

Evaluating PV Fleet Output Variability

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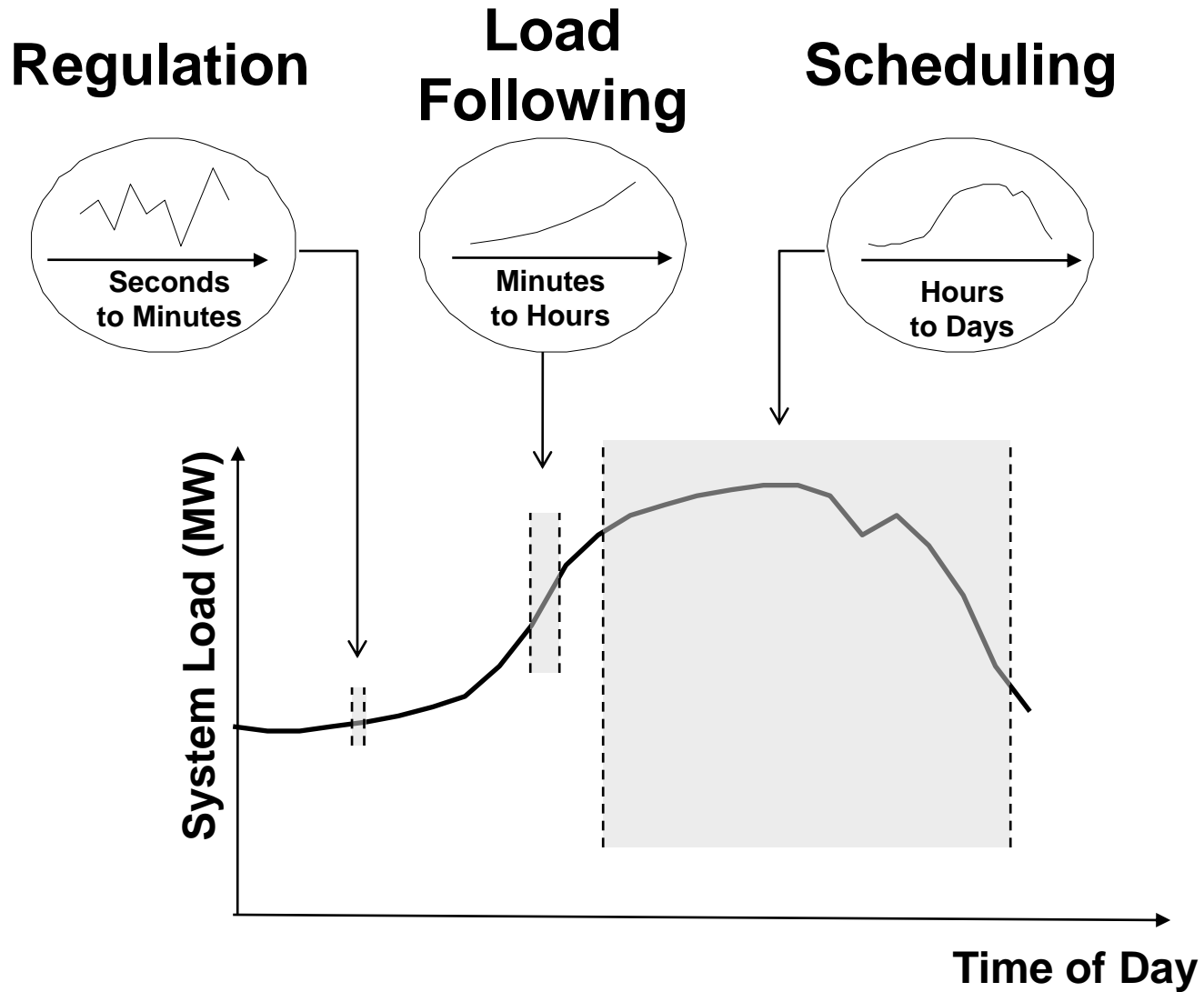
System Planning Perspective

Maximizing benefits while minimizing grid impacts requires utilities to influence where and how PV systems are installed

System Operation

Optimizing utility system operation once systems are installed requires the ability to forecast PV variability

Variability In Context of Multiple Time Scales



Three Variability Questions

Load Following

Does PV output match utility loads?

Regulation

Will short-term output variability be an issue?

Scheduling

Can PV output be forecasted?

Question #1

Load Following

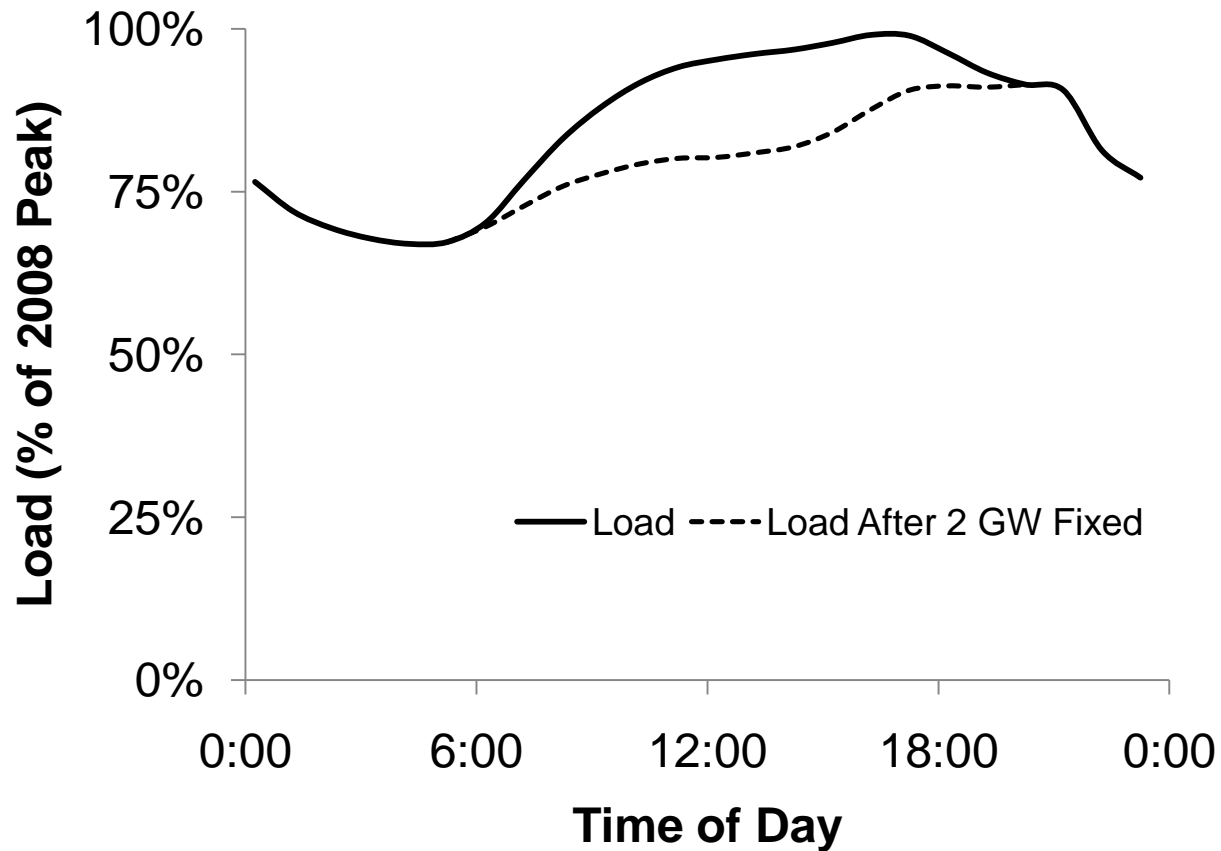
Does PV output match utility loads?

Hourly Load Match for NY City

- Obtain hourly weather & load data for 2005 to 2008
 - Load data from NY ISO
 - Weather and irradiance data from SolarAnywhere®
- Calculate output from 2 GW_{AC} of horizontal, fixed orientation PV using PVSimulator™
- Match simulated PV output data to NYC loads
- Full study available at www.cleanpower.com

PV Output Matches Peak Loads

2008 Peak Load Day for NYC (June 10)



Results are similar for 2005, 2006, and 2007

Question #2

Regulation

Will short-term output variability be an issue?

Objective

Quantify relative power output variability for a fleet of identical PV systems

Key Findings

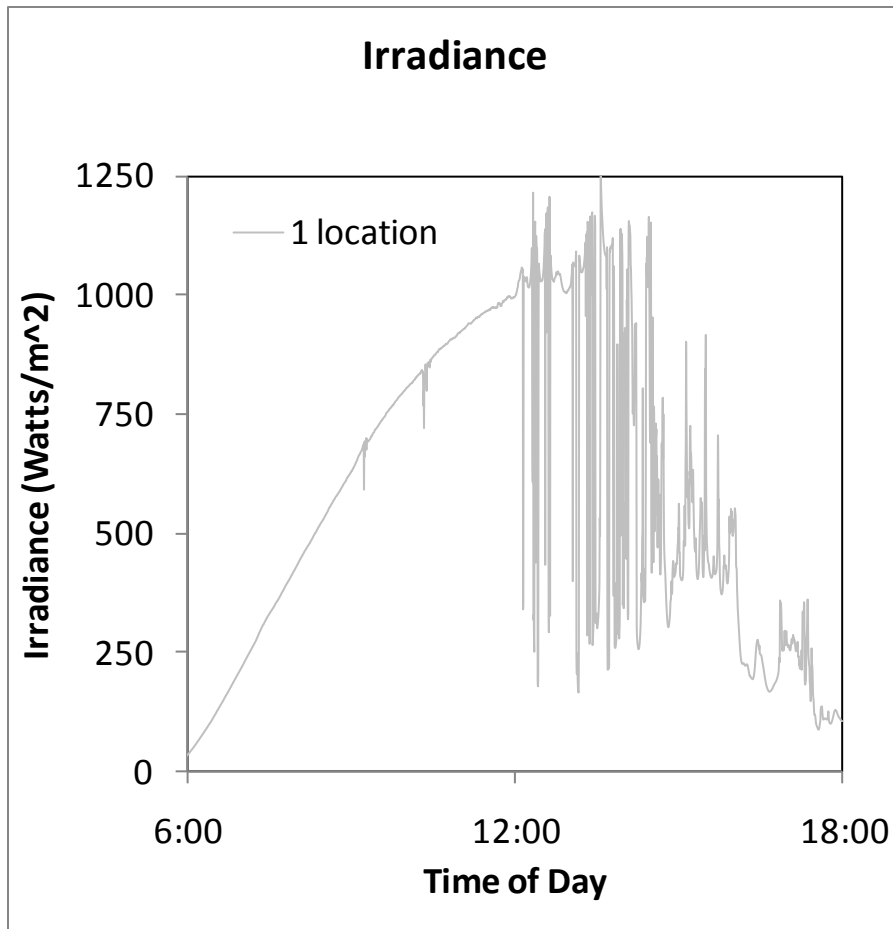
Relative Output Variability is based on:

1. Number of PV systems
2. Dispersion Factor

Relative Output Variability

Output variability for fleet / Output variability at single location

What is Meant by Variability?

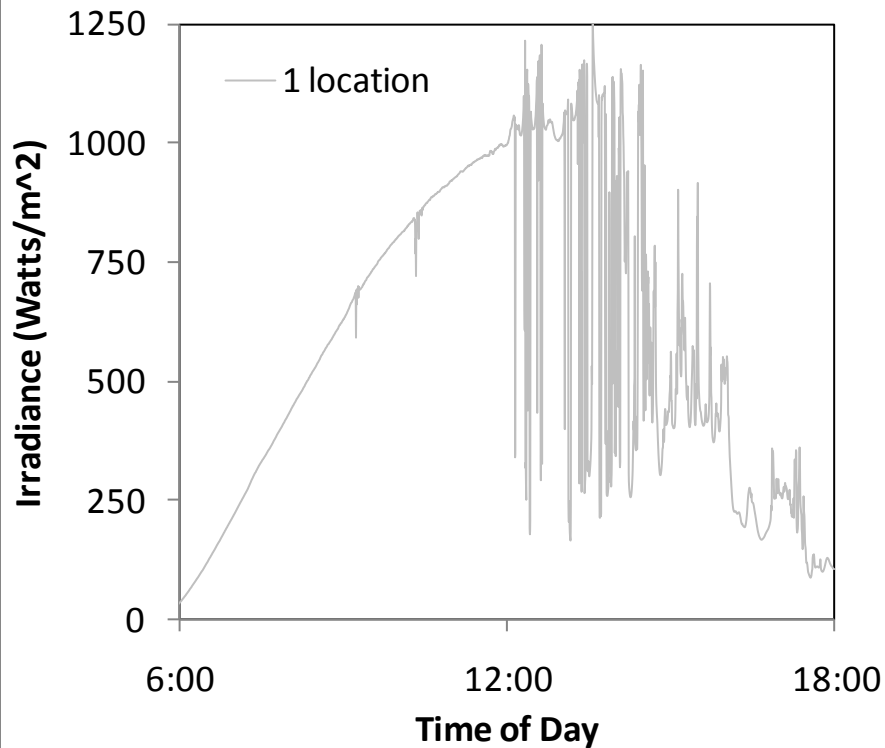


Relative Output Variability

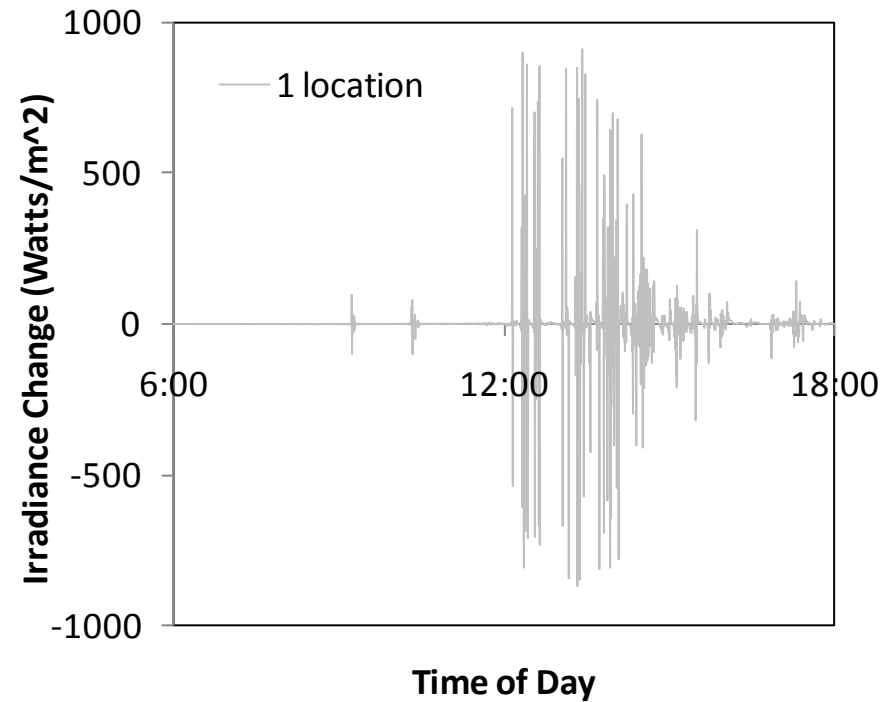
Output variability for fleet / Output variability at single location

What is Meant by Variability?

Irradiance



Change in Irradiance

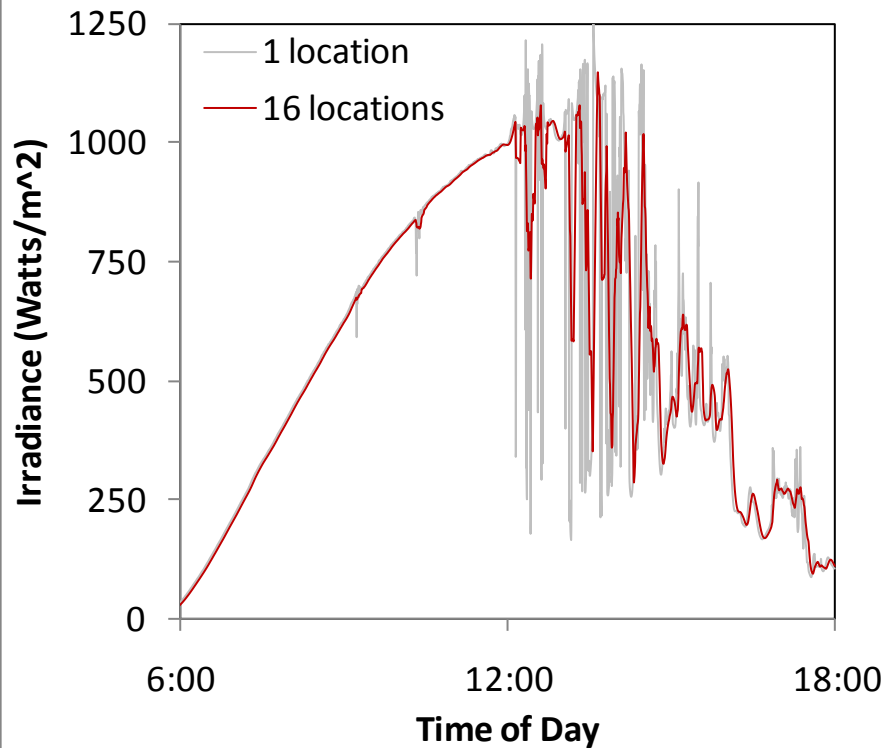


Relative Output Variability

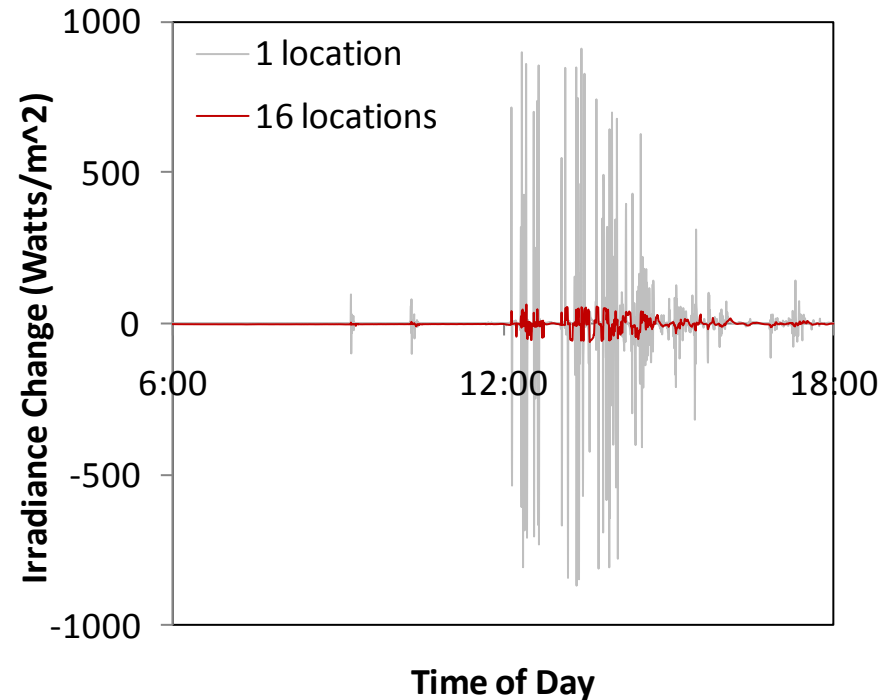
Output variability for fleet / Output variability at single location

How Number of Systems Affects Variability

Irradiance



Change in Irradiance



Relative Output Variability

Output variability for fleet / Output variability at single location

What is Dispersion Factor

- Dispersion Factor is the number of Time Intervals for a cloud to pass across the distance of the entire PV Fleet

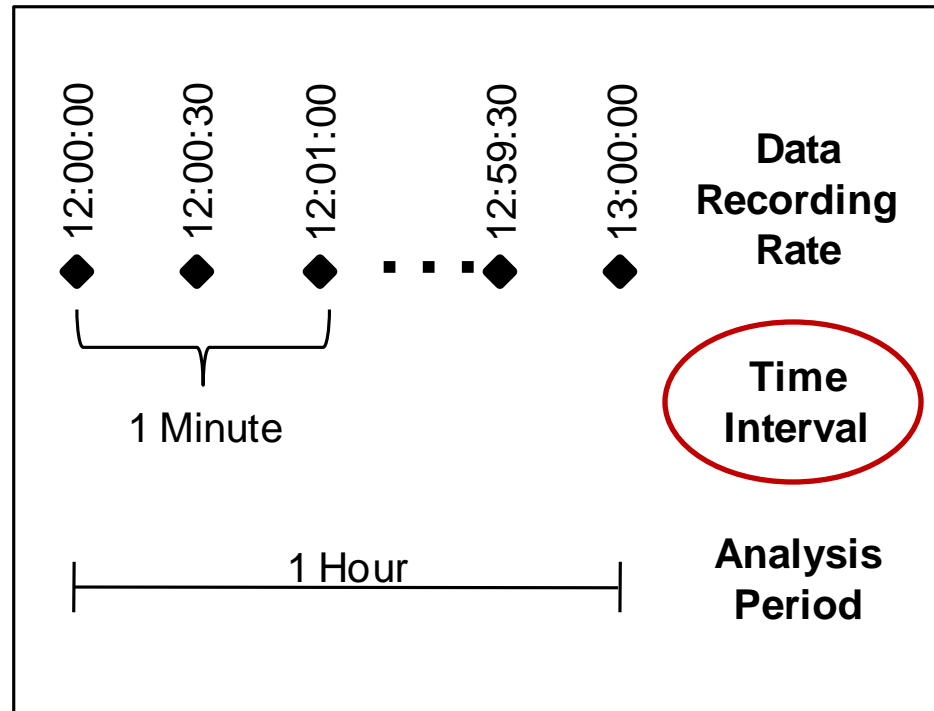
Relative Output Variability

Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

What is Time Interval?



Relative Output Variability

Output variability for fleet / Output variability at single location

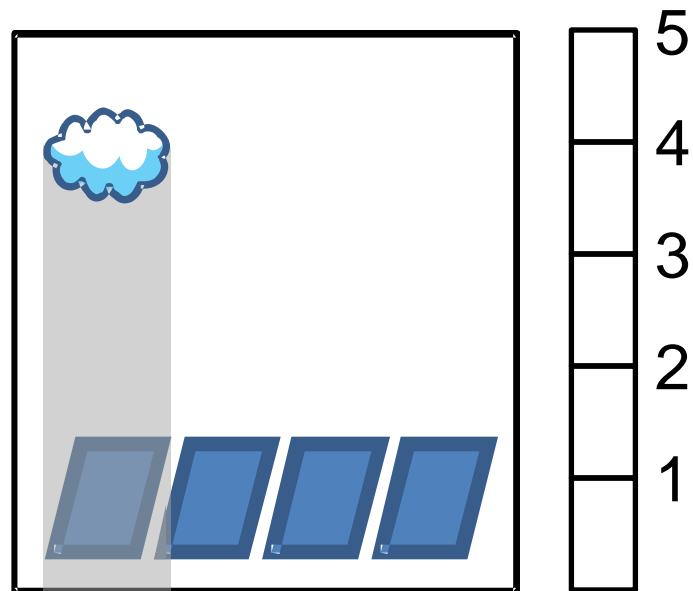
Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Dispersion Factor For Moderate Cloud Transit Speed

Moderate Cloud Transit Speed
(Dispersion Factor = 4)

12:00



Dispersion
Factor

Relative Output Variability

Output variability for fleet / Output variability at single location

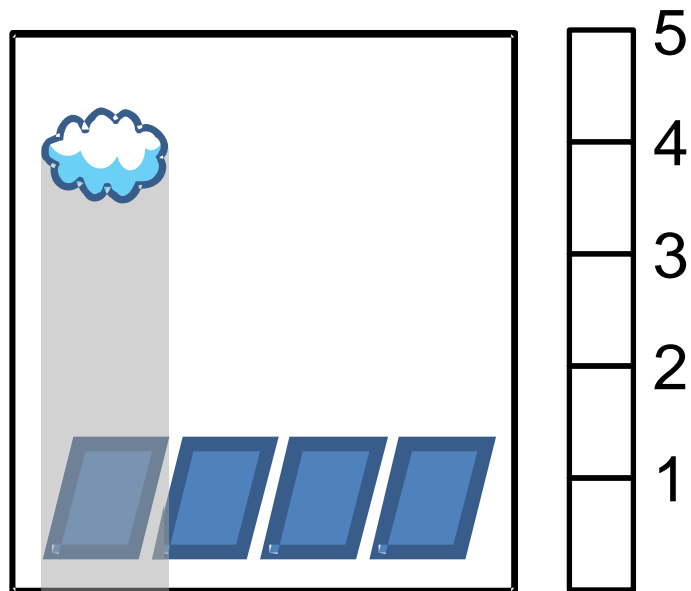
Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Dispersion Factor

**Fast Cloud Transit Speed
(Dispersion Factor = 2)**

12:00



**Dispersion
Factor**

Relative Output Variability

Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Model Results Categorized in 4 Regions

Crowded	Number of Systems $>$ <i>Dispersion Factor</i>
Optimal (Point)	Number of Systems $=$ <i>Dispersion Factor</i>
Limited	Number of Systems $<$ <i>Dispersion Factor</i>
Spacious	Number of Systems \ll <i>Dispersion Factor</i>

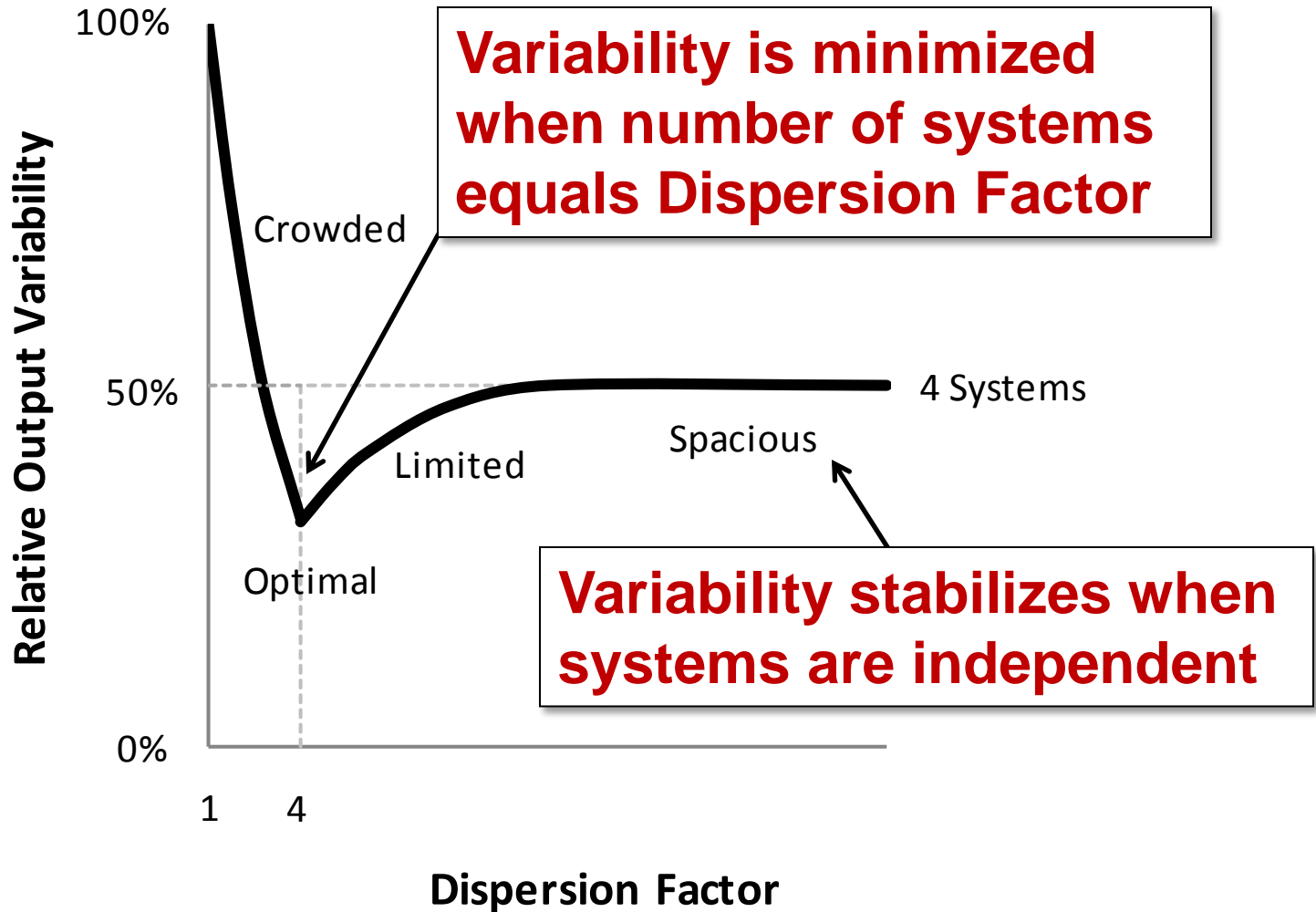
Relative Output Variability

Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Relative Output Variability: 4 Systems



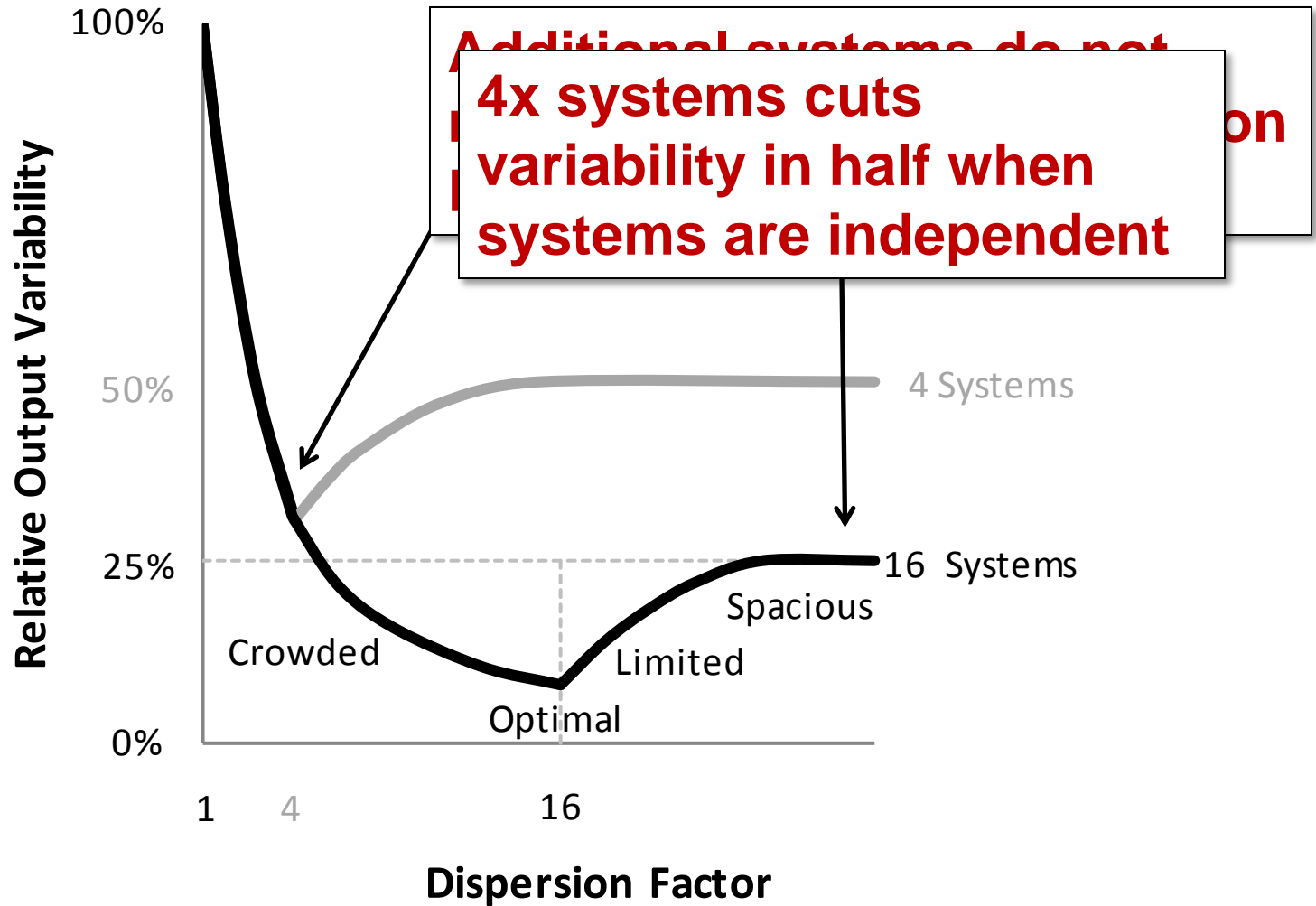
Relative Output Variability

Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Relative Output Variability: 16 Systems



Relative Output Variability

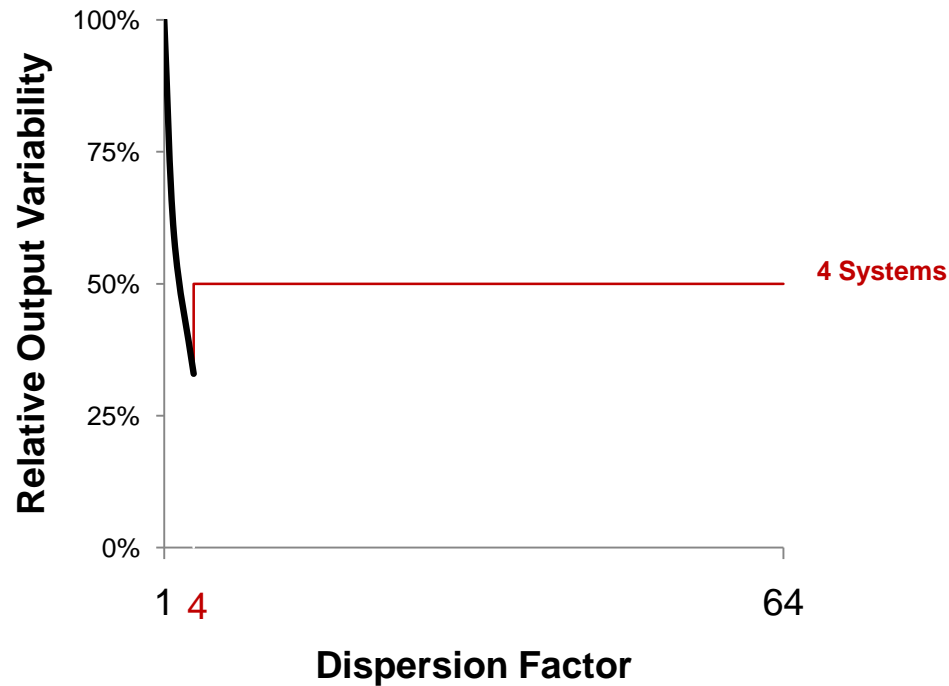
Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Validation: Construct Model for 4 Systems

Model Validation Results (Virtual Network 5 - May 7, 1999)



60-second Time Interval (Solid)

Relative Output Variability

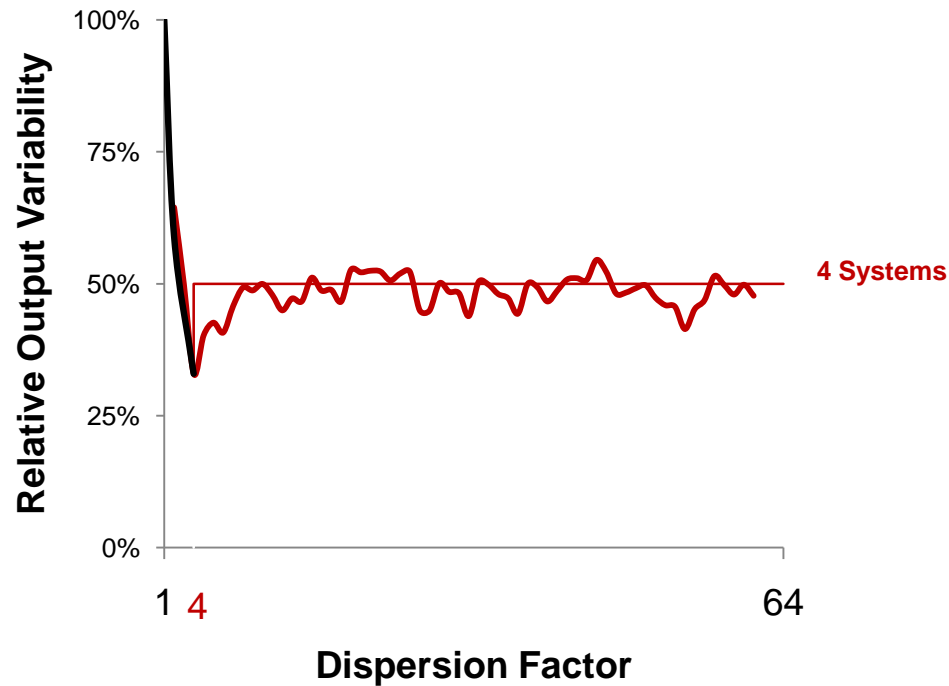
Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Add Measured Data

Model Validation Results (Virtual Network 5 - May 7, 1999)



60-second Time Interval (Solid)

Relative Output Variability

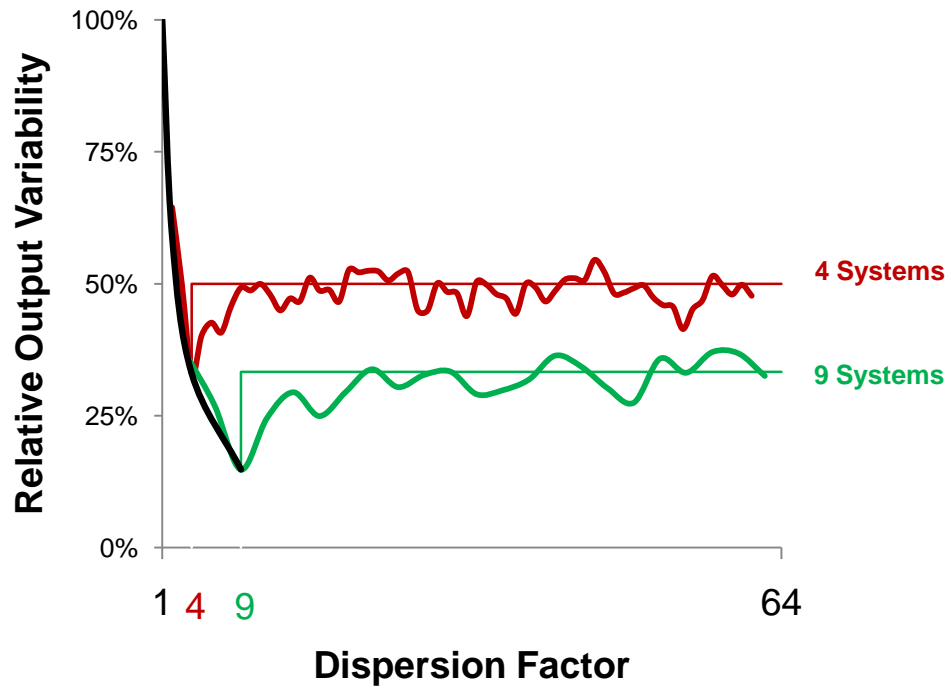
Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Repeat for 9 Systems

Model Validation Results (Virtual Network 5 - May 7, 1999)



60-second Time Interval (Solid)

Relative Output Variability

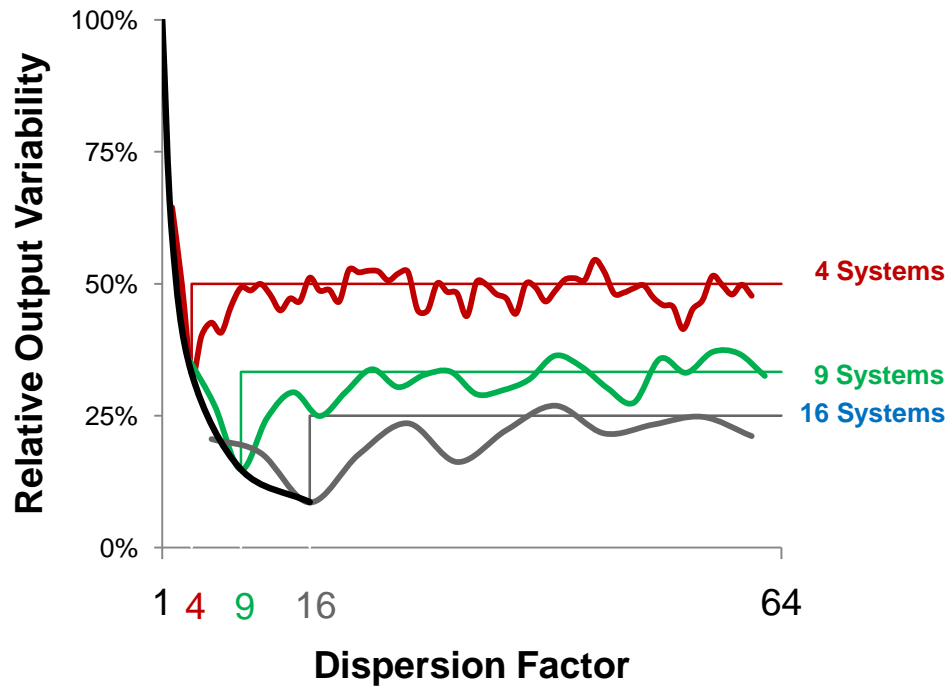
Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Repeat 16 Systems

Model Validation Results (Virtual Network 5 - May 7, 1999)



60-second Time Interval (Solid)

Relative Output Variability

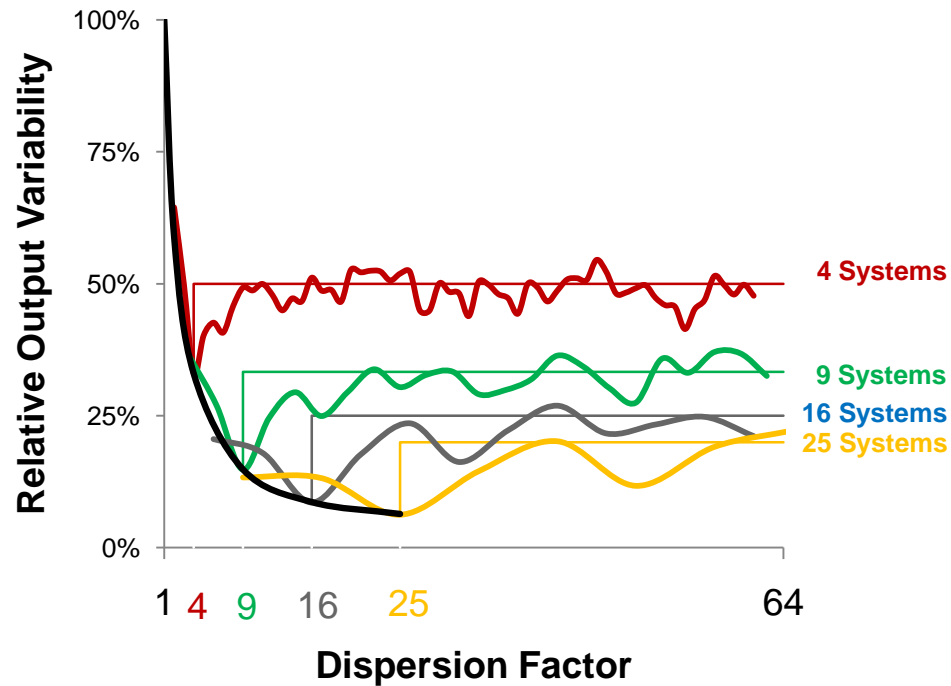
Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Repeat for 25 Systems

Model Validation Results (Virtual Network 5 - May 7, 1999)



60-second Time Interval (Solid)

Relative Output Variability

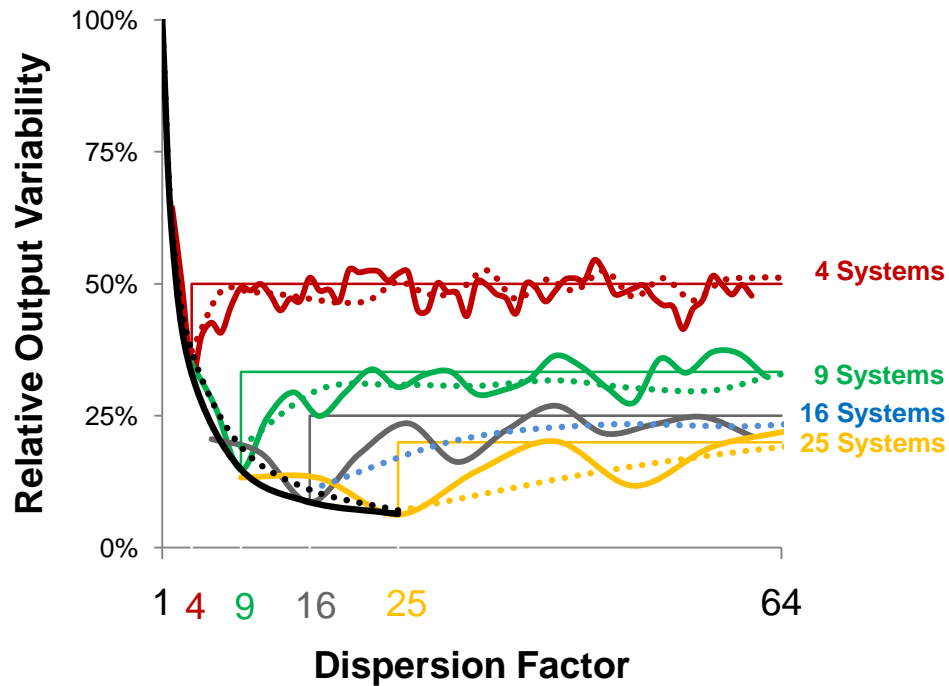
Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

Repeat w/ 20 Second Time Interval

Model Validation Results (Virtual Network 5 - May 7, 1999)



20-second Time Interval (Dashed) 60-second Time Interval (Solid)

Relative Output Variability

Output variability for fleet / Output variability at single location

Dispersion Factor

Number of Time Intervals for cloud to pass across the PV Fleet

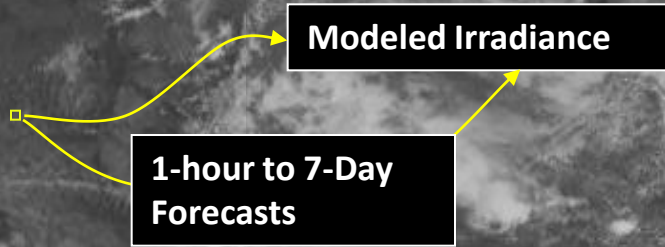
Question #3

Scheduling

Can PV output be forecasted?

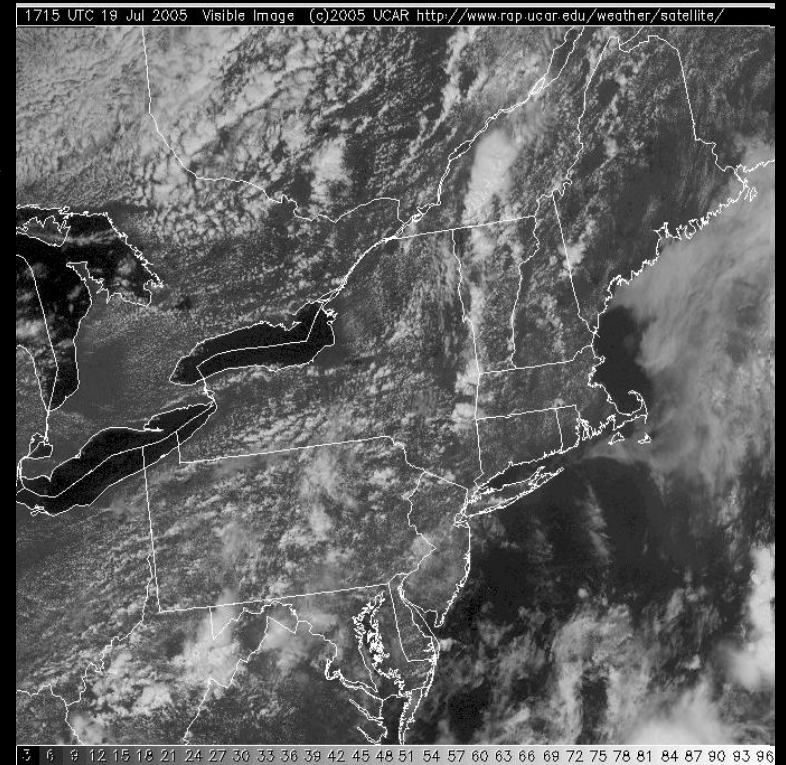
SOLAR ANYWHERE

PV



Current-to-5 hours CLOUD MOTION

Patterned after Lorenz et al.



Conclusions

- Utility load/PV output match can be analyzed (load following quantifiable)
- Short-term variability can be evaluated (regulation can be assessed)
- PV output can be forecasted (scheduling can be accommodated)

Next Steps



- Further model validation
- Extend model to arbitrary fleet configuration
- Integrate with SolarAnywhere forecasting



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