Technical Analysis of Prospective Photovoltaic Systems in Utah

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Photovoltaics and Distributed Systems Integration

Sandia National Laboratories

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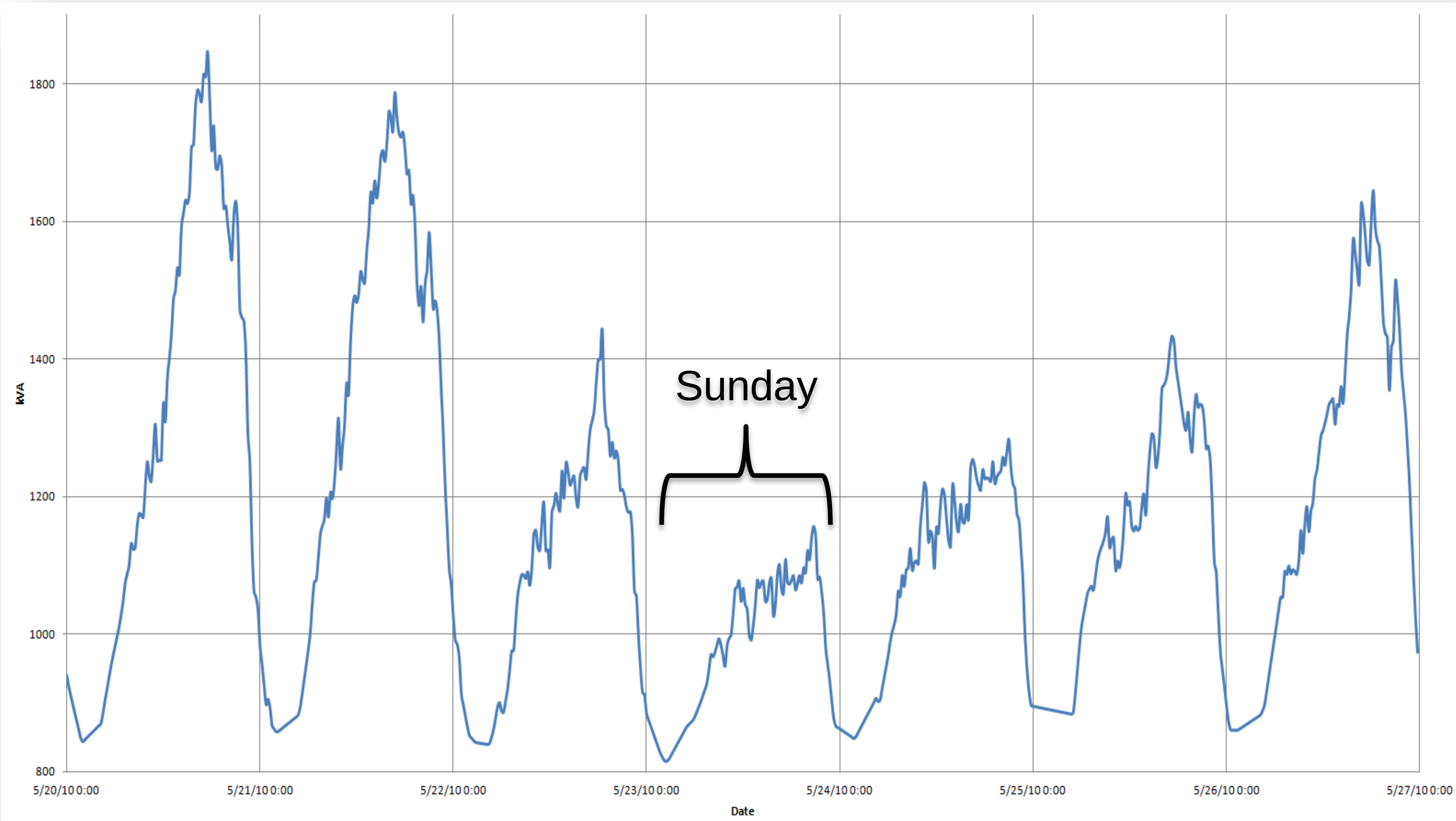
Introduction

- Collaboration with Rocky Mountain Power
- 2 MW_{AC} nominal central plant PV systems (prospective)
- Three feeder locations
  - Toquerville 11, southwestern Utah
  - Delta 11, central Utah
  - Terminal 19, northern Utah
- Technical and performance analyses
- *PLEASE NOTE: Not intended to be a complete interconnection analysis*
  - *PV type, size, and location specific; changing any of these would change the results*
  - *No system protection impacts were studied, a necessary aspect*
  - *Other load periods and using local irradiance may reveal other impacts*
  - *IEC 61000-4-15 flicker standards would differ from IEEE Std 141-1993*

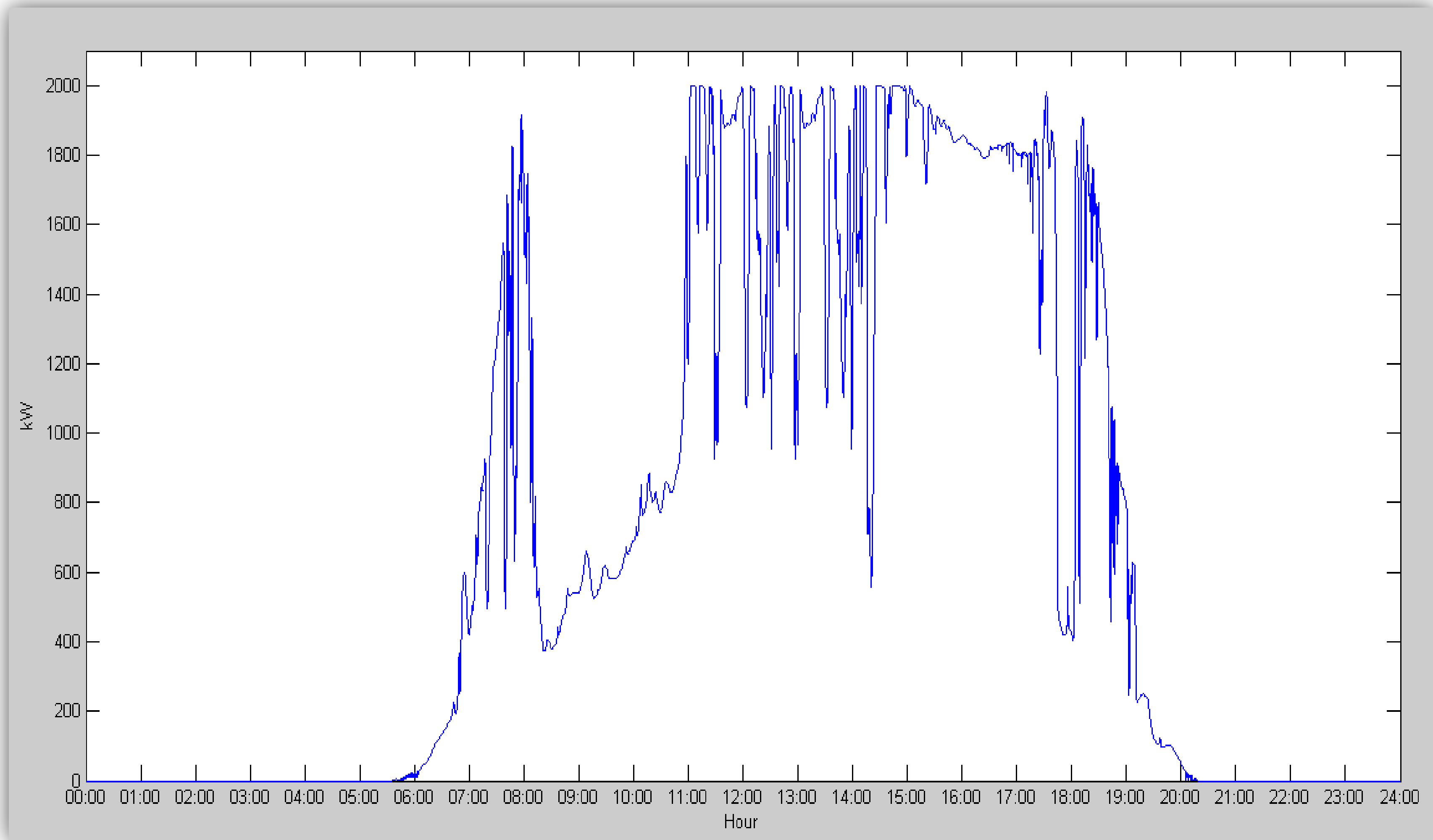
Technical Analysis Approach

- Time-series analysis
  - OpenDSS analysis software
    - Feeder models converted from utility software models
    - Source and transformer impedances
    - Other feeders on substation
- Load periods – one week, one second resolution
  - Peak penetration period
  - Peak load period
- PV profiles
  - High variability from actual system in Colorado
  - Duplicated for entire week
  - Unity PF output
  - Sunrise/sunset adjustments

Load Profile Example – Toquerville 11 Peak Penetration Period

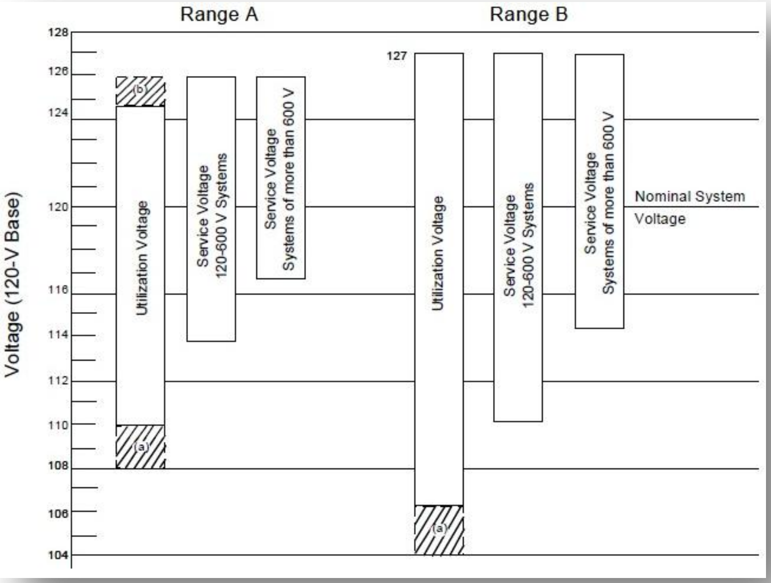


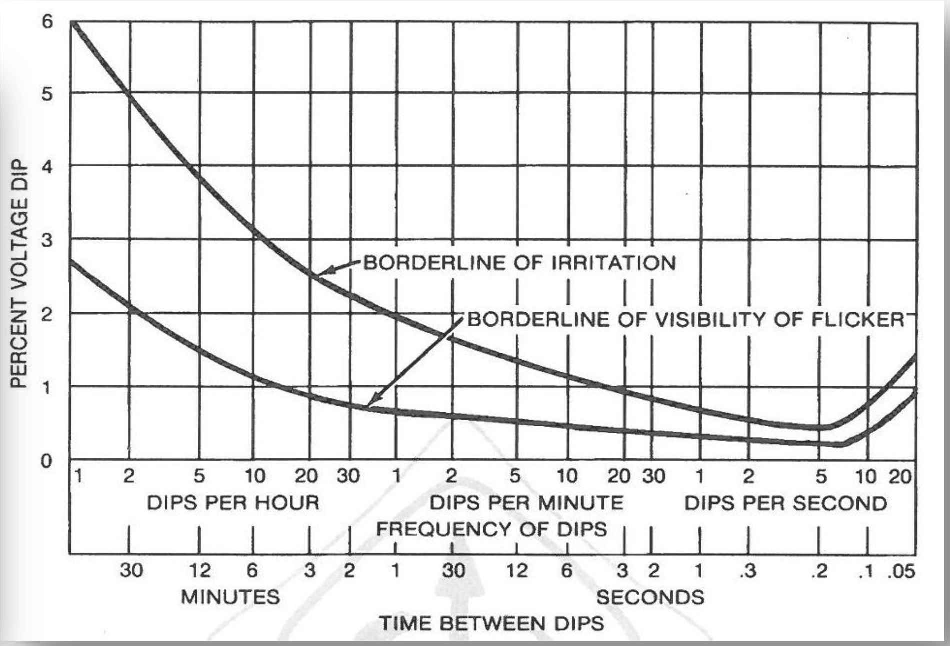
PV Output Profile



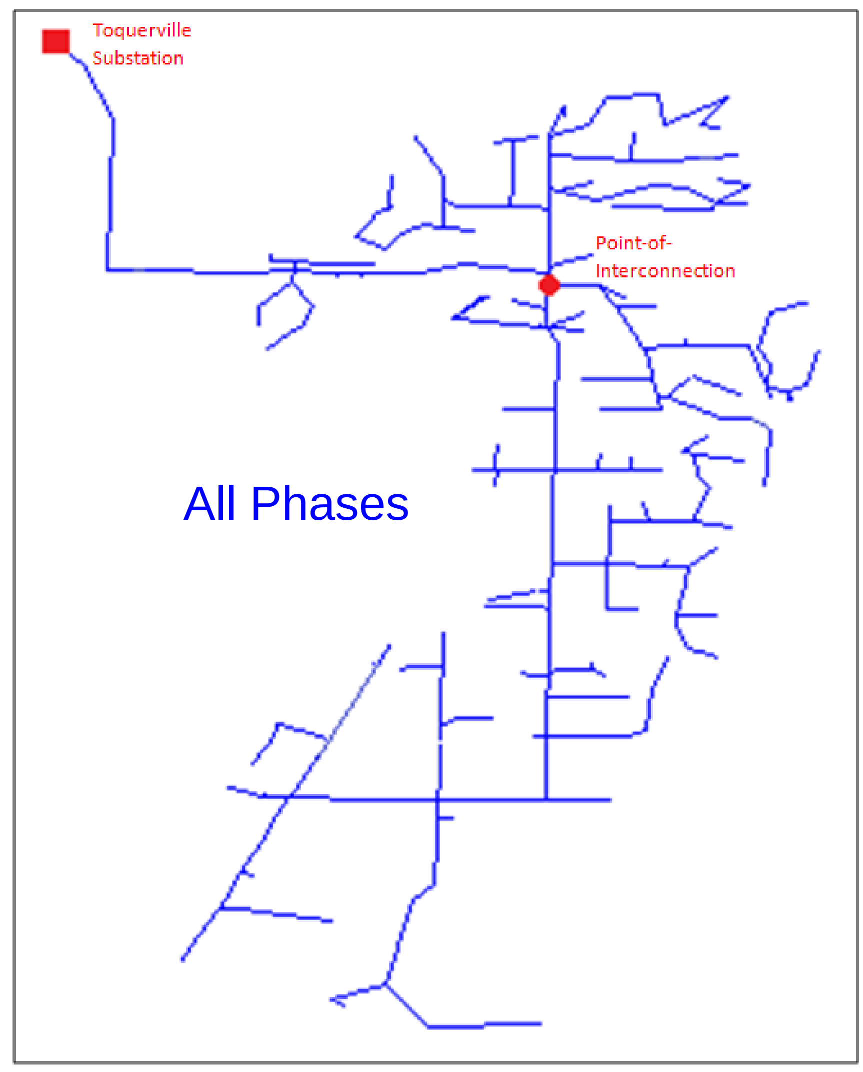
Integration Impact Analysis

- Maximum and Minimum Voltages (ANSI C84.1)
- Feeder demand reduction
- Voltage regulation equipment operations (LTC)
- Voltage flicker (IEEE Std 141-1993)
  - 100% to 0% PV output



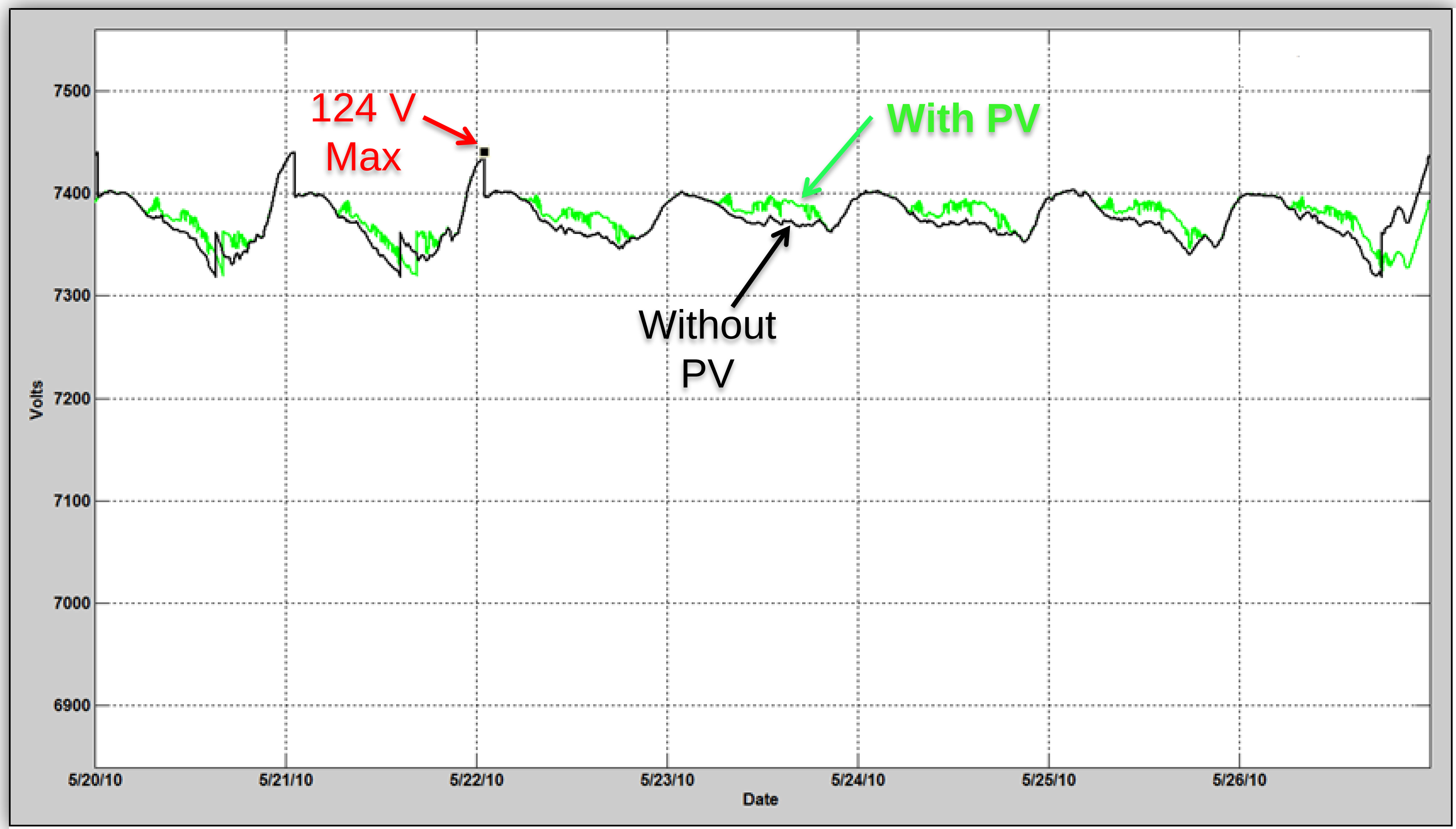


Toquerville 11

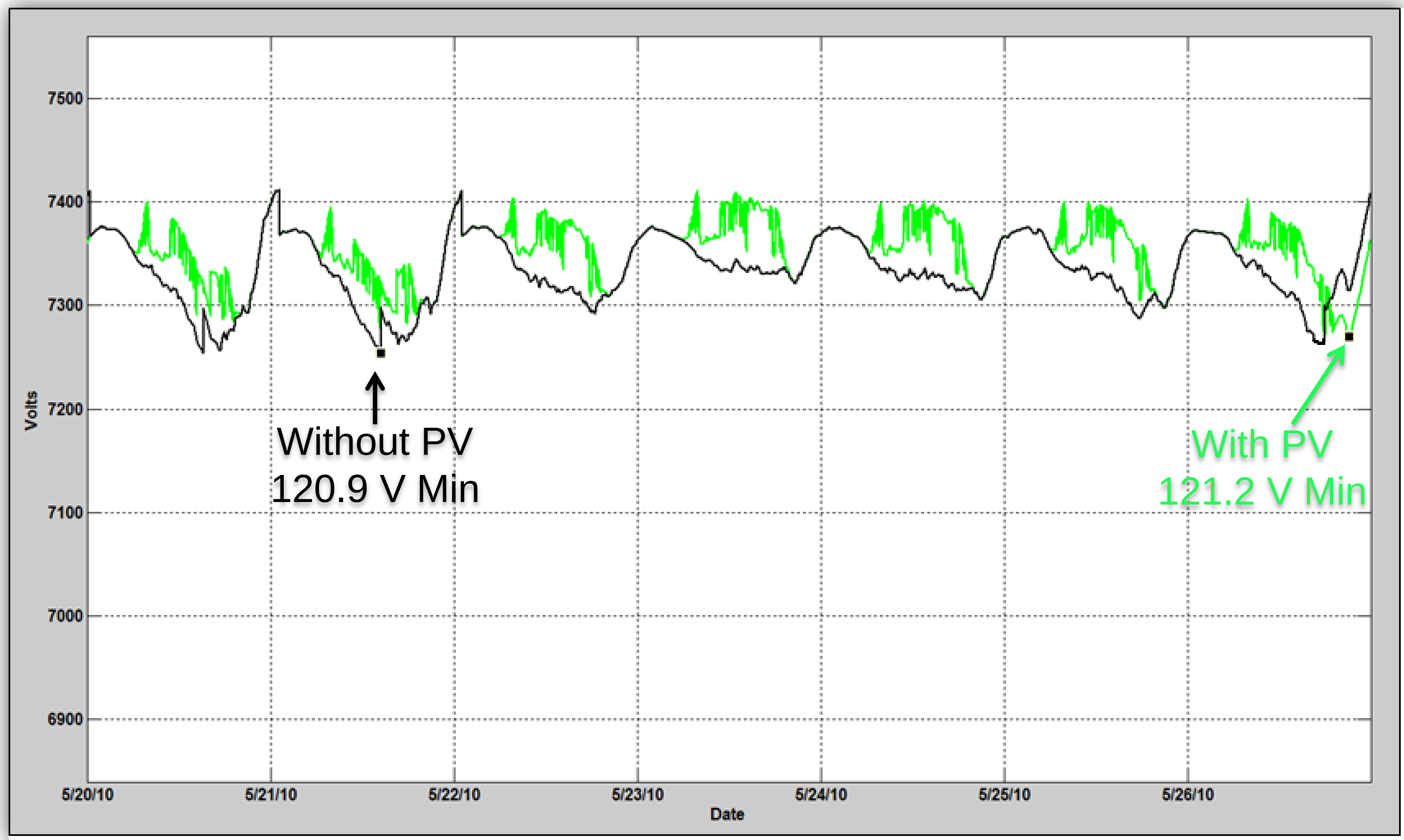


- PV system 1.3 miles from substation
- 2 MW system is 63% of annual feeder peak load
- One fixed 600 kVAr capacitor bank
- LTC settings – 123 V, 2 V bandwidth, 60 second delay

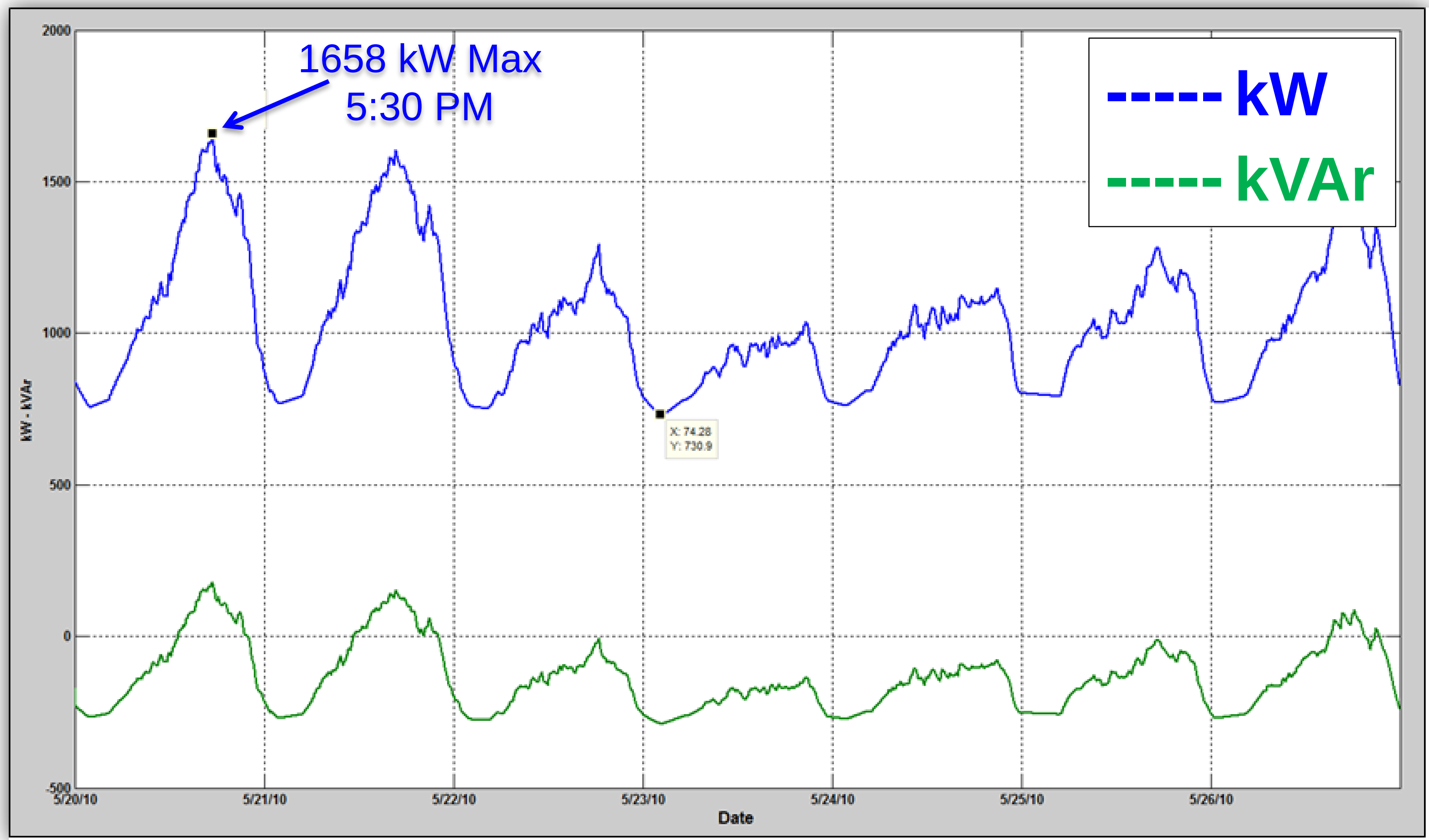
Toquerville 11 – Peak Penetration Period - Maximum Voltages



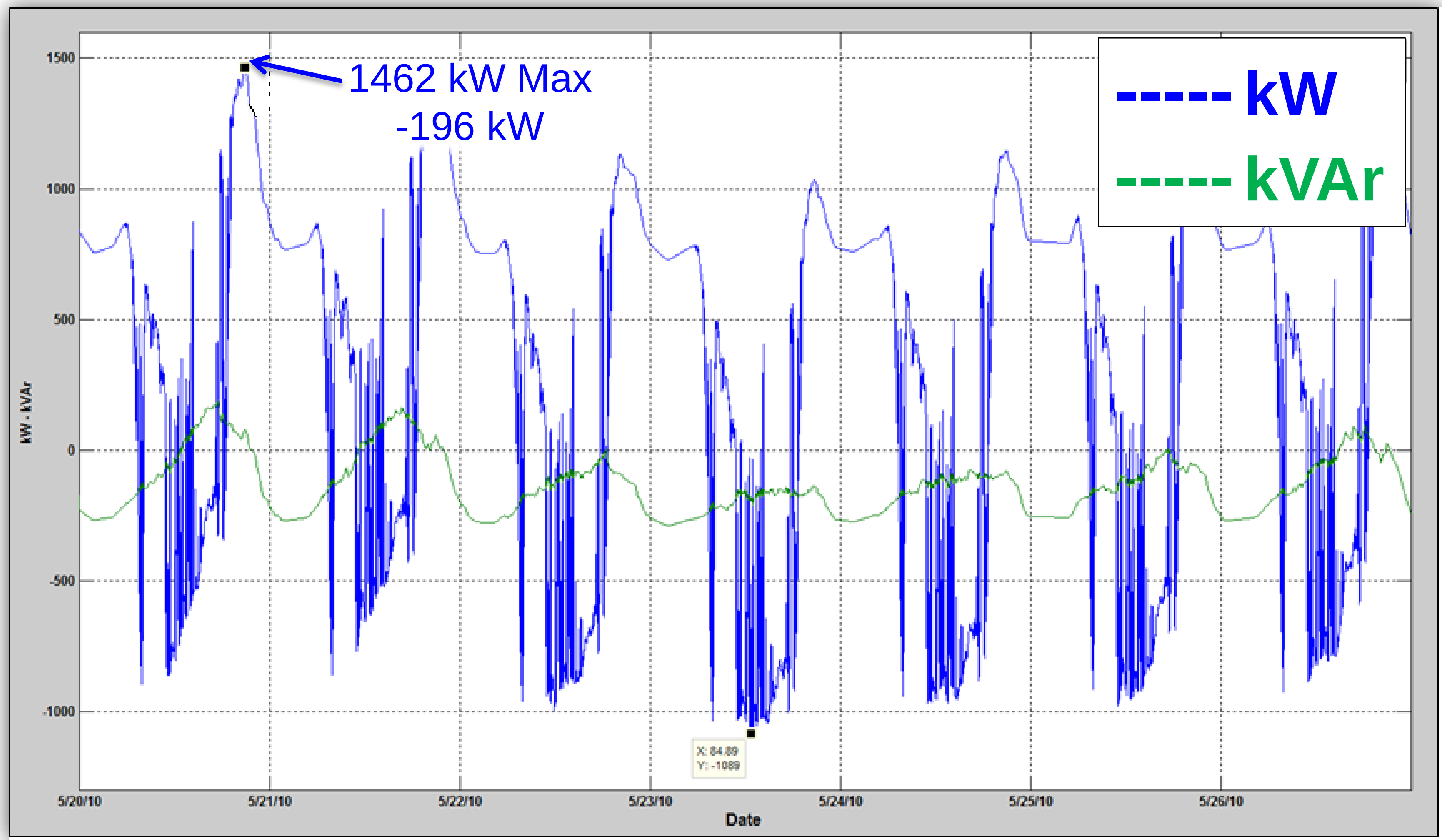
Toquerville 11 - Peak Penetration Period - Minimum Voltages



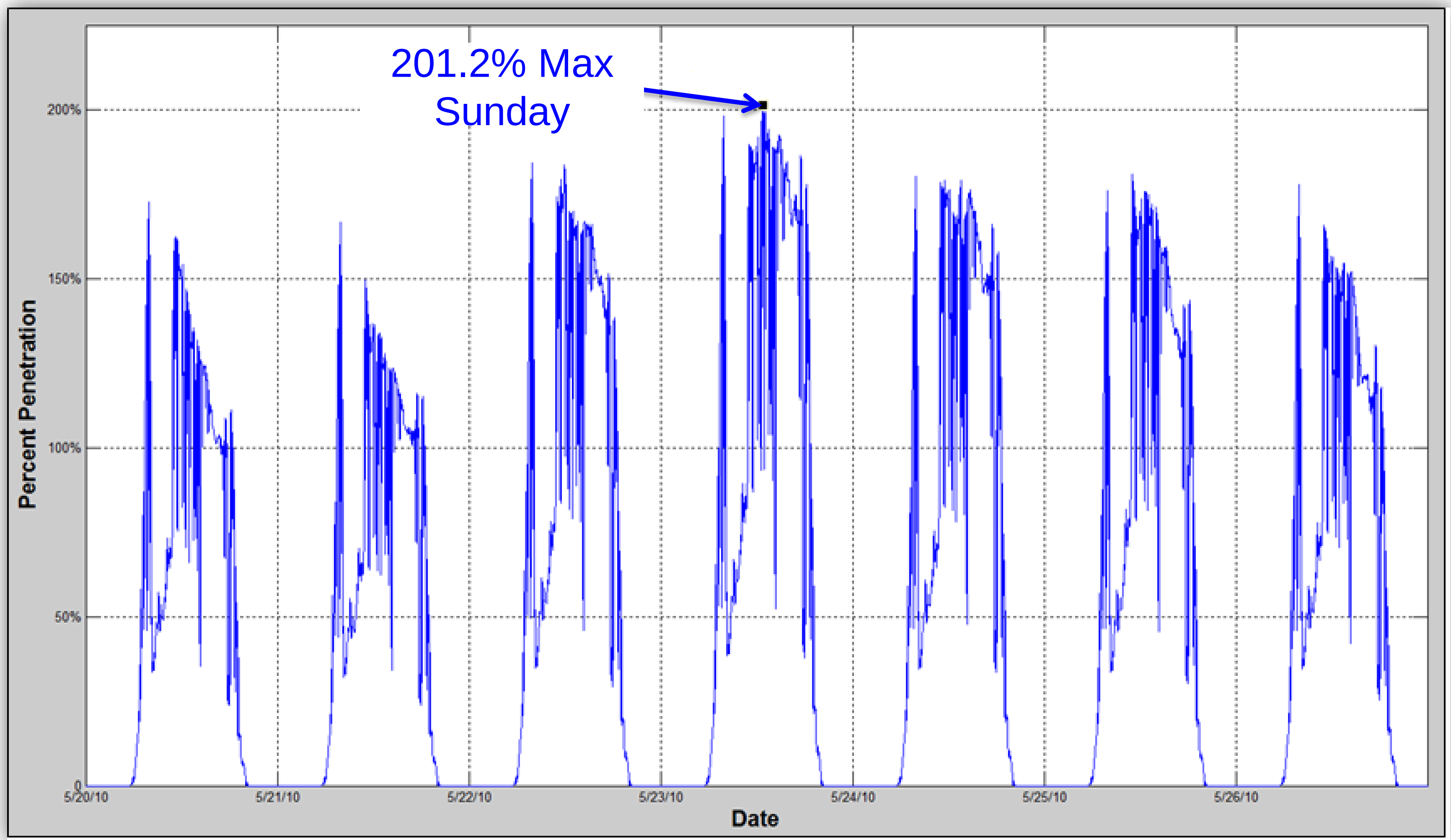
Toquerville 11 - Peak Penetration Period – Demand Without PV



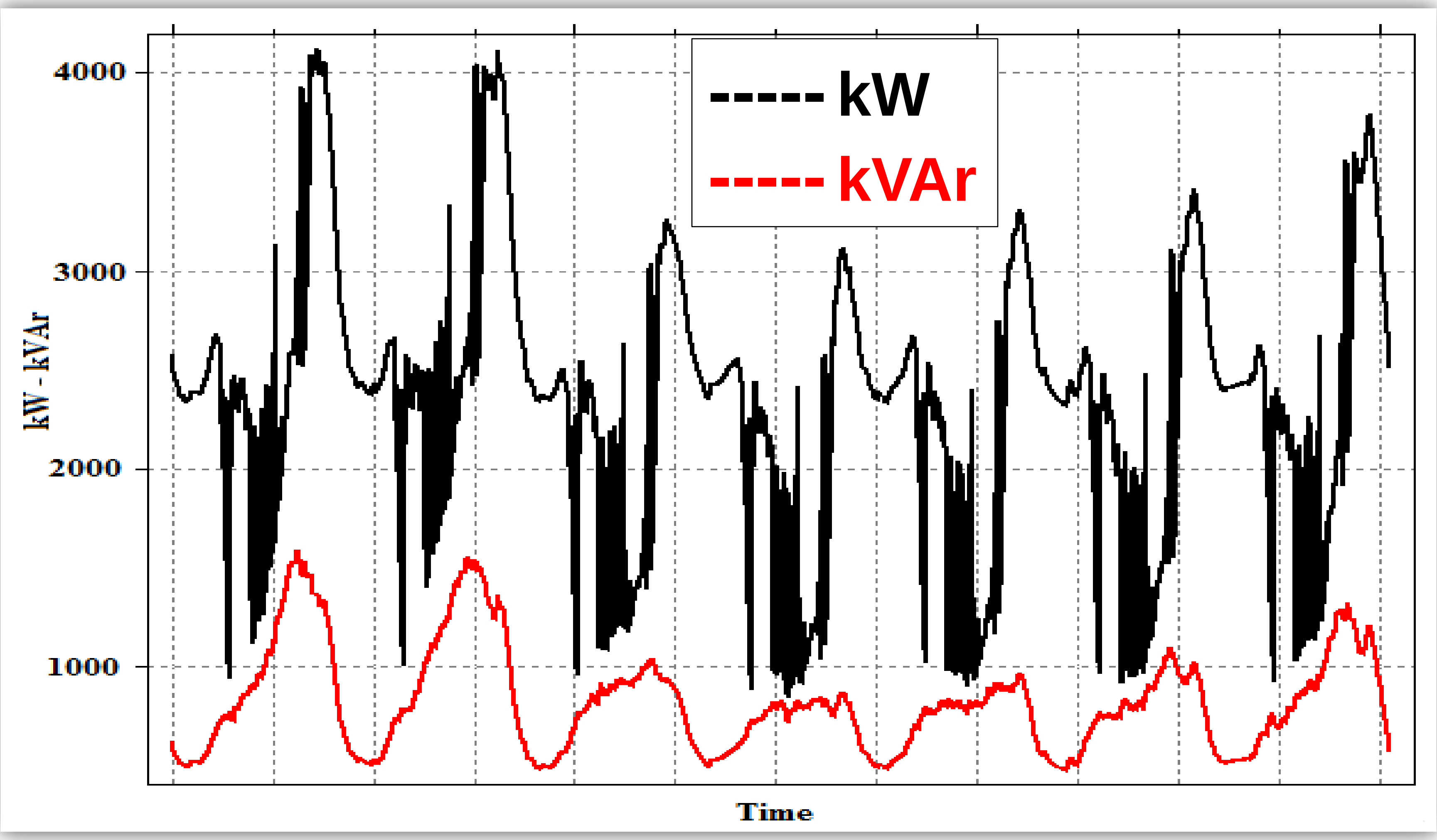
Toquerville 11 - Peak Penetration Period – Demand With PV



Toquerville 11 - Peak Penetration Period – PV Percent Penetration



Toquerville Substation - Peak Penetration Period – Demand With PV



Toquerville 11 – Peak Penetration Period - LTC Operations and Flicker

- LTC operations:

	Without PV	With PV
Operations	6	5

  - PV offset of load reduces voltage drop

- Flicker (100% to 0% PV output)
  - 1.00% voltage change would only cause an irritation if it occurred 15 times a minute or more, per IEEE Std 141-1993
  - Worst ramp found in PV output profile was approximately 71.9% over 8.2 minutes
  - No problems anticipated

Toquerville 11 – Peak Load Period – Voltages and Demand

- Maximum and minimum voltages (120 V base):

	Without PV	With PV
Maximum	124	124
Minimum	118.1	118.6

- Feeder demand (kW):

	Without PV	With PV
Peak demand	3167	2783 (-384 kW)

  - No reverse power through substation transformer

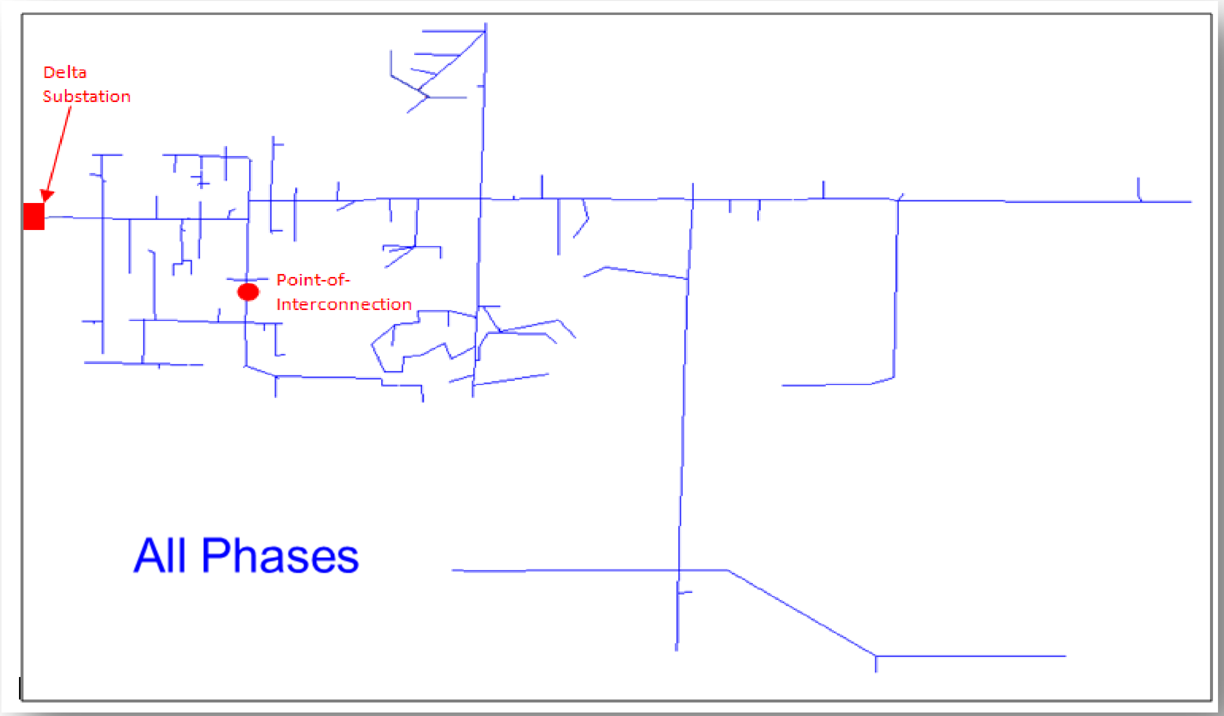
Toquerville 11 – Peak Load Period - LTC Operations and Flicker

- LTC operations:

	With PV	Without PV
Operations	61	61

- Flicker (100% to 0% PV output)
  - 1.04% voltage change would only cause an irritation if it occurred 15 times a minute or more, per IEEE Std 141-1993
  - Worst ramp found in PV output profile was approximately 71.9% over 8.2 minutes
  - No problems anticipated

Delta 11



- PV system 0.6 miles from substation
- 2 MW system is 116% of annual feeder peak load
- Two fixed 300 kVAr capacitor banks
- LTC settings – 123 V, 2 V BW, 30s delay, 4+j3 V LDC

Delta 11 – Peak Penetration Period – Voltages and Demand

- Maximum and minimum voltages (120 V base):

	Without PV	With PV
Maximum	124.9	124.7
Minimum	122.4	122.4

- Feeder demand (kW):

	Without PV	With PV
Peak demand	1246	-1291 (+45 kW)

  - No reverse power through substation transformer

Delta 11 – Peak Penetration Period - LTC Operations and Flicker

- LTC operations:

	Without PV	With PV
Operations	10	8

  - PV offset of load reduces voltage drop

- Flicker (100% to 0% PV output)
  - 1.31% voltage change would only cause an irritation if it occurred 5 times a minute or more, per IEEE Std 141-1993
  - Worst ramp found in PV output profile was approximately 71.9% over 8.2 minutes
  - No problems anticipated

Delta 11 – Peak Load Period – Voltages and Demand

- Maximum and minimum voltages (120 V base):

	Without PV	With PV
Maximum	125.2	125.2
Minimum	122.4	122.3

- Feeder demand (kW):

	Without PV	With PV
Peak demand	1725	1538(-187 kW)

  - No reverse power through substation transformer

Delta 11 – Peak Load Period - LTC Operations and Flicker

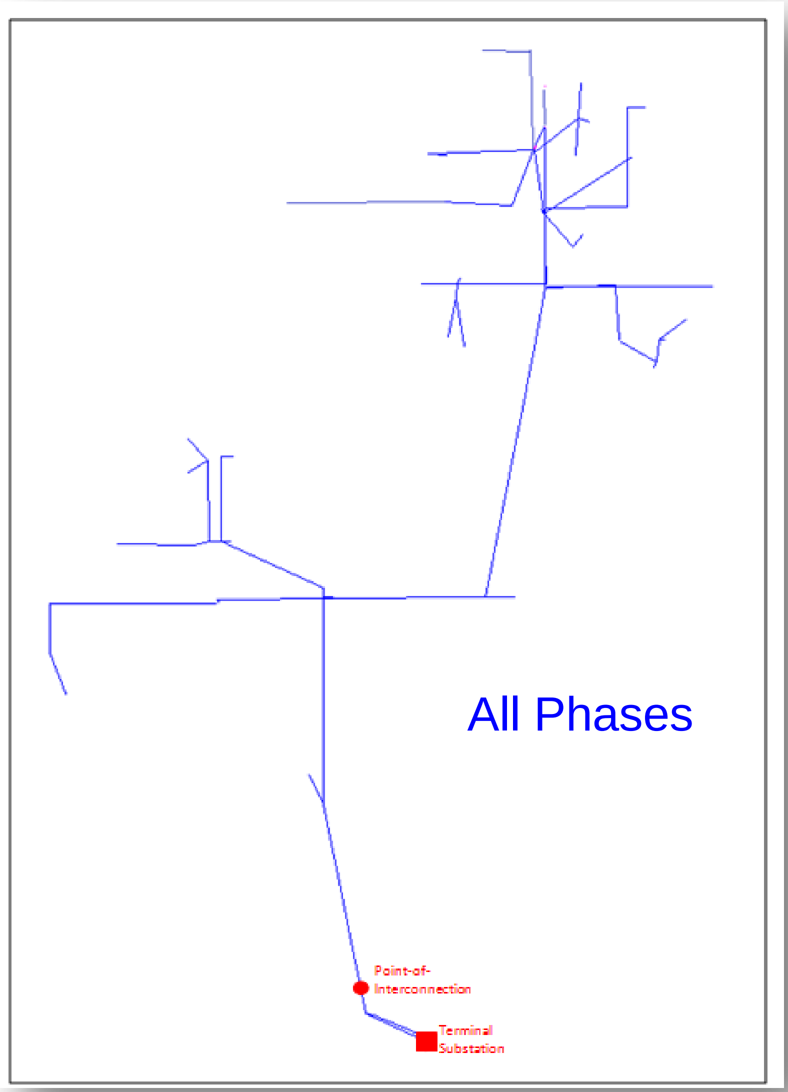
- LTC operations:

	Without PV	With PV
Operations	35	31

  - PV offset of load reduces voltage drop

- Flicker (100% to 0% PV output)
  - 1.36% voltage change would only cause an irritation if it occurred 5 times a minute or more, per IEEE Std 141-1993
  - Worst ramp found in PV output profile was approximately 71.9% over 8.2 minutes
  - No problems anticipated

Terminal 19



- PV system is just north of substation
- 2 MW system is 67% of annual feeder peak load
- No capacitor banks
- LTC settings – 123 V, 2 V bandwidth, 60 second delay

Terminal 19 – Peak Penetration Period – Voltages and Demand

- Maximum and minimum voltages (120 V base):

	Without PV	With PV
Maximum	123.2	123.2
Minimum	121.5	121.5

- Feeder demand (kW):

	Without PV	With PV
Peak demand	1889	1603 (-286 kW)

  - No reverse power through substation transformer

Terminal 19 – Peak Penetration Period - LTC Operations and Flicker

- LTC operations:

	Without PV	With PV
Operations	1	1

- Flicker (100% to 0% PV output)
  - 0.08% voltage change would never cause an irritation, regardless of frequency, per IEEE Std 141-1993
  - Worst ramp found in PV output profile was approximately 71.9% over 8.2 minutes
  - No problems anticipated

Terminal 19 – Peak Load Period – Voltages and Demand

- Maximum and minimum voltages (120 V base):

	Without PV	With PV
Maximum	123.9	123.9
Minimum	121.3	121.3

- Feeder demand (kW):

	Without PV	With PV
Peak demand	2703	2087 (-616 kW)

  - No reverse power through substation transformer

Terminal 19 – Peak Load Period - LTC Operations and Flicker

- LTC operations:

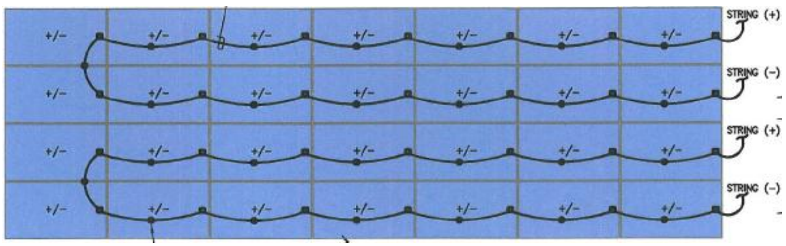
	Without PV	With PV
Operations	2	2

- Flicker (100% to 0% PV output)
  - 0.09% voltage change would never cause an irritation, regardless of frequency, per IEEE Std 141-1993
  - Worst ramp found in PV output profile was approximately 71.9% over 8.2 minutes
  - No problems anticipated

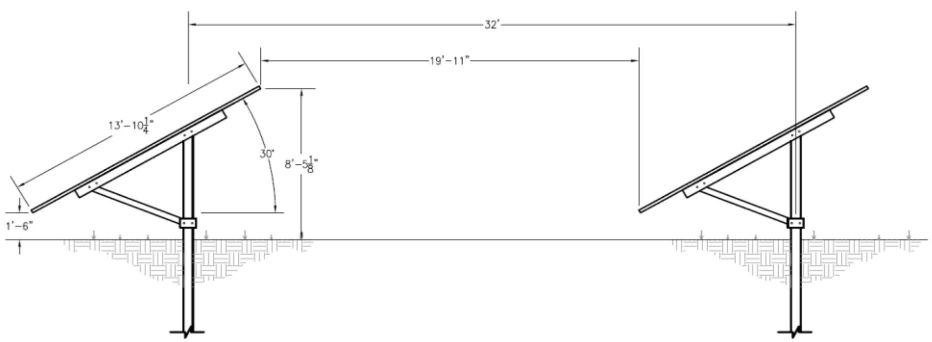
Performance Modeling

- System designs
  - 2 MW_{AC} nominal systems
  - Fixed-tilt multicrystalline silicon
  - Fixed-tilt thin-film
  - One-axis tracking (east to west) multicrystalline
- PVsyst tool used for production estimation
  - Ability to model shading and tracking
- TMY-2 weather data from Solar Prospector site

Fixed-tilt Multicrystalline System

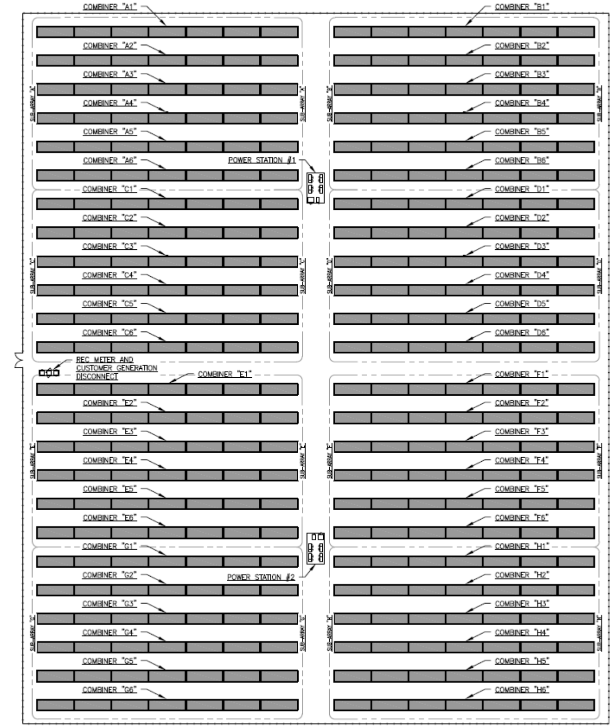


Two series strings per rack



Racks at 30° Tilt and 32 ft spacing

11.2 acres



Eight subarrays, two power blocks

Fixed-tilt thin-film system

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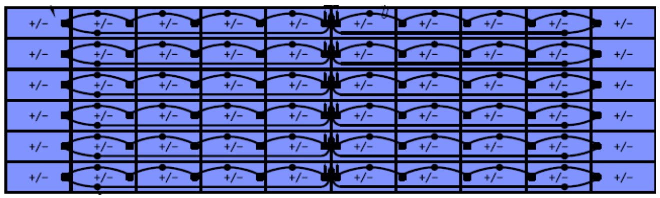
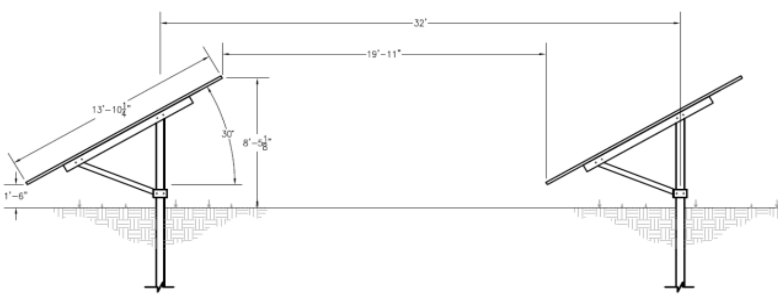
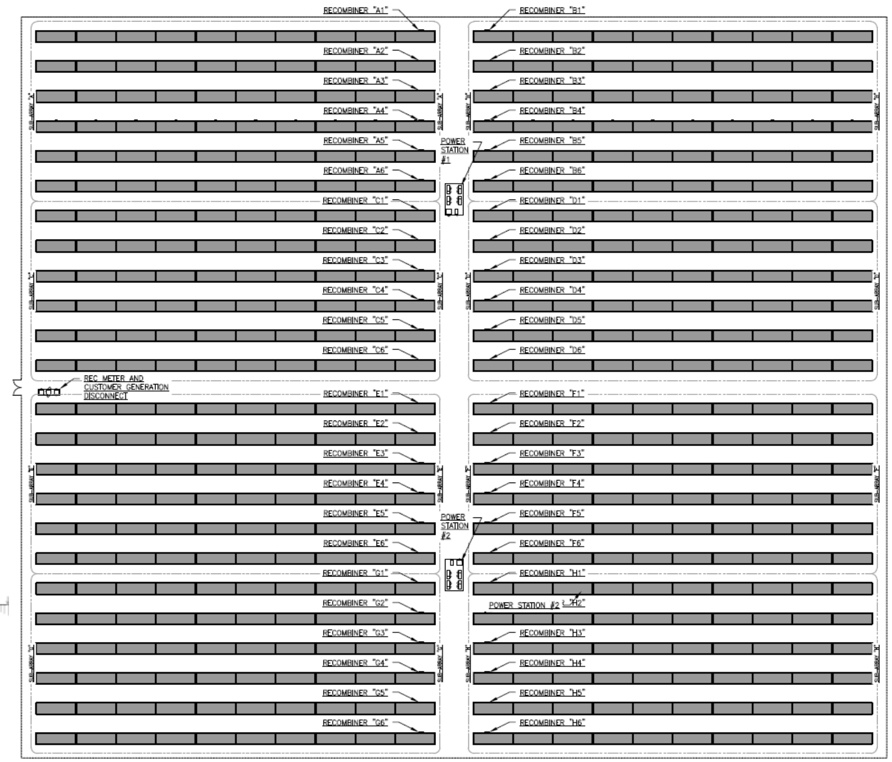


Twelve series strings per rack



Racks at 30° Tilt and 32 ft spacing

15.9 acres



Eight subarrays, two power blocks

One-axis tracking multicrystalline

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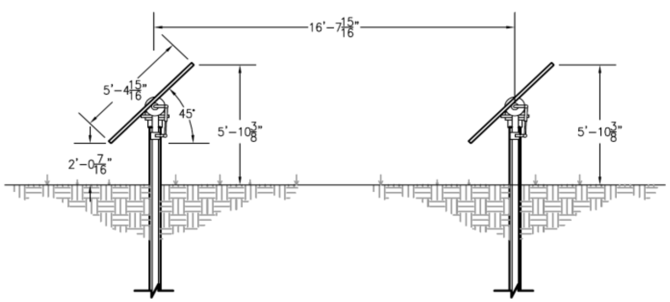
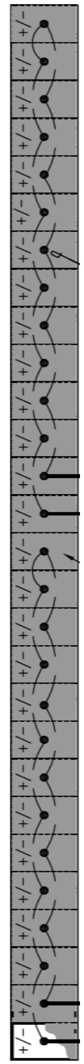
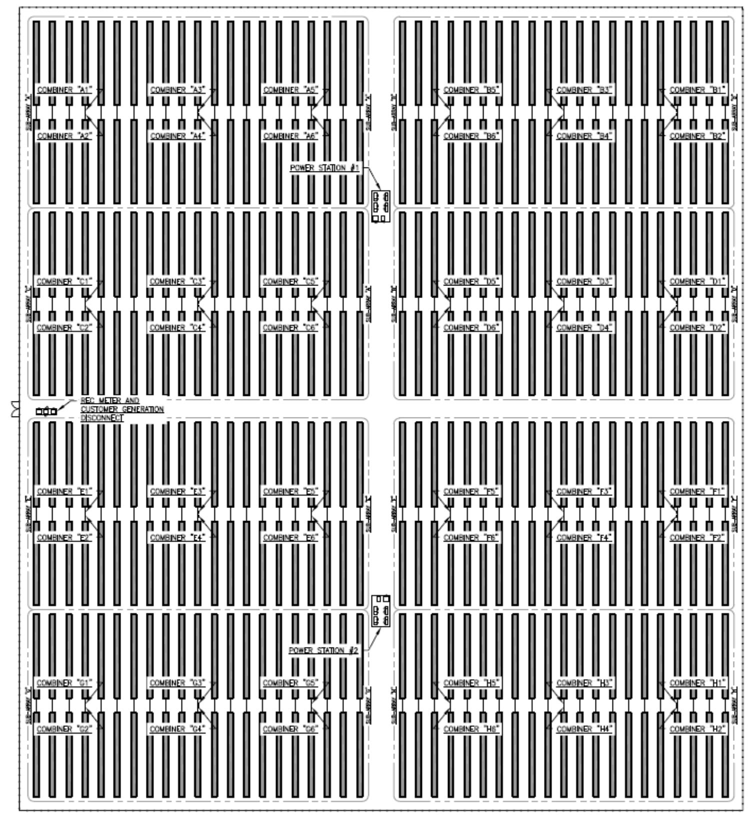


1-axis ±45° Tilt and 16’ 8” spacing



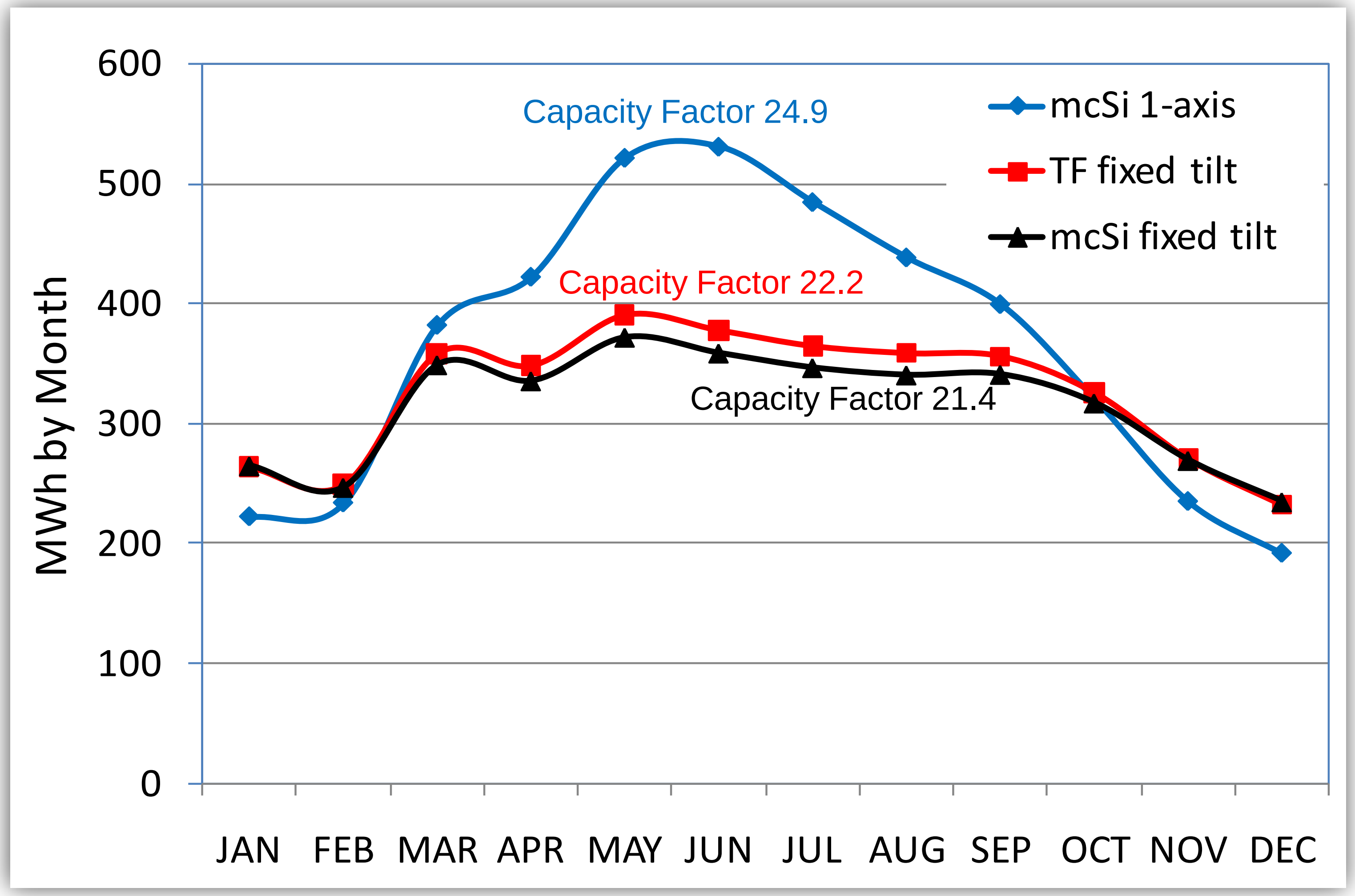
Racks at 30° Tilt and 32 ft spacing

14.9 acres

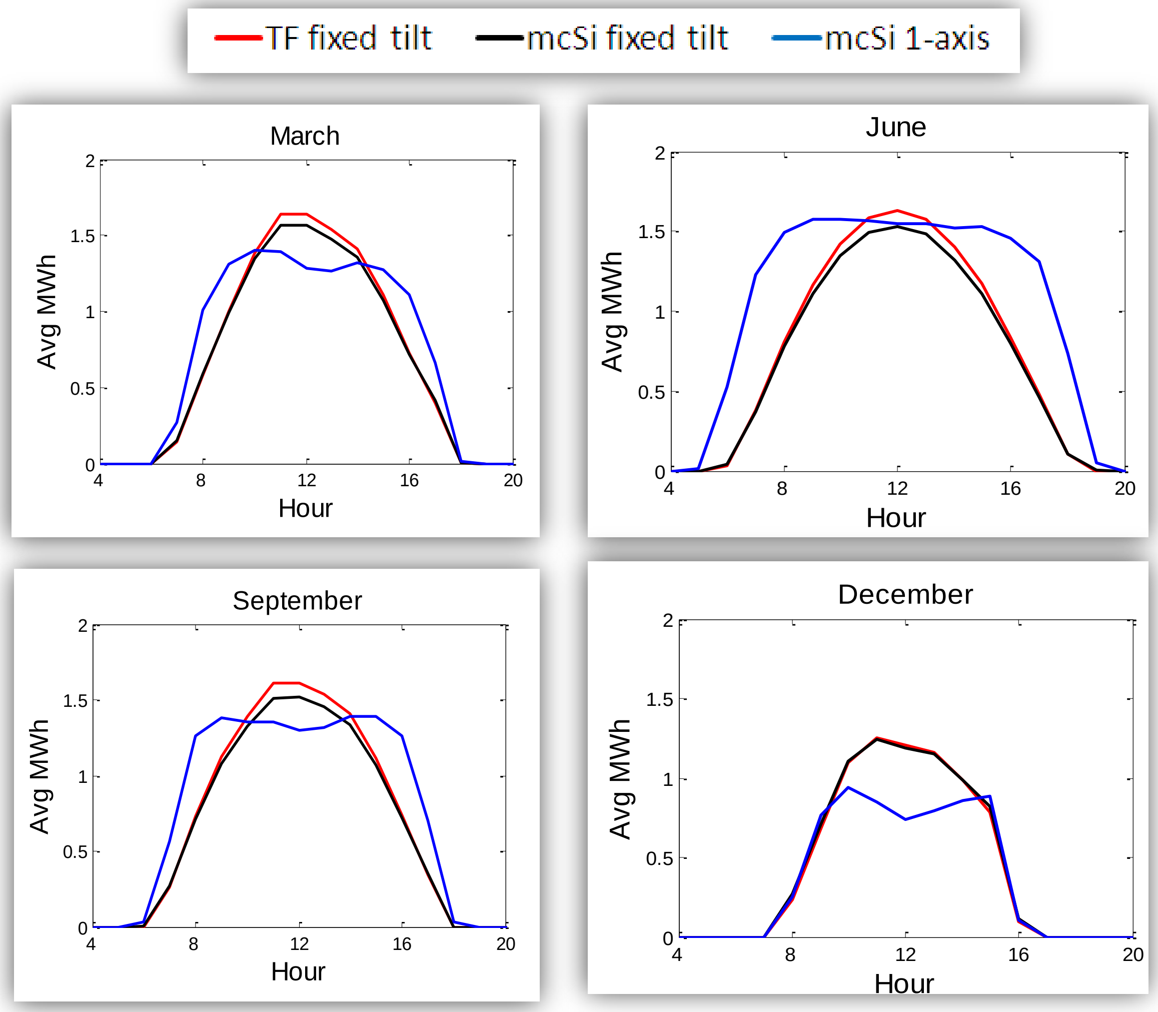


Eight subarrays, two power blocks

System Output by Month - Toquerville



Average Hourly Output by Month - Toquerville



Conclusions

- *PLEASE NOTE: Not intended to be a complete interconnection analysis*
  - *PV type, size, and location specific; changing any of these would change the results*
  - *No system protection impacts were studied, a necessary aspect*
  - *Other load periods and using local irradiance may reveal other impacts*
  - *IEC 61000-4-15 flicker standards would differ from IEEE Std 141-1993*
- Utility planning value
  - Snapshot periods – Peak penetration and peak load periods
  - LTC operations – time-series dependent
  - Flicker – 100% to 20% PV output
- Not a question of whether integration is possible, just a question of what it takes!

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