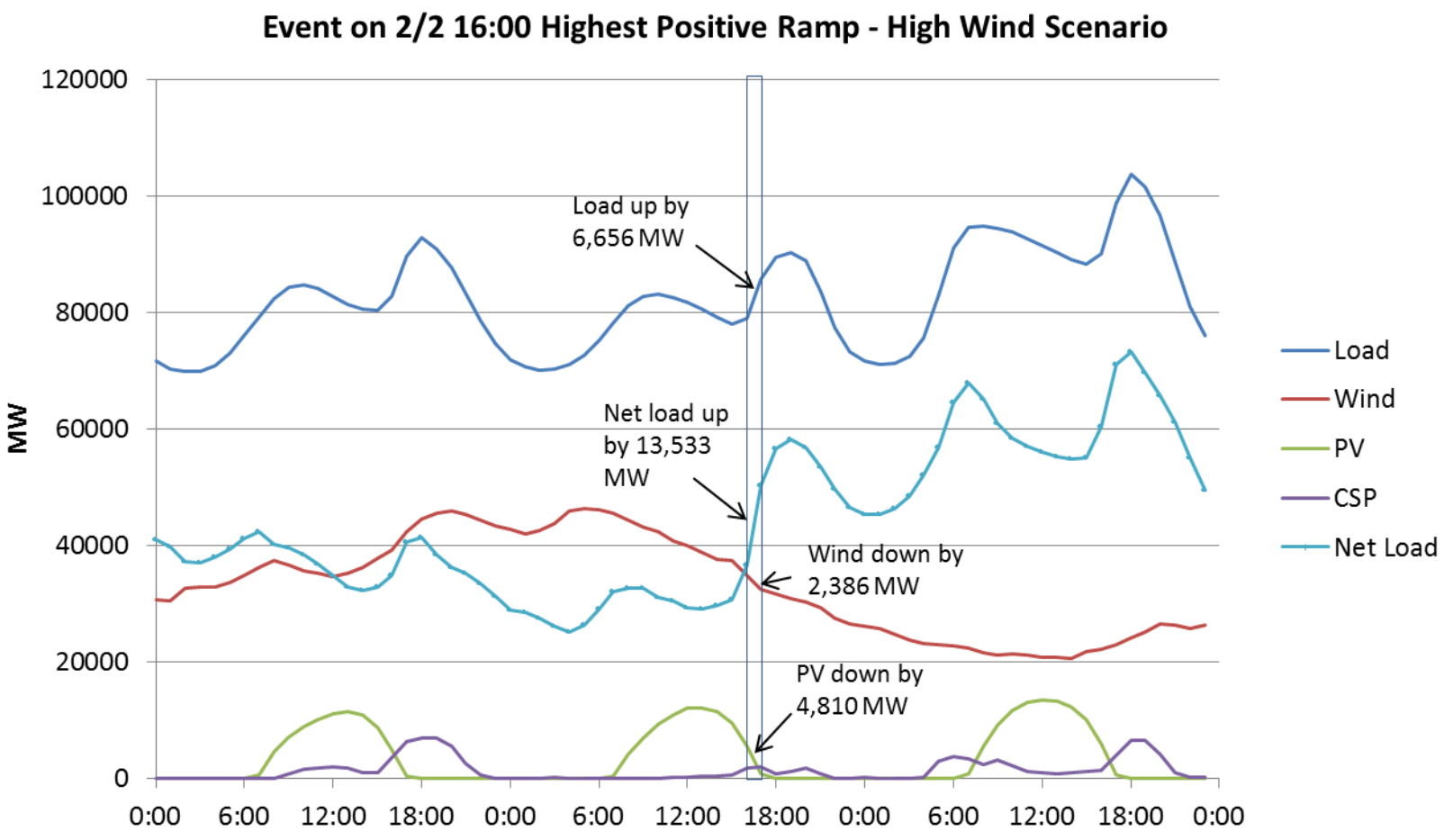
Events - High-Solar Highest Positive Net Load Ramp



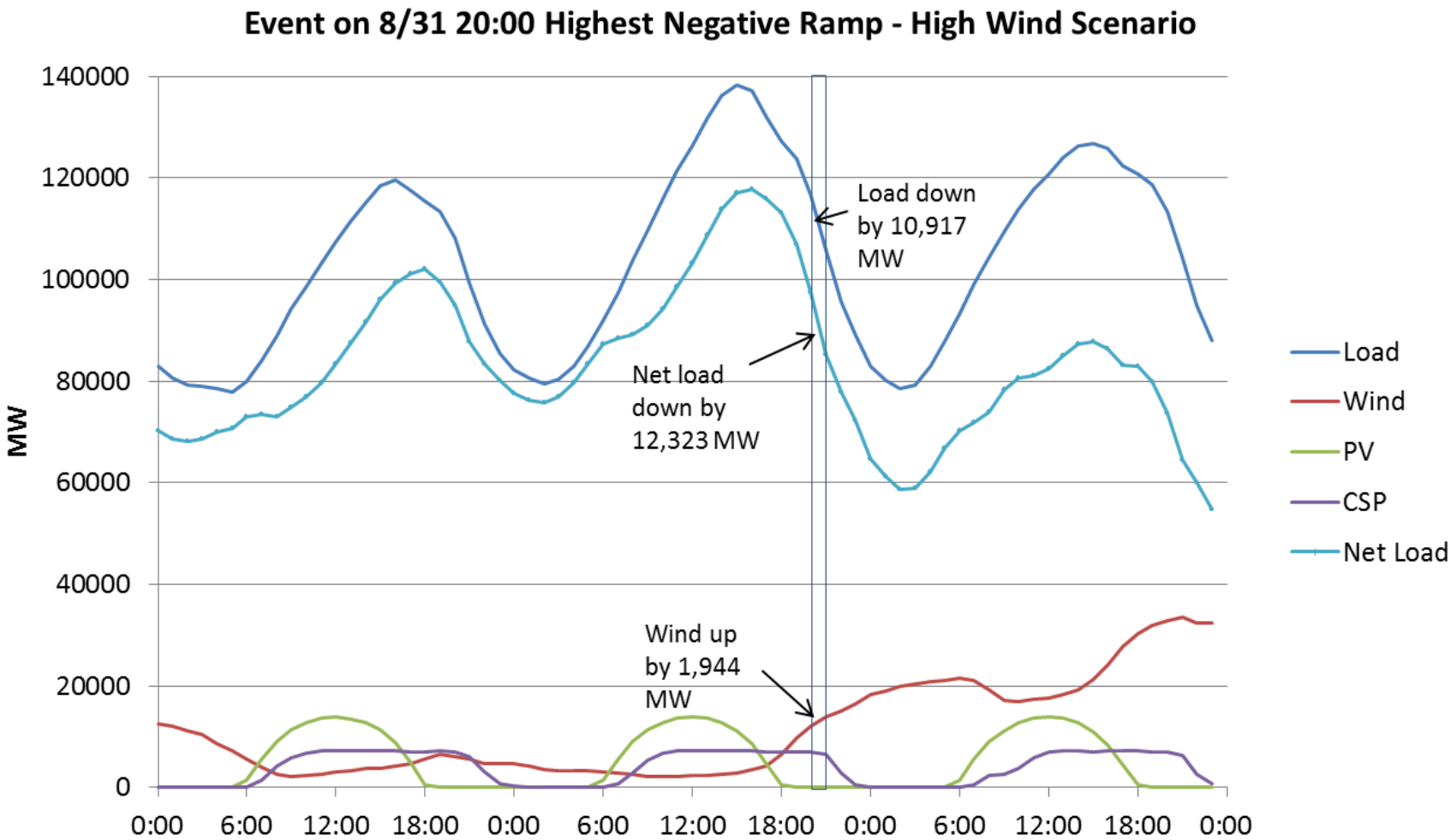
High-Solar Highest Negative Net Load Ramp



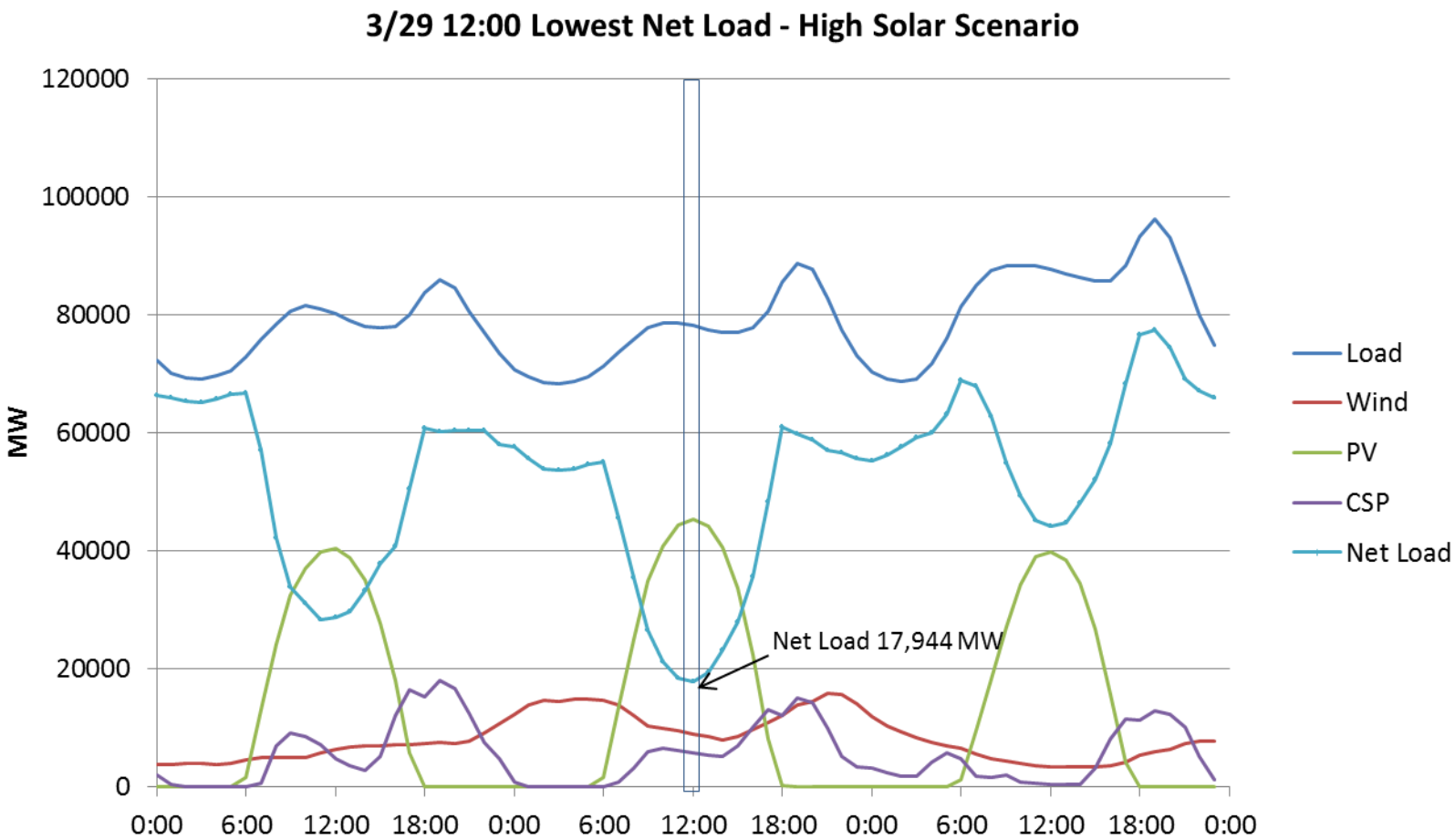
High-Wind Highest Positive Net Load Ramp



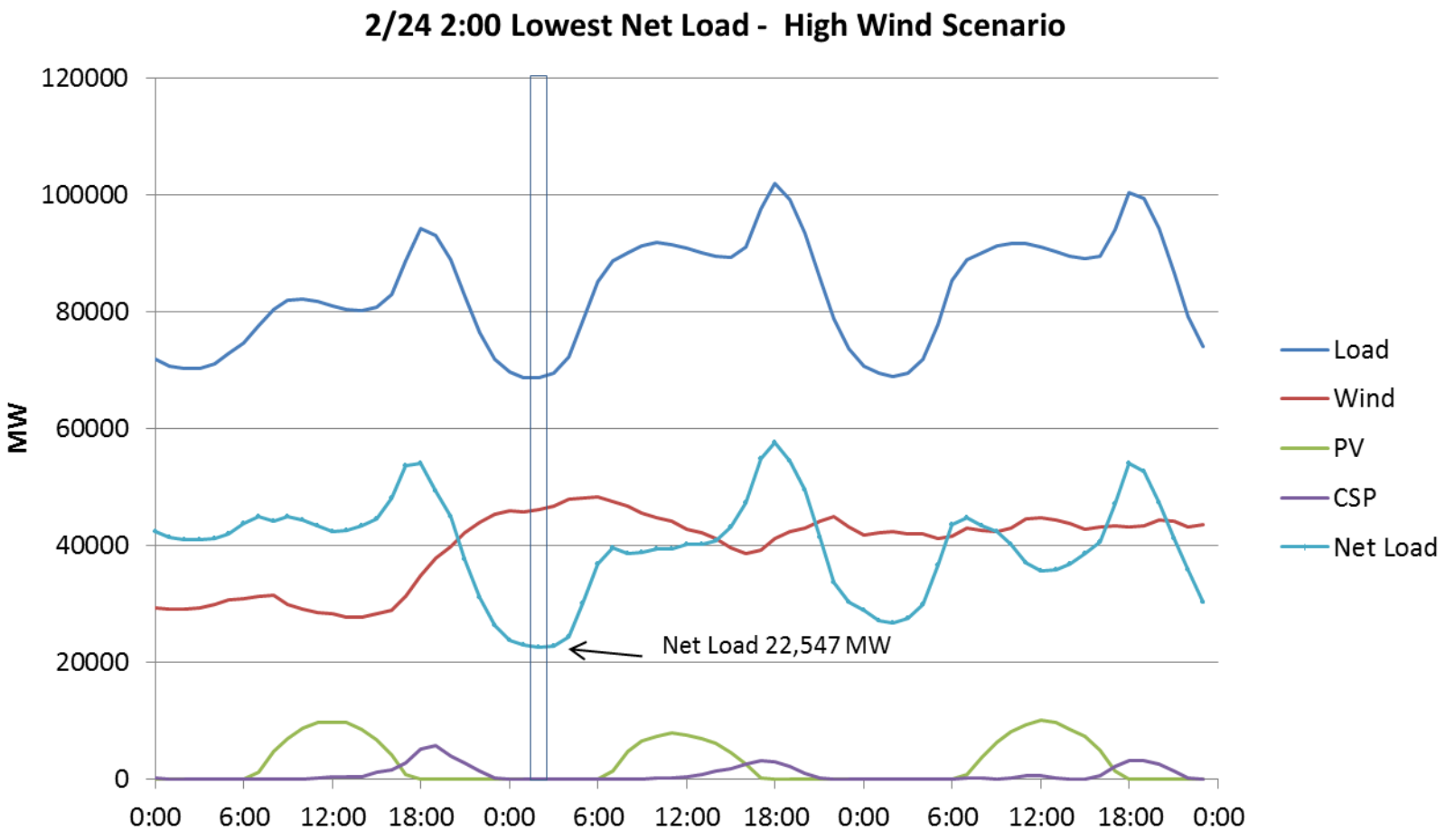
High-Wind Highest Negative Net Load Ramp



High-Solar Lowest Net Load



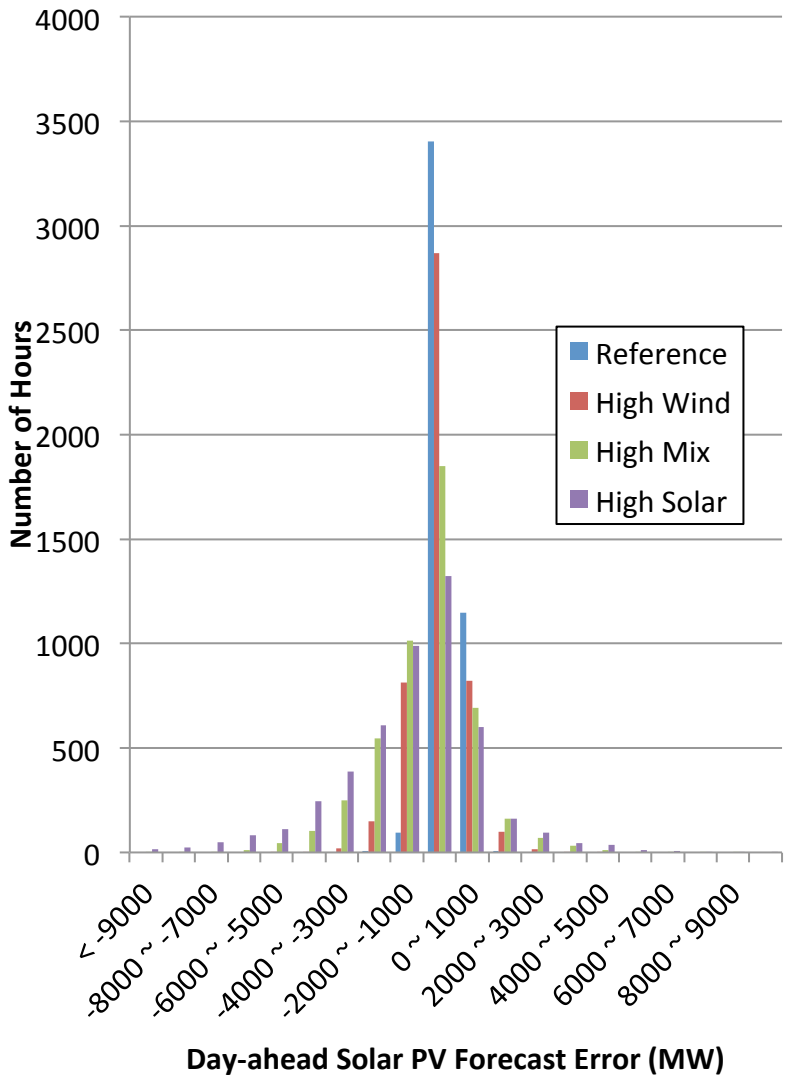
High-Wind Lowest Net Load

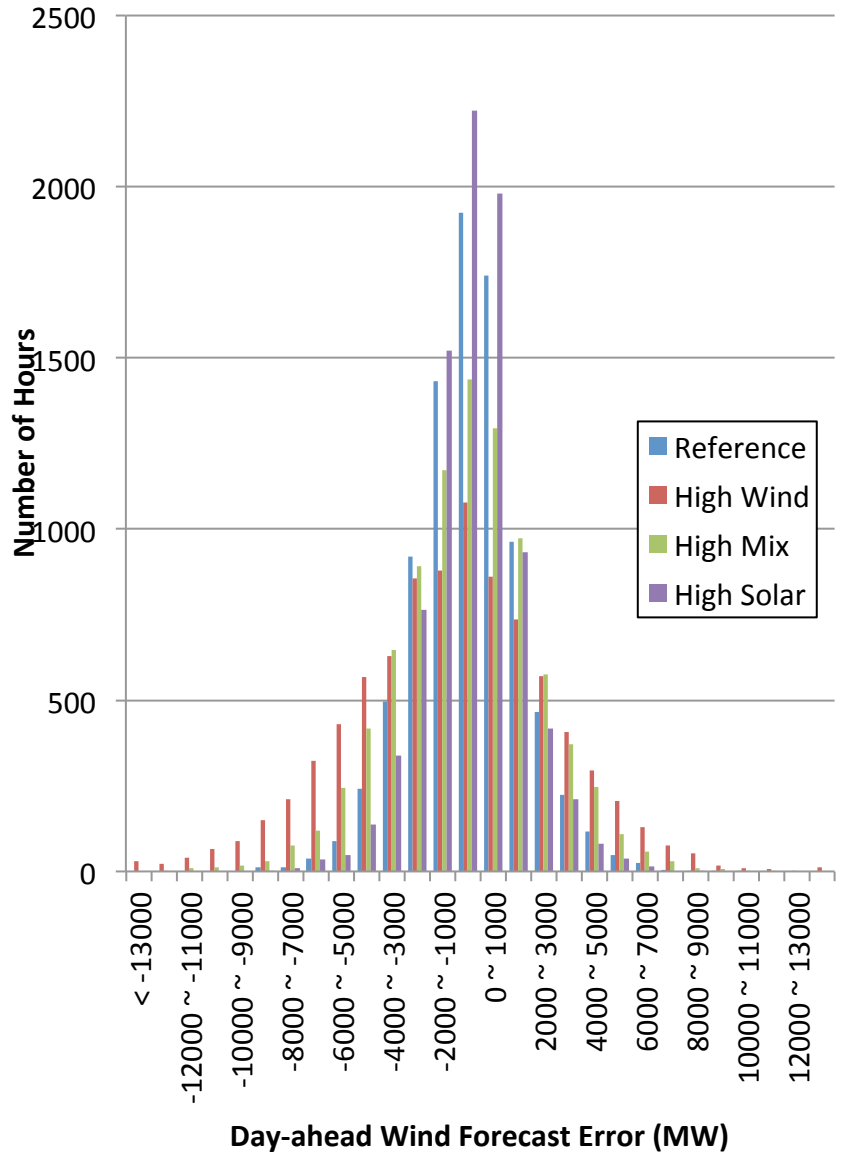


Forecast Error Analysis

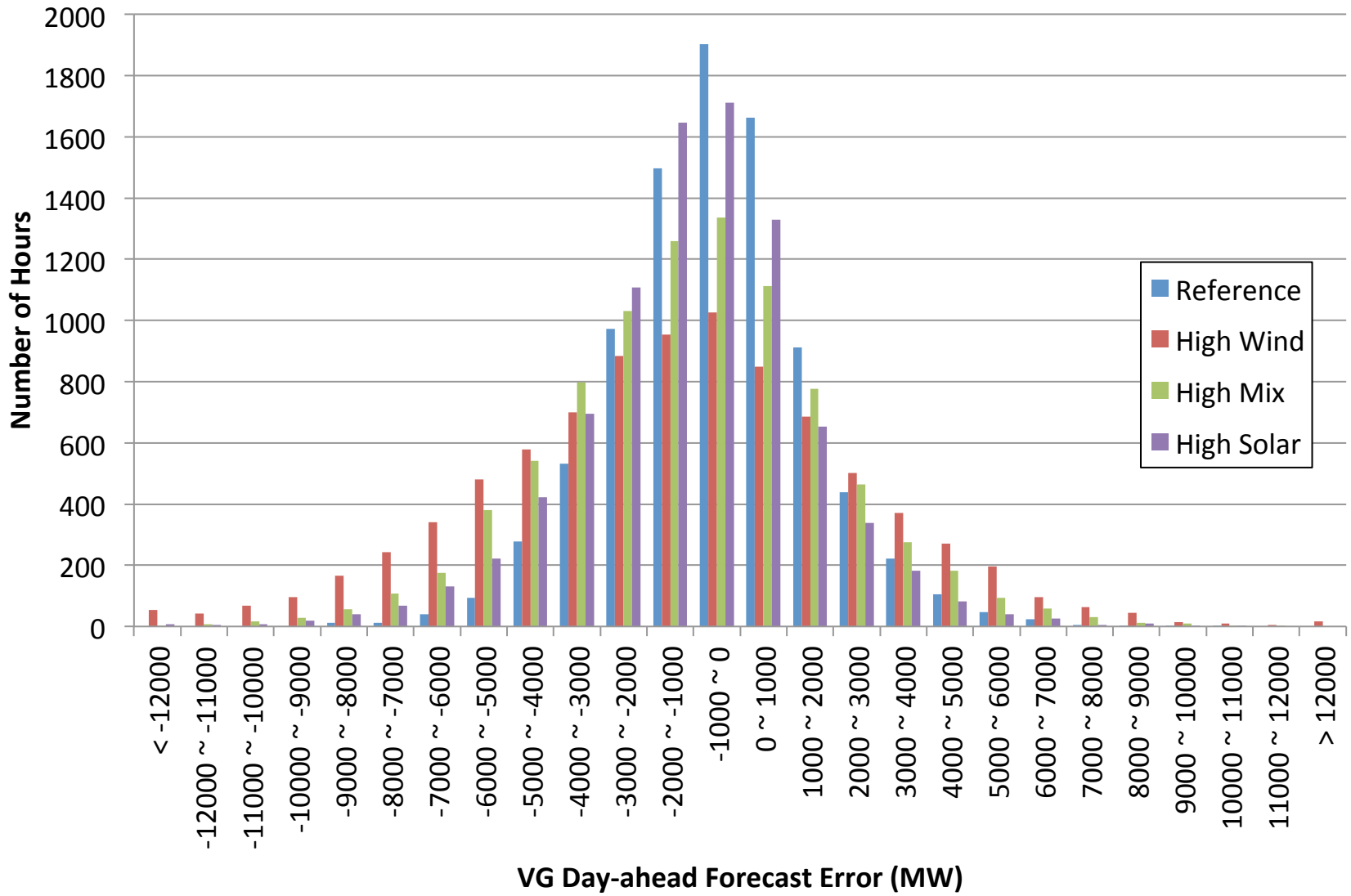
- **Day-ahead wind forecast error distribution for wind, solar and net load**
- **4-hour-ahead forecast errors**
- **Compare the error statistics for day-ahead and 4-hour-ahead forecasts**

Day-Ahead Forecast Error Distributions

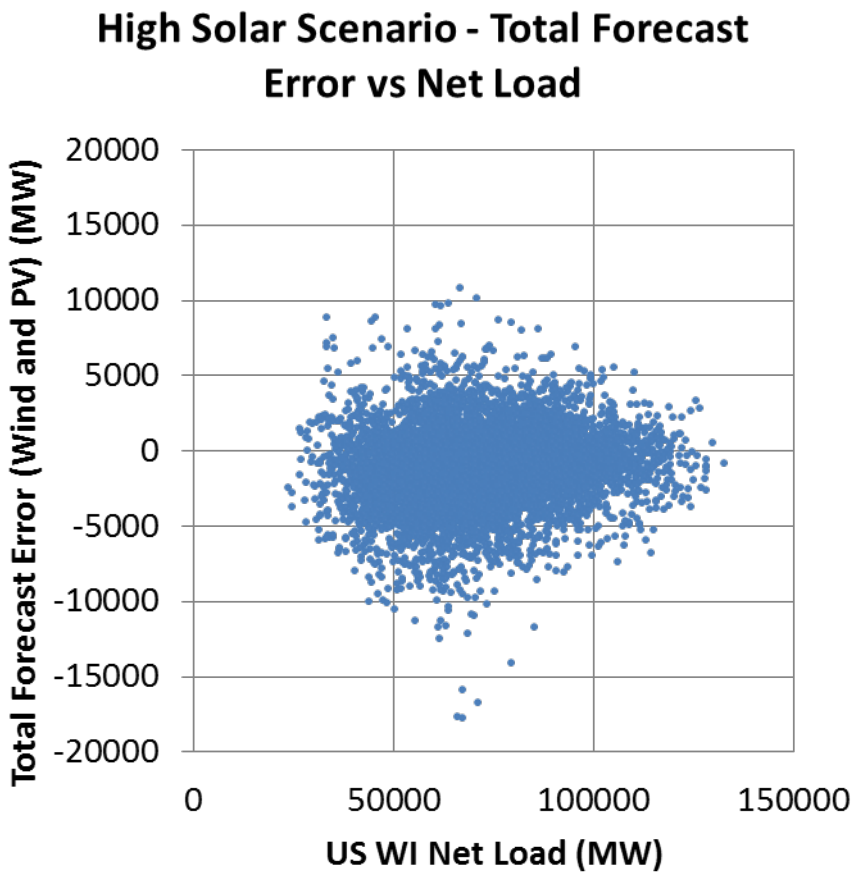


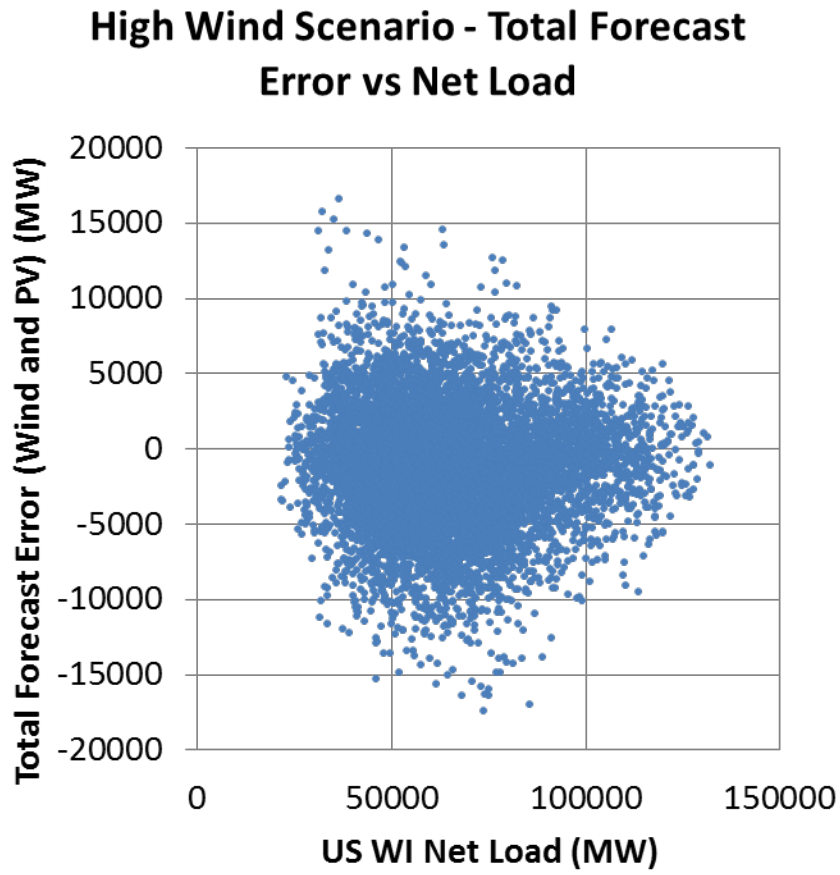


Day-ahead Total VG Forecast Error



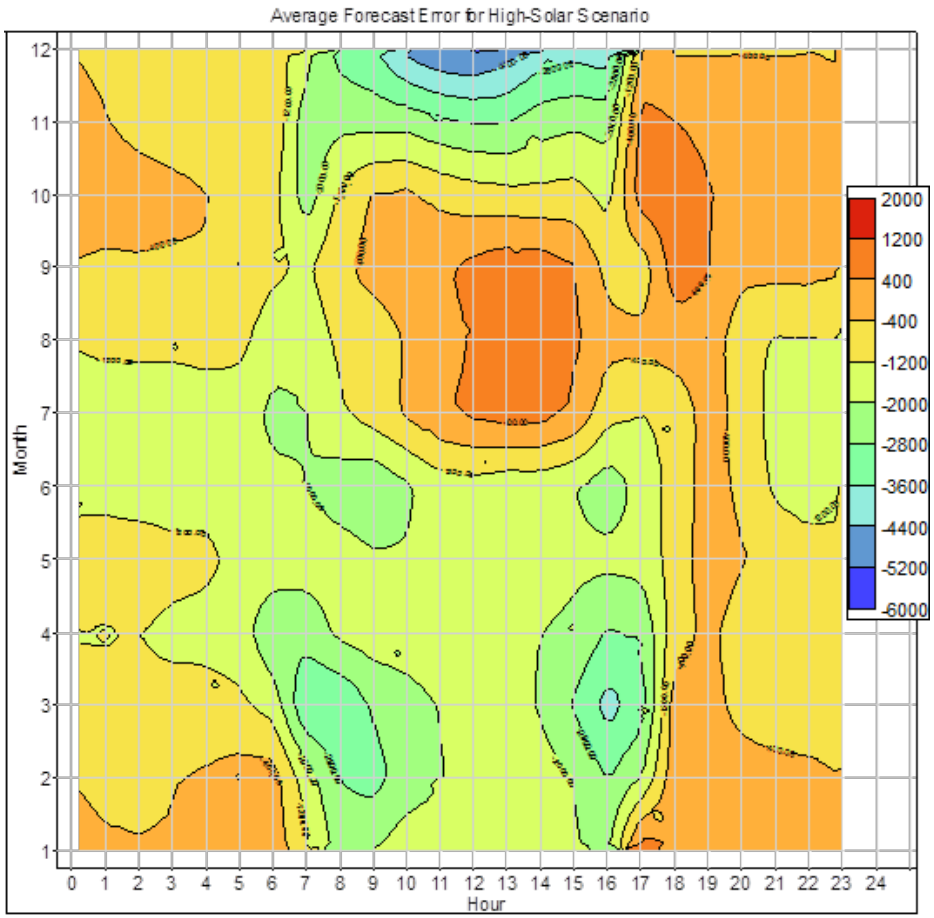
Forecast Error and Net Load



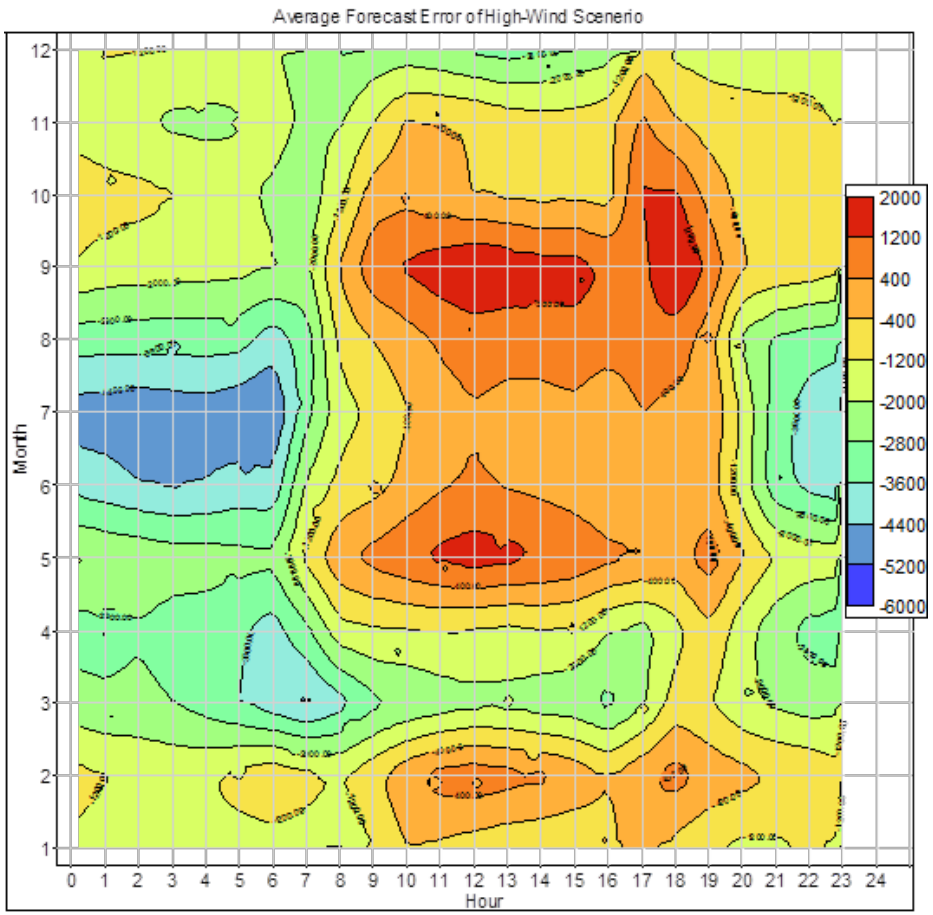


When Forecast Errors Occur

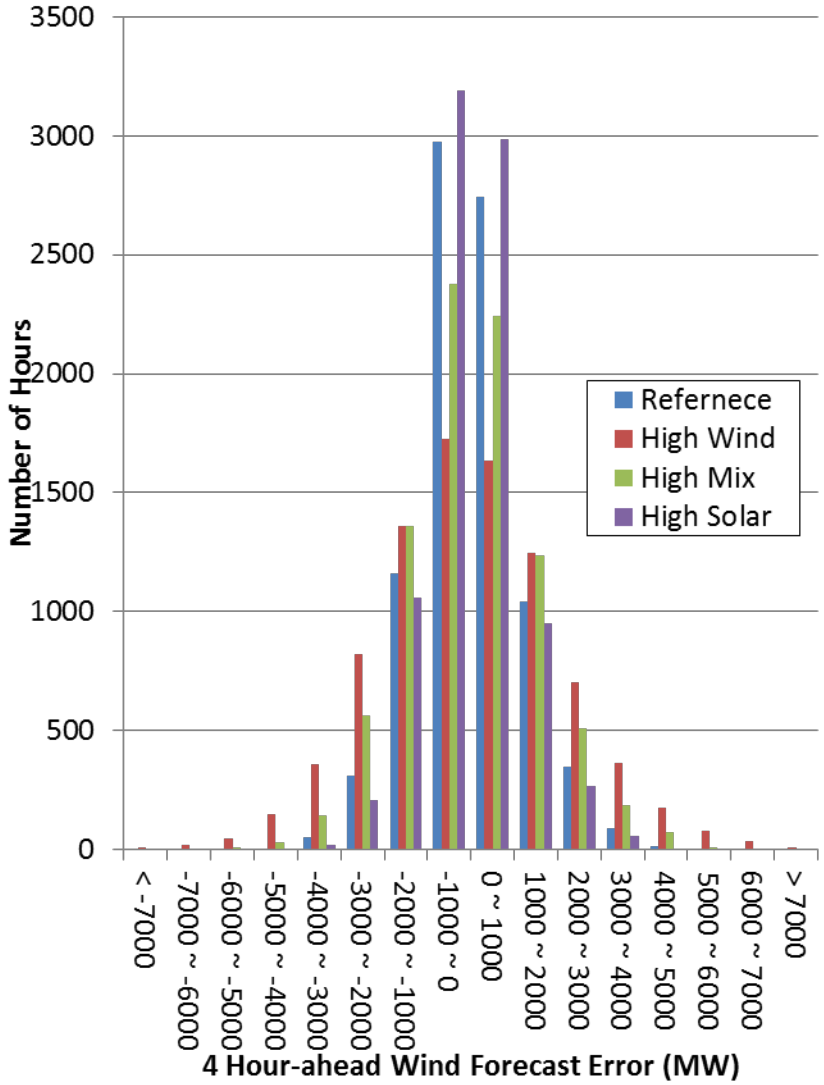
High-Solar Scenario Monthly Average Total Forecast Errors

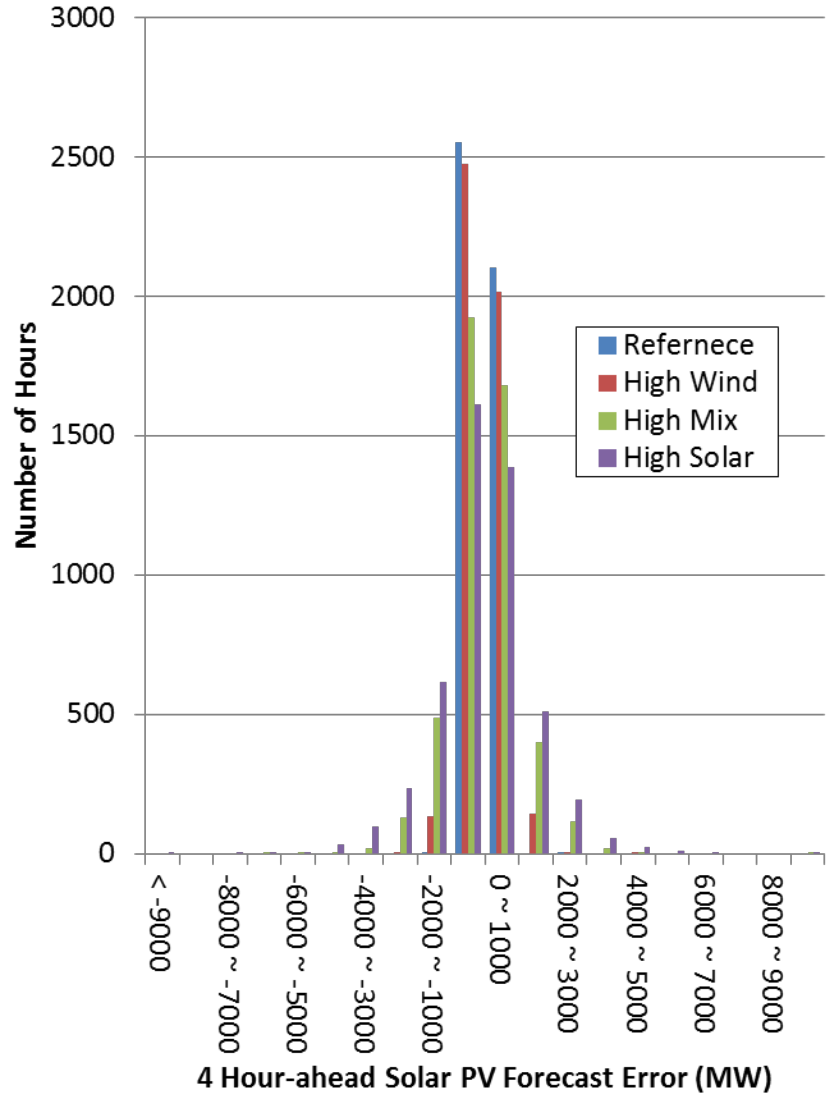


High-Wind Scenario Monthly Average Total Forecast Errors

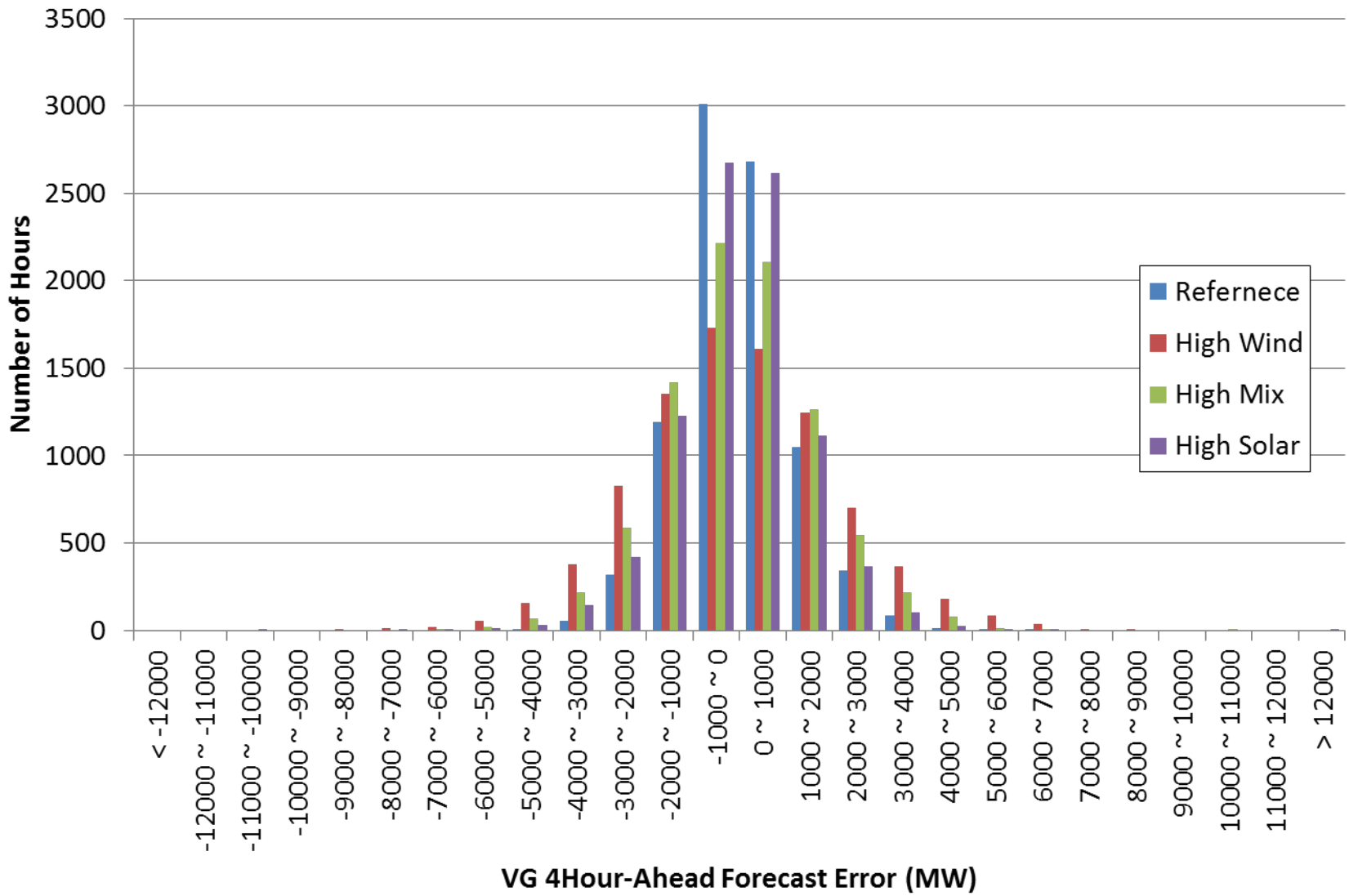


4 Hour-Ahead Forecast Error Distributions

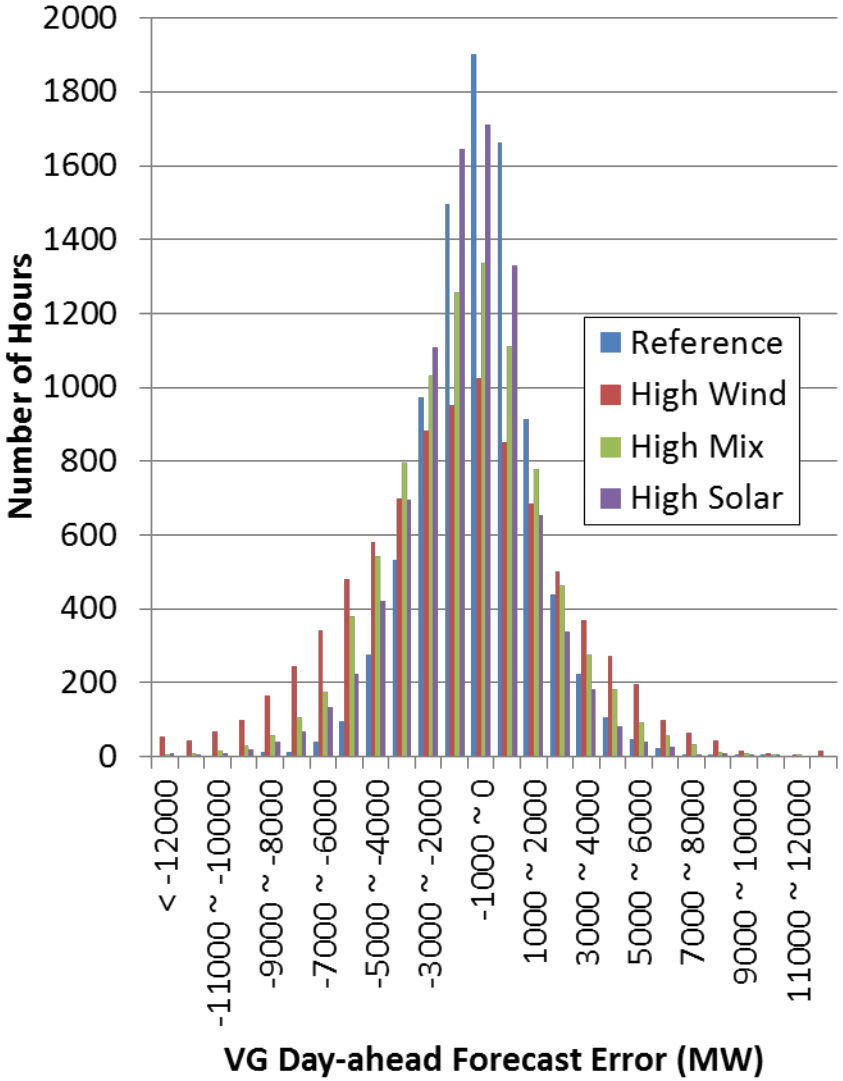


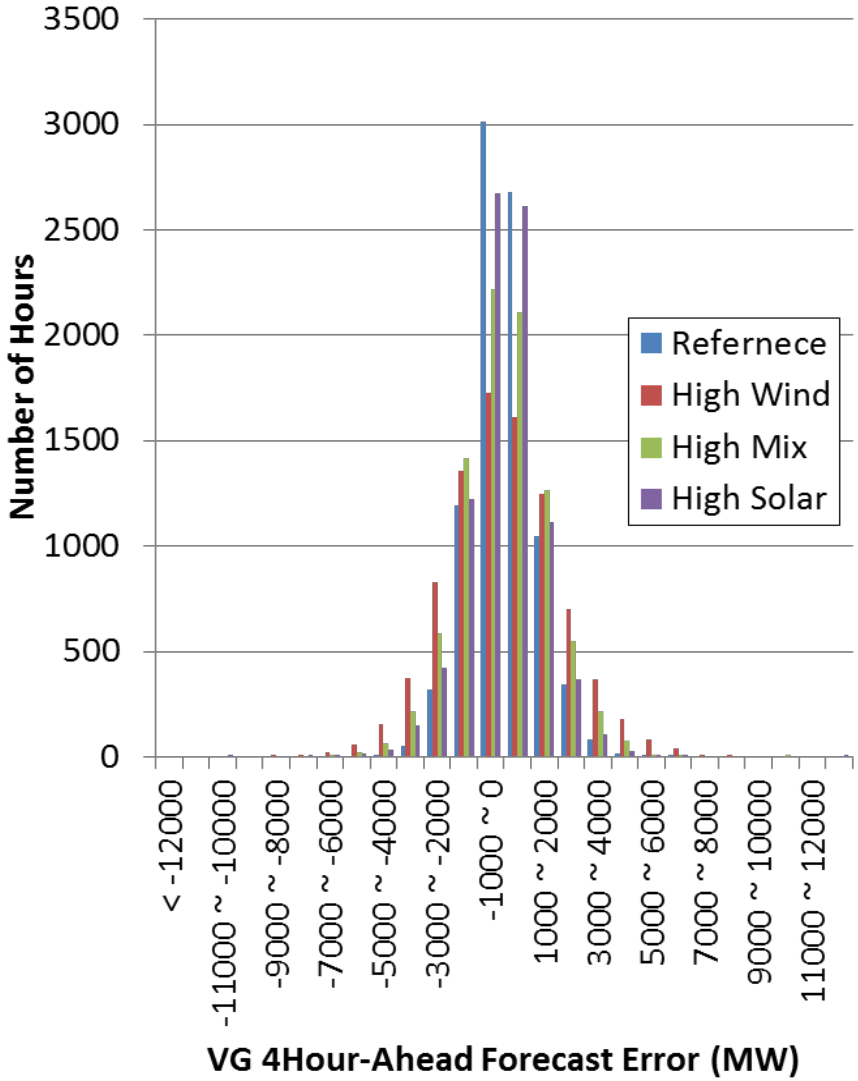


4 Hour-ahead Total VG Forecast Error



Comparing Day-ahead to 4 Hr. Forecast Error





Forecast Error Observations

- **Forecast error for wind is higher than for solar both at DA and 4HA**
  - On average the MAE and RMSE for wind is 1.5 to 2x that of solar
- **For the aggregated full study footprint**
  - Solar MAE ranges from 2% to 3% DA and 1% to 2% for 4HA
  - Wind MAE ranges from 5% to 6% DA and 2% to 3% for 4HA
  - Combined forecast MAE has a similar range as solar