Solar Power Variations in the Regulation and Sub-Regulation Time Frames

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Outline

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- Arizona Public Service Solar Variability Study
- Integration and interconnection of renewables: “regulation”
- Defining “Regulation” and “Sub-Regulation”
- Results

Solar Power Integration and Interconnection

- For our purposes, when connecting soalr power to the grid, consider:
  - *Integration* – the effects of variable and uncertain renewable energy on net load balance, power quality, and reliability that can be handled during system operation via provision of “ancillary services” such as regulation.
  - *Interconnection* – the hardware/software build into the distribution system to ensure the power quality on the distribution or transmission line is acceptable

"Regulation"

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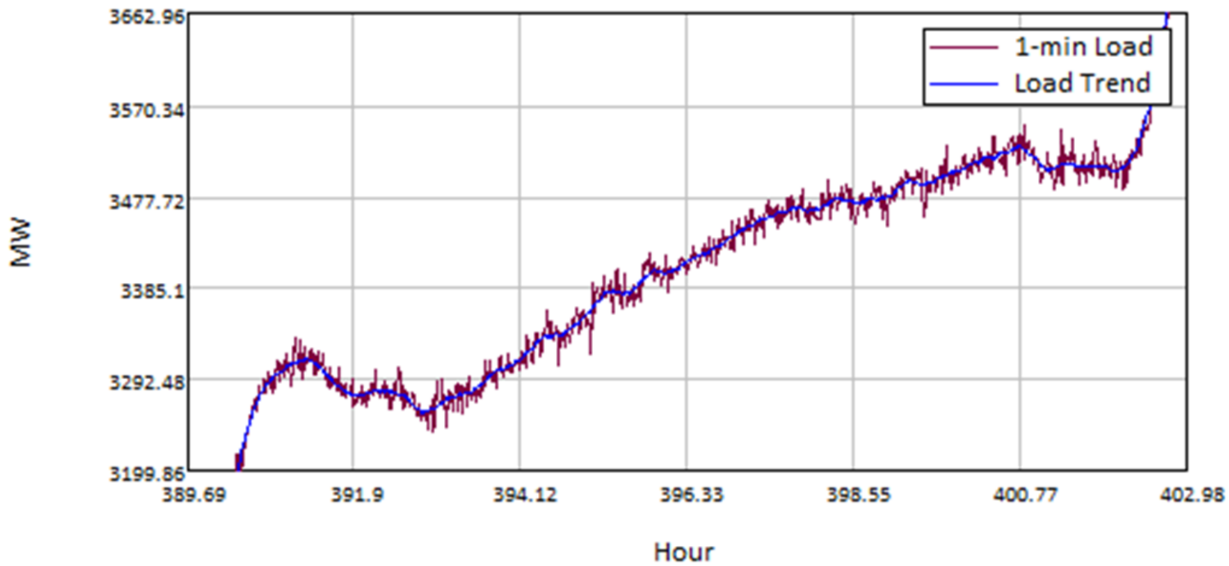
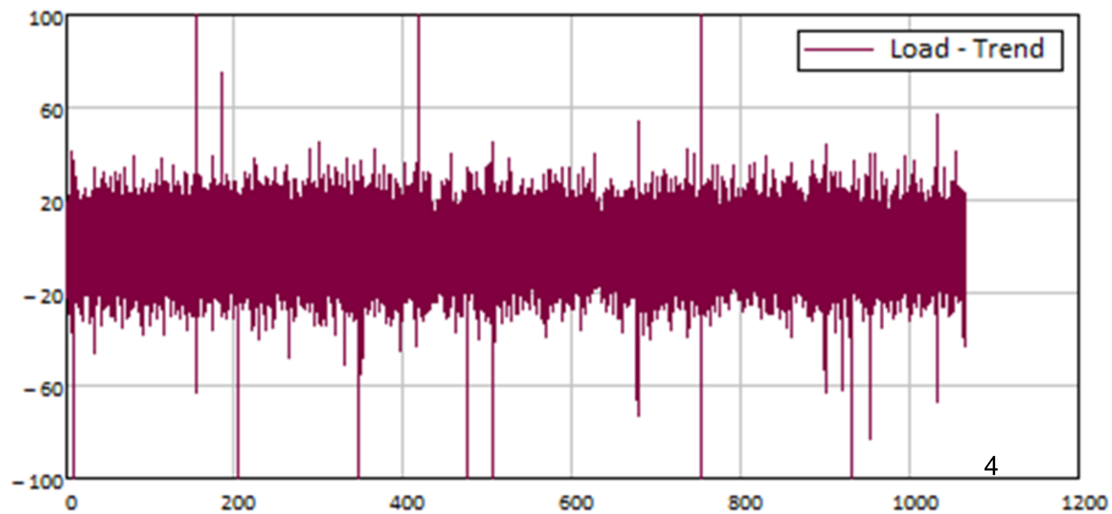
- Short term variability
- Units on AGC
- 1-min load data
- Load trend based on a 20-min rolling average
- Regulation can be characterized using the standard deviation of the 1-min (load – trend) data





$$Example:$$

$$\sigma_{\text{Load}} = 10\,\text{MW}$$

$$\text{Reg} = 5 \times \sigma_{\text{Load}} = 50\,\text{MW}$$

Regulation Impact of RE

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Assume *1-min* load and renewable energy (solar or wind) *fluctuations are uncorrelated*

$$\sigma_{\text{Load}} = 10\,\text{MW}$$

$$\text{Reg}_{\text{Load}} = 5 \times \sigma_{\text{Load}} = 50\,\text{MW}$$

Add variable renewable energy:

$$\sigma_{RE} = 1\,\text{MW}$$

$$\boxed{\sigma_{Load+RE} = \sqrt{(\sigma_{\text{Load}})^2 + (\sigma_{RE})^2}} = 10.05\,\text{MW}$$

$$\Delta\text{Reg}_{\text{Load+RE}} = 5 \times (\sigma_{Load+RE} - \sigma_{\text{Load}}) = 0.05\,\text{MW}$$

So, it is useful to know the std. dev. of 1-min fluctuations

Regulation and Sub-Regulation

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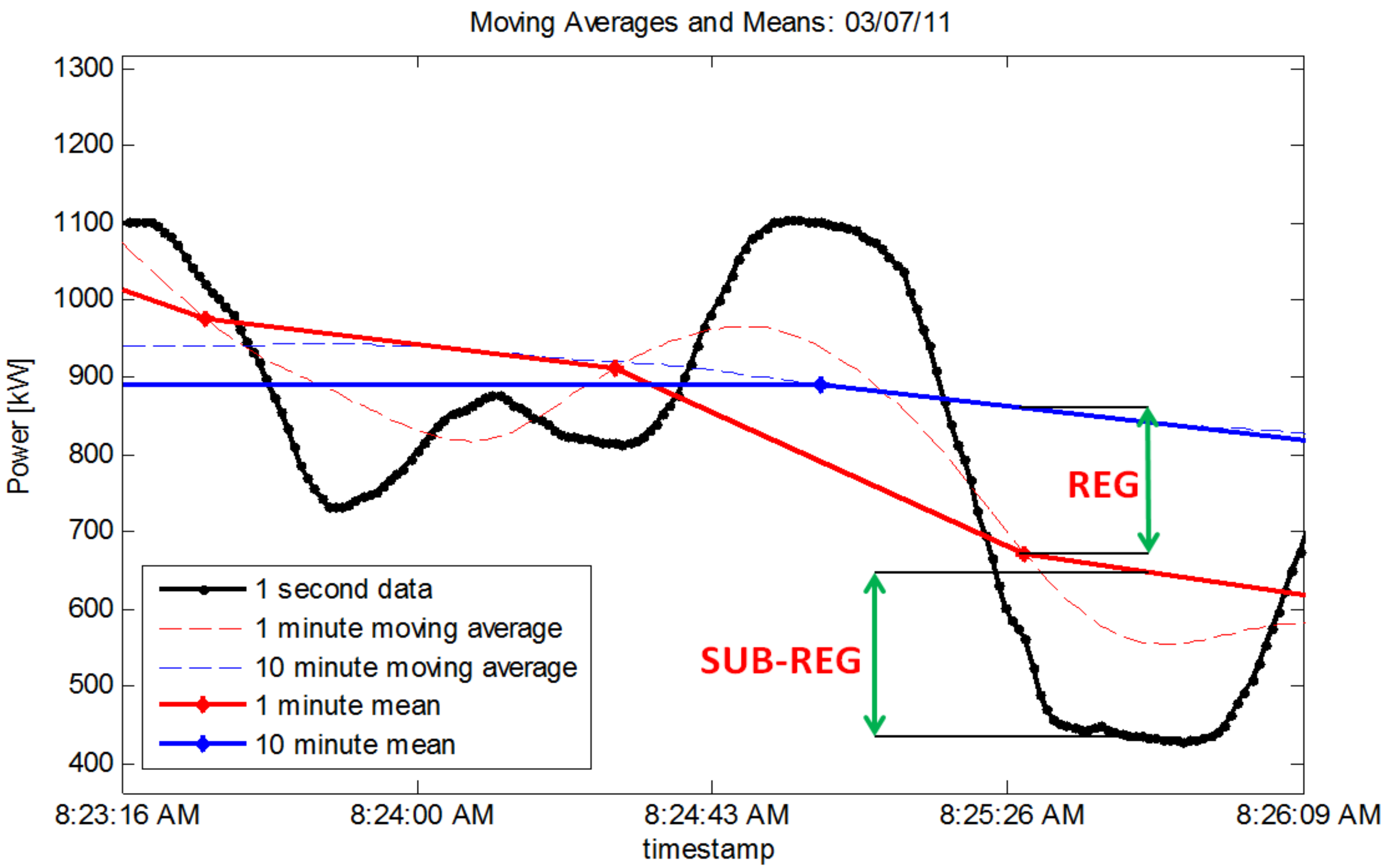
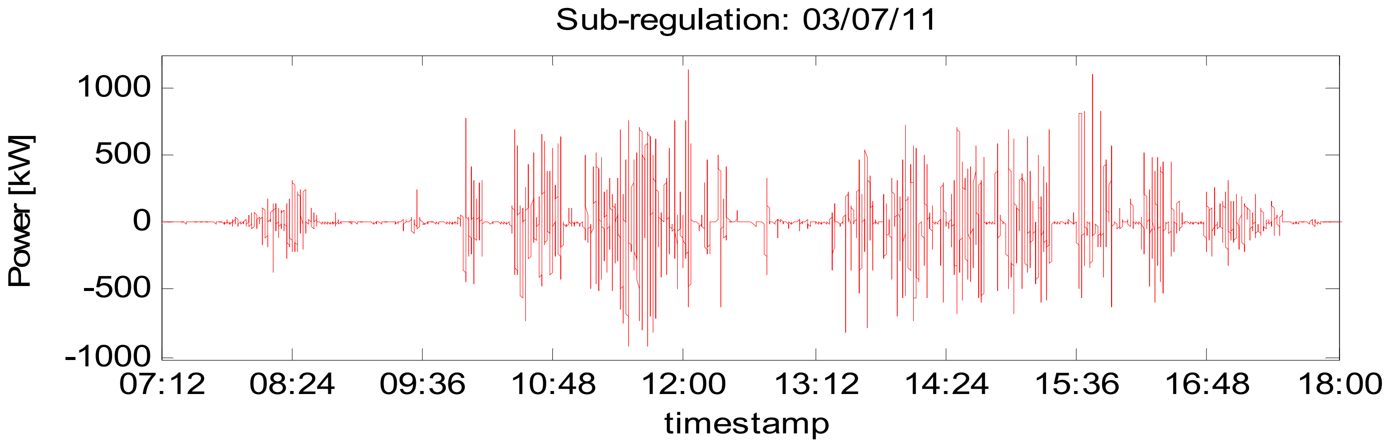
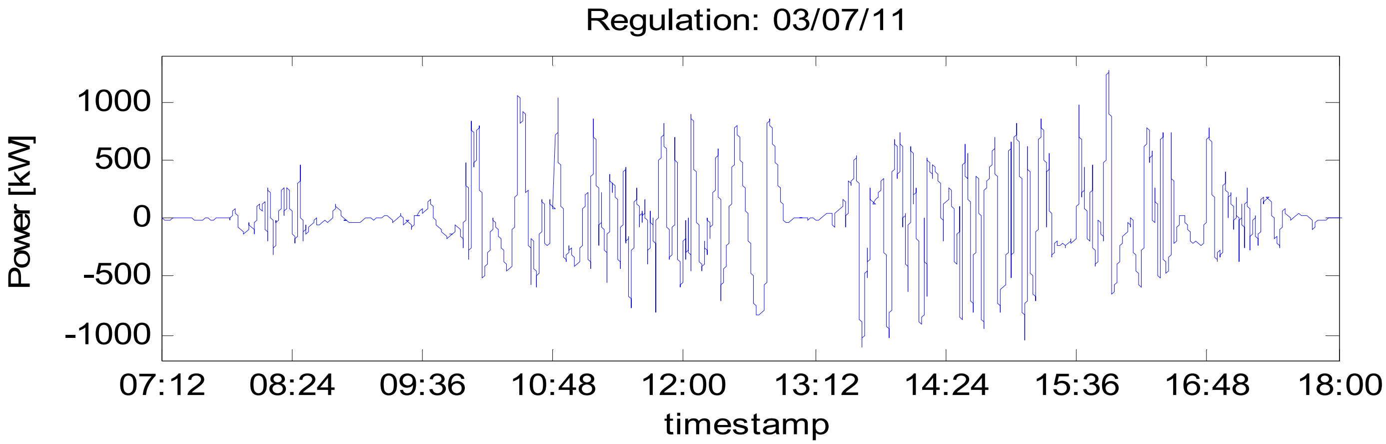


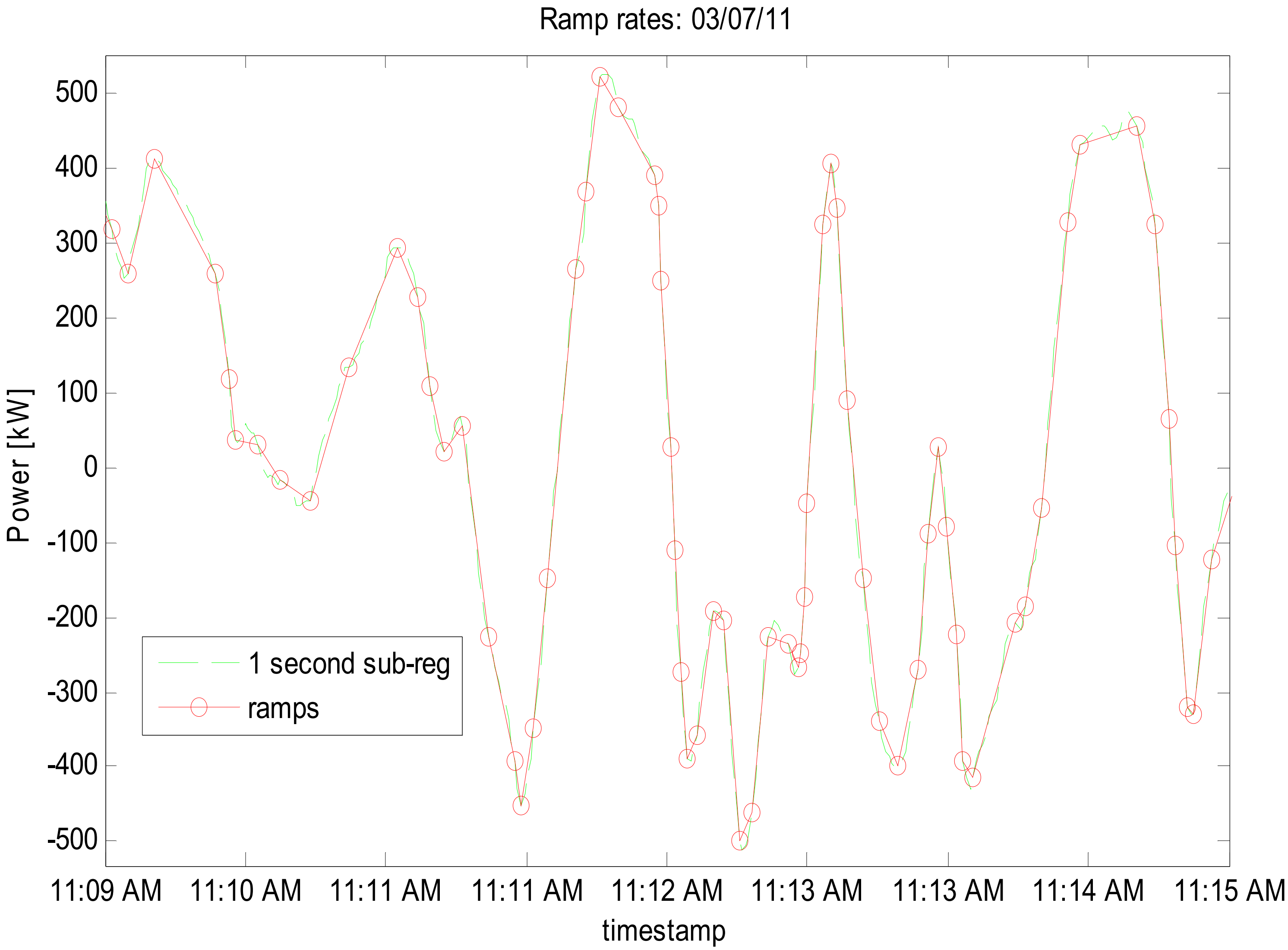
Regulation vs. Sub-Regulation



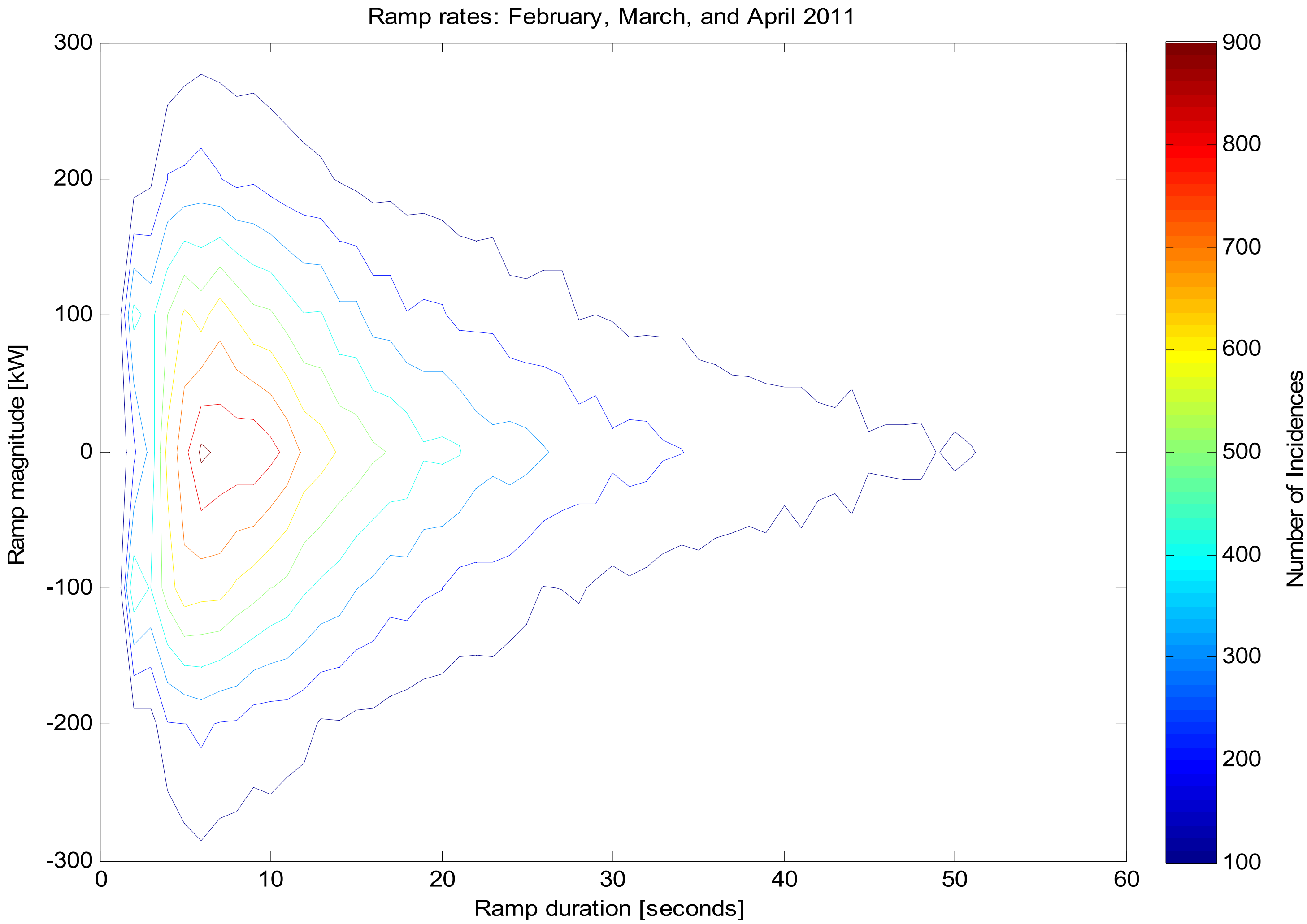


		σ (kW)	Min (kW)	Max (kW)
February, March, and April	Reg	84.0	-1352	1218
	Subreg	34.7	-1277	1173

Ramp in Sub-Reg Time Series

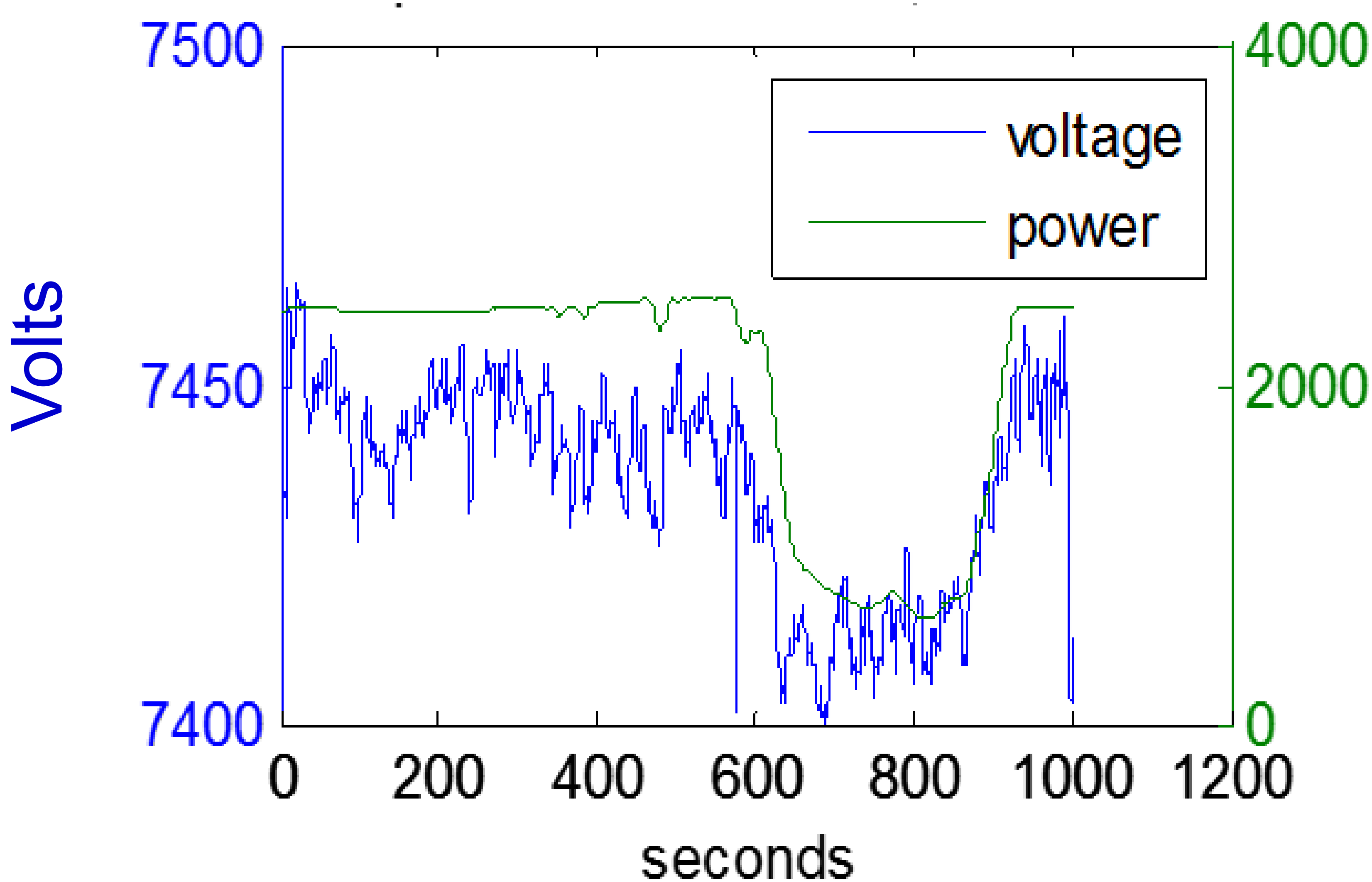


Ramp Events



Ramp rates: February, March, and April 2011
300
200
100
0
-100
-200
-300
0
10
20
30
40
50
60
Ramp magnitude [kW]
Ramp duration [seconds]
900
800
700
600
500
400
300
200
100
Number of Incidences

At Output of PV Plant



Conclusions

- "Sub-Regulation" defined to identify rapid fluctuations from a PV power plant that must be handled during interconnection
- Large, rapid fluctuation in the PV plant output were identified
- Rapid power fluctuations were found to be correlated with some changes in feeder voltage, but in no case did the voltage exceed the regulation band and have a deleterious effect on the distribution line

Thank you!

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Appendix

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References

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(2) Flood, R.K., Acker, T.L., Willy, D., Lerner J., and A. Vandervoort, "Prescott airport solar facility solar variability study." 2011. Web. 1 May 2014. < https://www.aps.com/library /renewables/PrescottVariability.pdf >

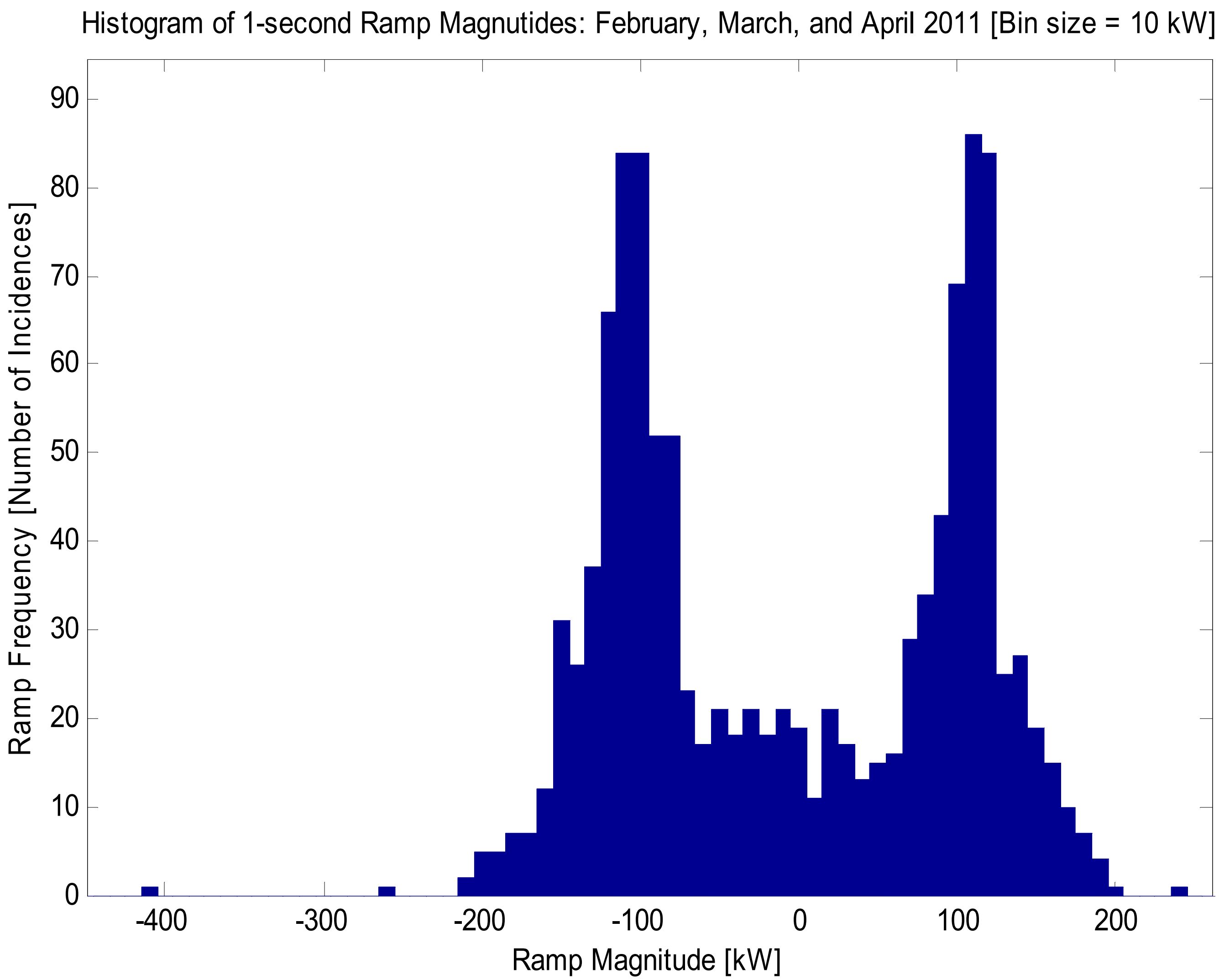
(3) Acker, T.L, Zavadil, R., Potter, C., and R. Flood. "Final Report: Arizona Public Service Wind Integration Cost Impact Study." *Wind Engineering*, vol.32, no.4, 2008, pgs. 339-354.

(4) Holttinen, H., Milligan, M., Kirby, B., Acker, T., Neimane, V., and T. Molinski. "Using Standard Deviation as a Measure of Increased Operational Reserve Requirement for Wind Power" *Wind Engineering*, vol.32, no.4, 2008, pgs. 355-378.

Table of Results

		σ (kW)	Min (kW)	Max (kW)	95.5% (kW)	99.0% (kW)	99.7% (kW)	99.9% (kW)
3/7/2011: relatively cloudy	Reg	219	-1066	1218	606	853	1027	1096
	Subreg	113	-923	1134	287	540	689	794
3/8/2011: relatively clear	Reg	8.6	-89.3	79.7	15.3	39.7	66.7	79.2
	Subreg	3.6	-67.2	34.9	8.1	15.4	21.7	27.3
February	Reg	67.7	-1195	1090	120	352	557	771
	Subreg	29.0	-1118	832	28.8	128	254	379
March	Reg	90.5	-1275	1218	180	470	731	917
	Subreg	35.4	-1030	1134	46.5	160	295	452
April	Reg	90.5	-1352	1125	162	495	752	949
	Subreg	38.5	-1277	1173	40.4	172	332	497
February, March, and April	Reg	84.0	-1352	1218	155	438	698	901
	Subreg	34.7	-1277	1173	39.0	154	296	445

1-second Ramp Events



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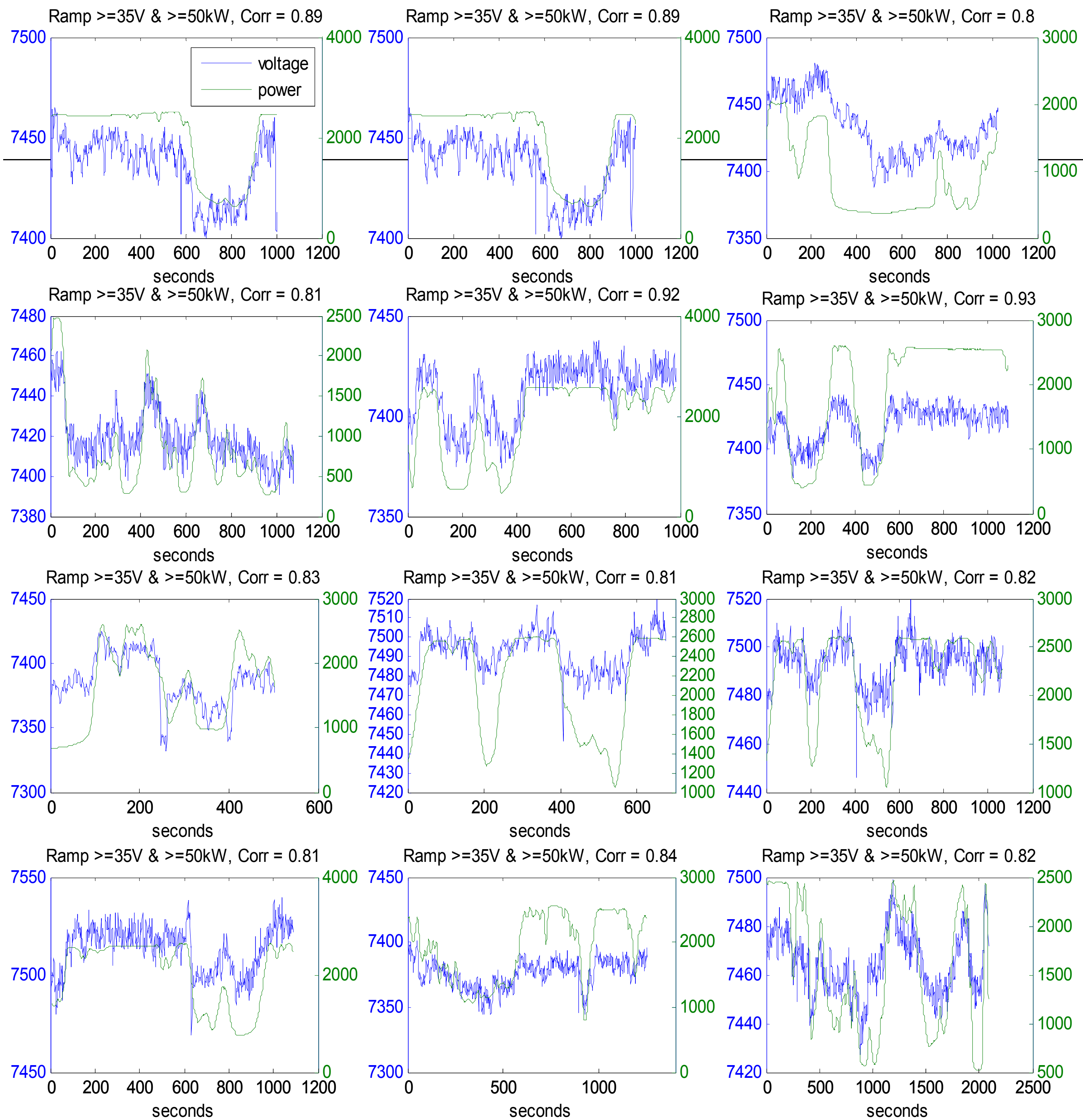
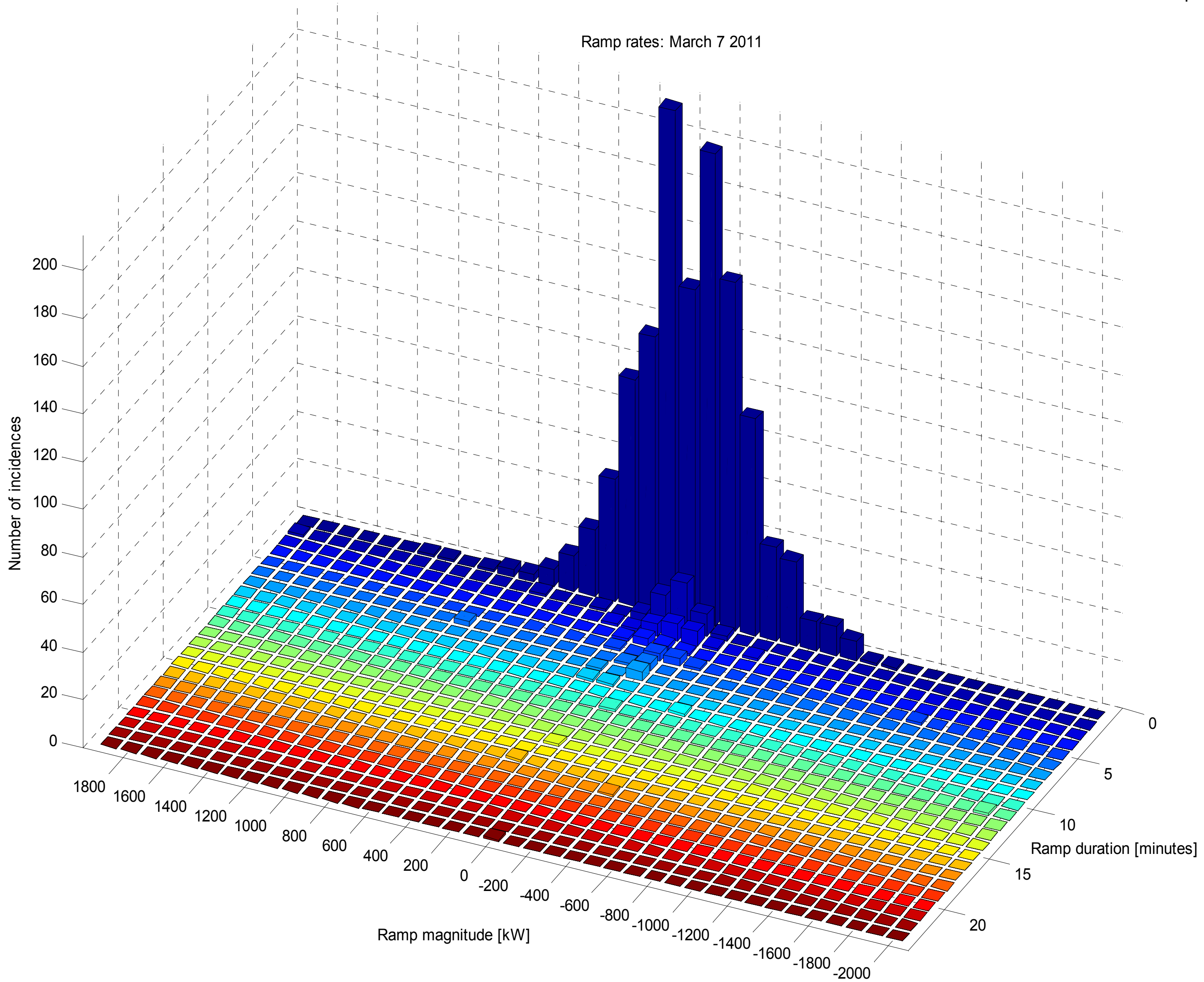
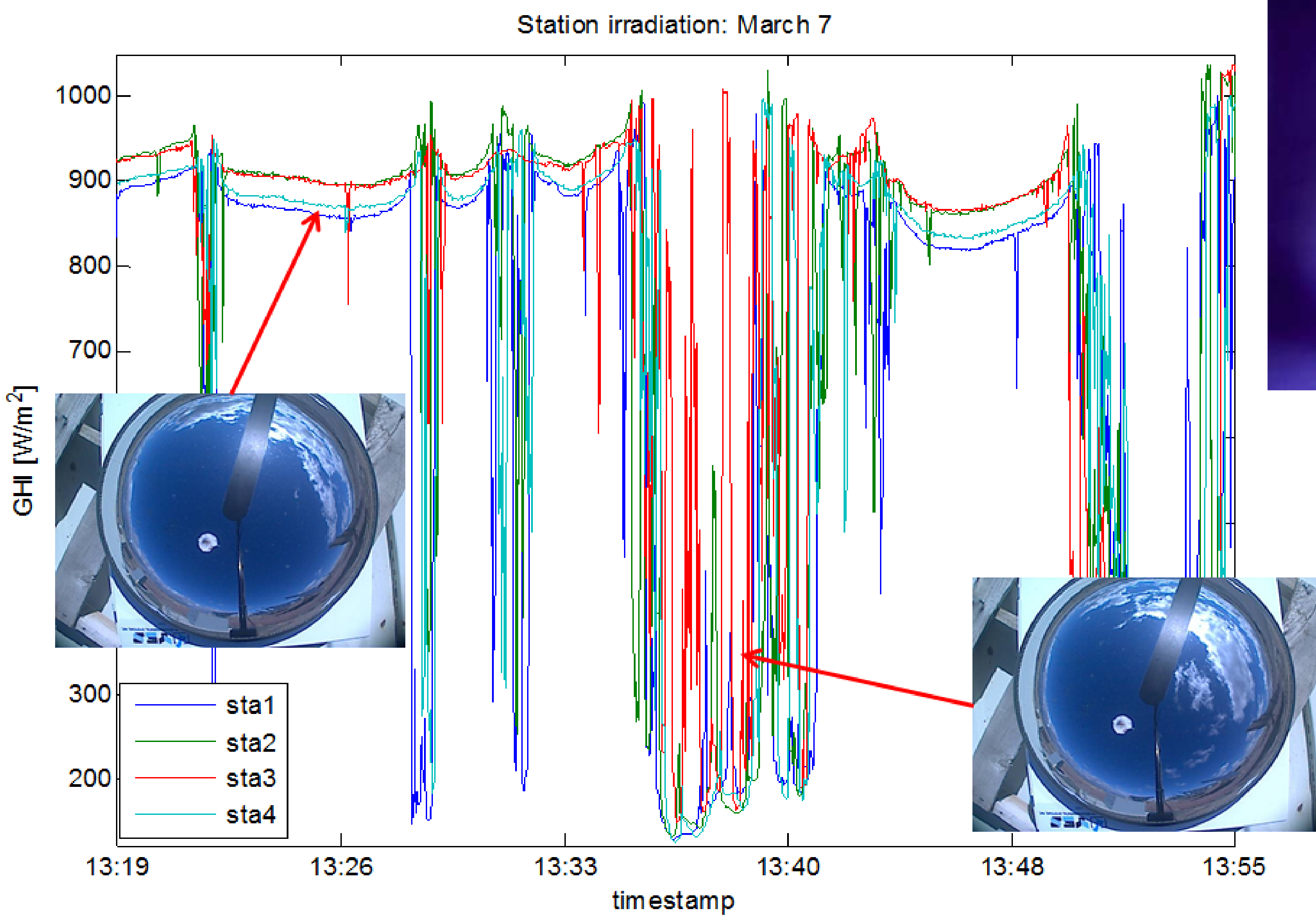


Ramp Events


Ramp rates: March 7 2011
Number of incidences
0
20
40
60
80
100
120
140
160
180
200
Ramp magnitude [kW]
1800
1600
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
Ramp duration [minutes]
0
5
10
15
20

Sky Imagery


Station irradiation: March 7
1000
900
800
700
300
200
GHI [W/m^2]
sta1
sta2
sta3
sta4
13:19
13:26
13:33
13:40
13:48
13:55
timestamp