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Solar Resource Modeling for Grid Integration Studies

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Why Solar Resource Models?

- Solar photovoltaic (PV) energy varies primarily with irradiance levels.
- Clouds can rapidly change irradiance at a point.
  - Nominal midday irradiance = 1,000 W/m^2
  - Irradiance can change >300 W/m^2 per sec.
- PV output from large areas or distributed plants will vary less than suggested by single point measurements.
  - Changes become uncorrelated over large distances.

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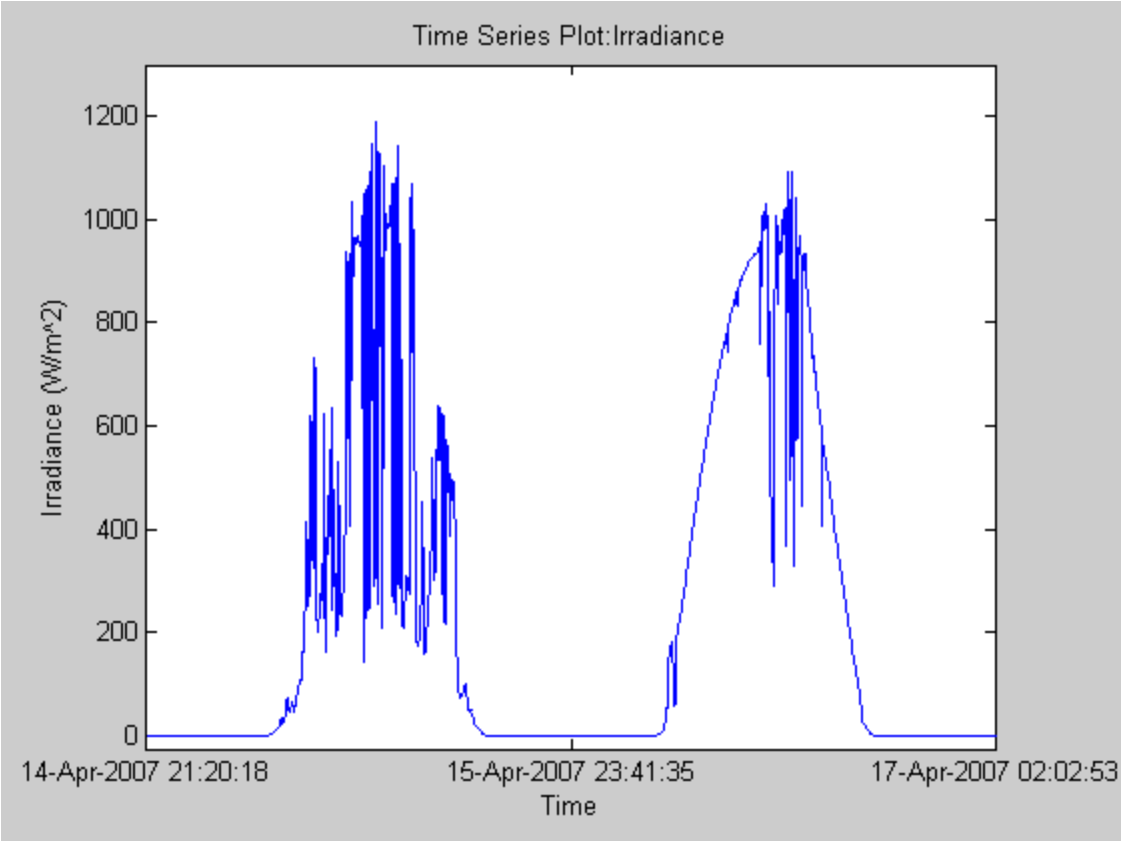
Irradiance Variability



LVVWD (Fort Apache) April 15-16, 2007

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What is the effect of different scenarios?

- How and where should solar be developed?
  - Very large plants?
  - Distributed mid to large plants?
  - Distributed small plants?

- We are developing a model that can predict aggregated solar output from different build-out scenarios at a timescale that will be useful for utility impact analyses.

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When is Variability Important?

- **Variability is important if it significantly adds to the net load variability.**
  - **net load = load – non-dispatchable generation**
- **Impact of variability depends on where the PV system is connected to the grid, penetration level, types of load serviced, and available generation options.**
- **Reliability standards can be affected (e.g., CPS2).**
  - **– Need for additional reserves?**
- **On clear days, solar (diurnal) variability can help utilities serve peak loads.**
  - **– Can we quantify this value?**

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Questions

- What controls PV output variability?
- How do we measure variability?
- How is PV output variability influenced by plant size, configuration, and geographic diversity (separation)?
- What can we learn from existing plants?
  - Las Vegas Valley Water District
  - Large multi-MW plants
- How can modeling help to predict the amount of variability for various build out scenarios?

What controls PV output variability?

- **Natural Causes**
  - **Diurnal cycle**
  - **Cloud shadows moving over PV field or fleet**
  - **Temperature and wind speed (minor effect)**
- **Engineered Causes**
  - **Orientation and/or tracking of modules**
  - **Plant size, geometry, location**
  - **Electrical (interconnection) location influences how much variability is permissible.**

How do we measure and predict variability?

- **Analyze irradiance and PV system outputs**
  - **Examine the distribution of power changes ('ramps') over a fixed time interval (e.g., 1-sec, 1-min, 10-min, etc.)**
    - **Step Changes: $P_t - P_{t+k}$, where t is time (1 to nt) and k is fixed time interval**
    - **Ramping Rates:**

    1) rate of change of moving average

    2) least squares linear regression slope of $P_{t \rightarrow t+k}$
- **Model Cloud Interactions**
  - **Allows insights to system sizes and configurations that are not yet built.**

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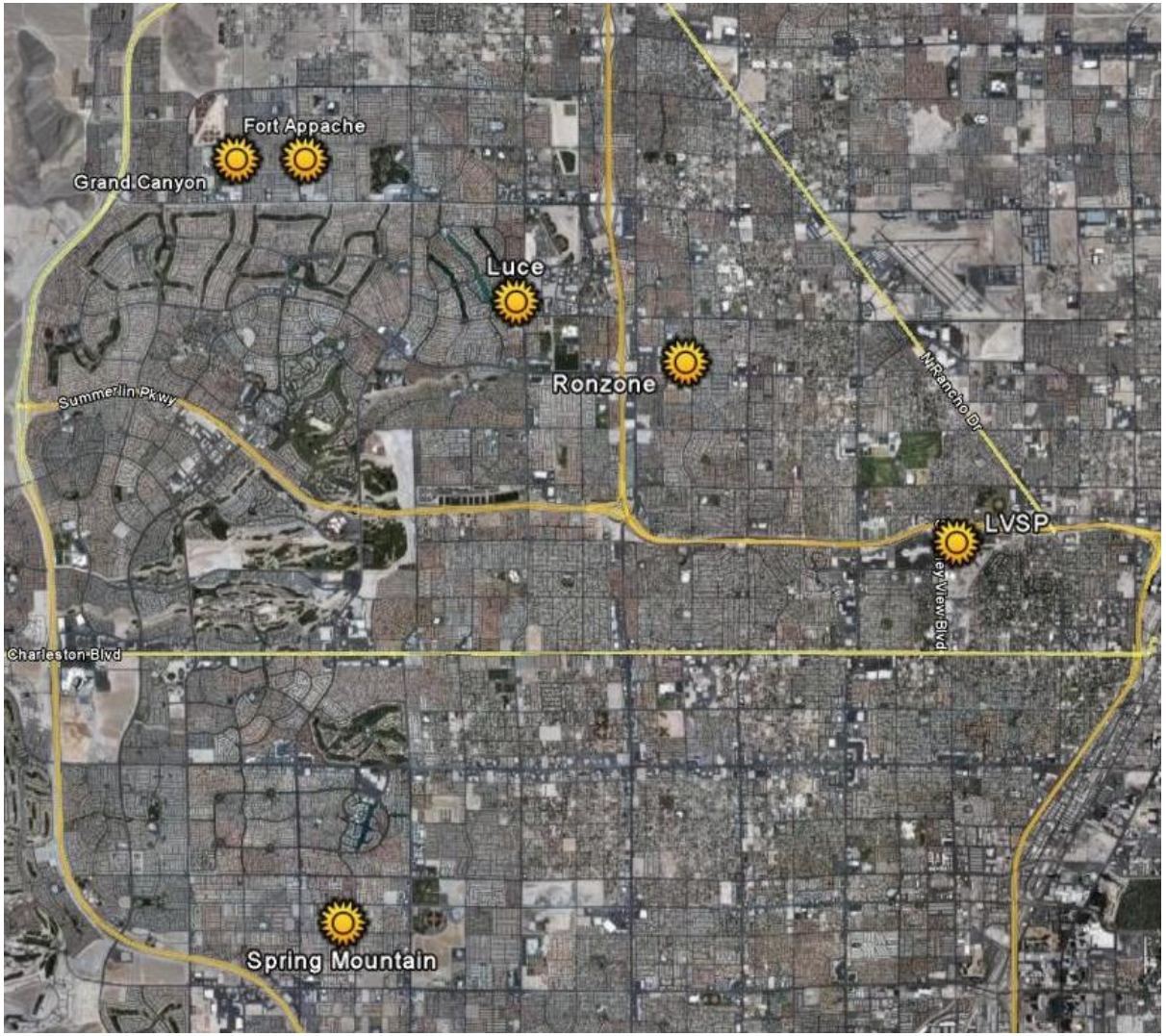
LVVWD Solar Site Map



Las Vegas, NV

What is the benefit of distributed PV generation?

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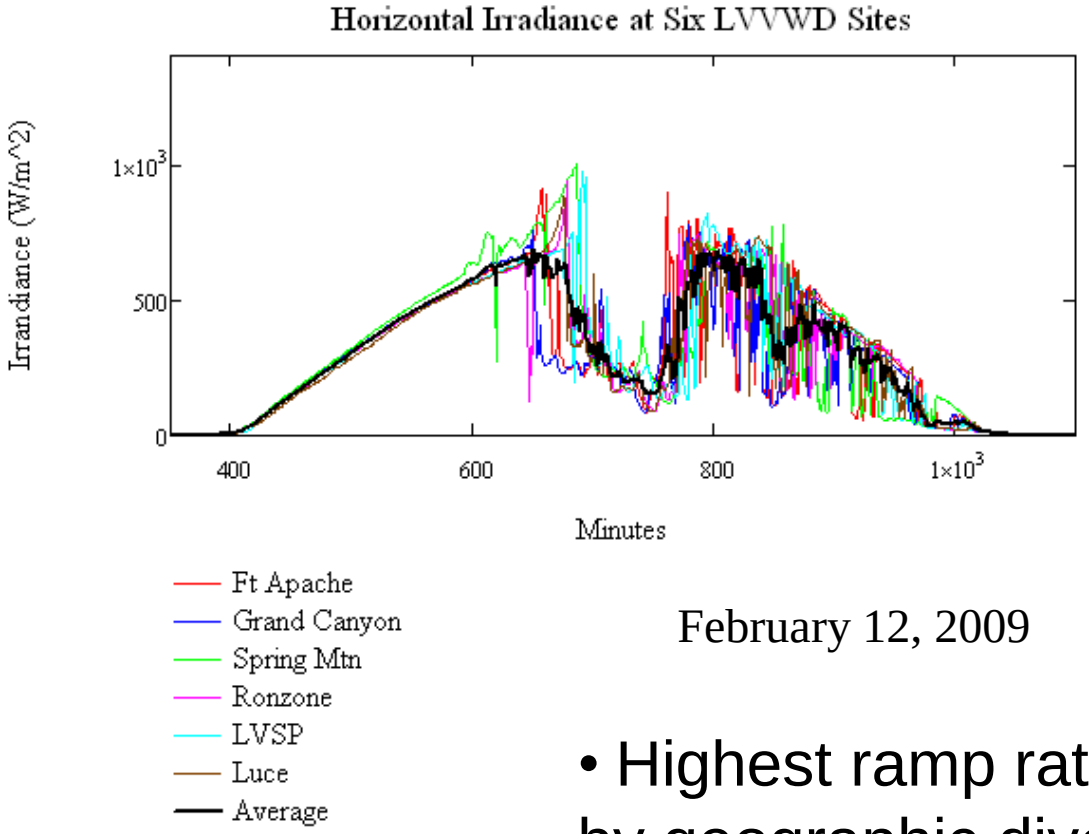
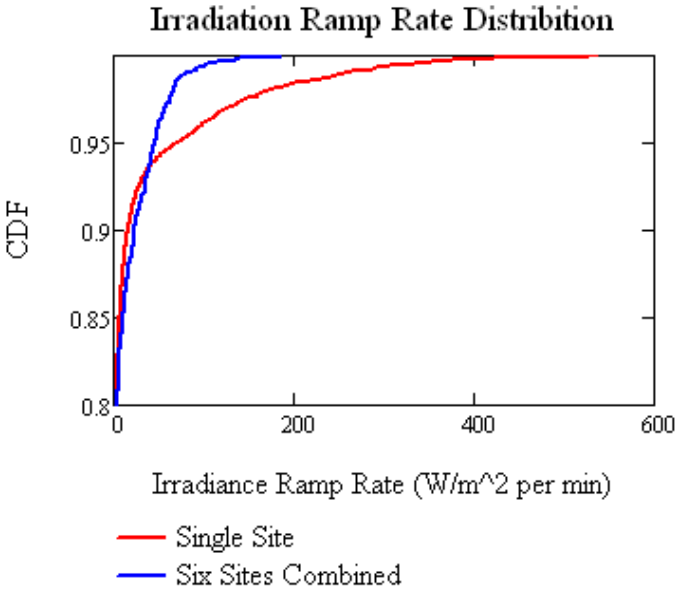
Effect of Geographic Diversity





February 12, 2009

- Highest ramp rates are reduced by geographic diversity
- Frequency of lower ramps can be increased

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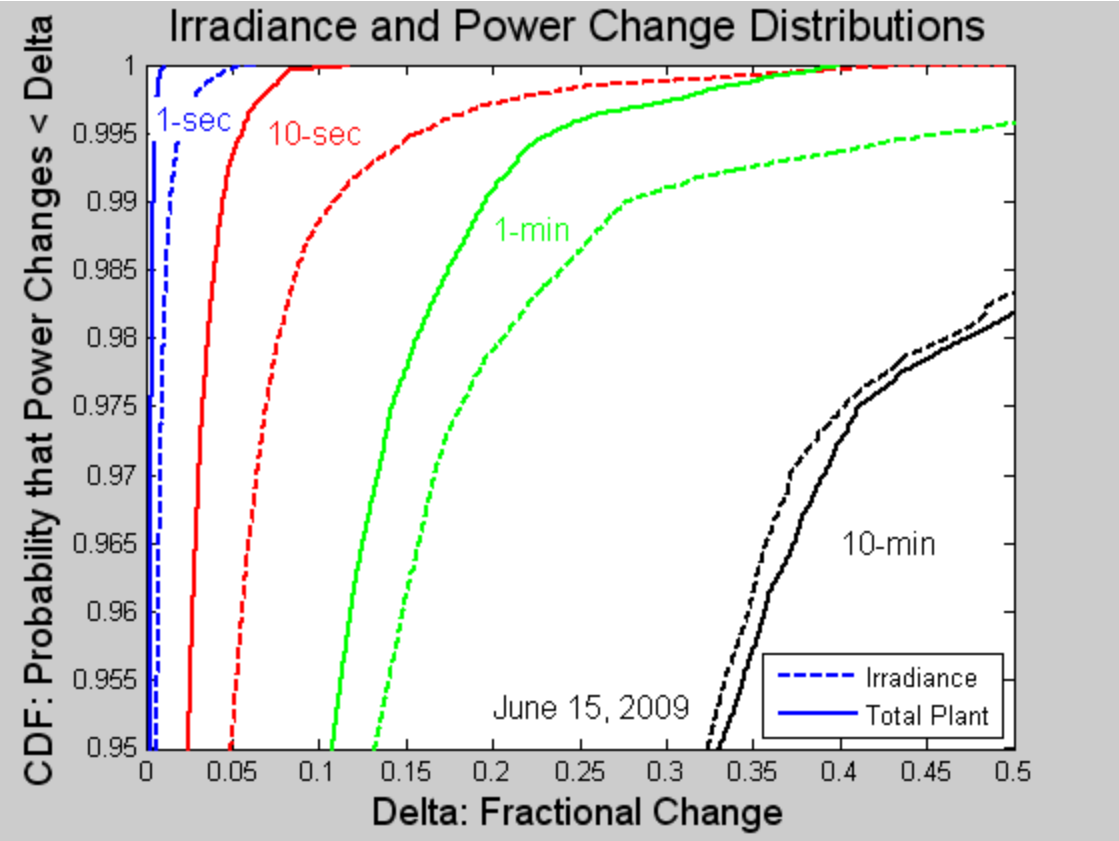
Effect of Plant Size



Data from multi MW PV plant in US.

Large 1-sec, 10-sec, and 1-min ramps are approximately 60%, 40%, and >10% less then irradiance changes at a point.

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Plants are Bigger Than Cloud Shadows

Olmedilla Park Solar Power Plant (60 MW)

Puertollano Park Solar Power Plant (50 MW)

Waldpolenz Solar Park (40 MW)

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Modeling Effect of Geographic Diversity

- Synthetic cloud model
  - Define cloud size range
  - Define cloud transmittance
  - Define cloud coverage
- (1) Compare small, large, and distributed output
- (2) Examine different spacing between plants
  - Fixed capacity PV plant (100 subarrays: 10 x 10)
  - Vary separation of subarrays
  - Examine output variability of fleet for a single synthetic day.

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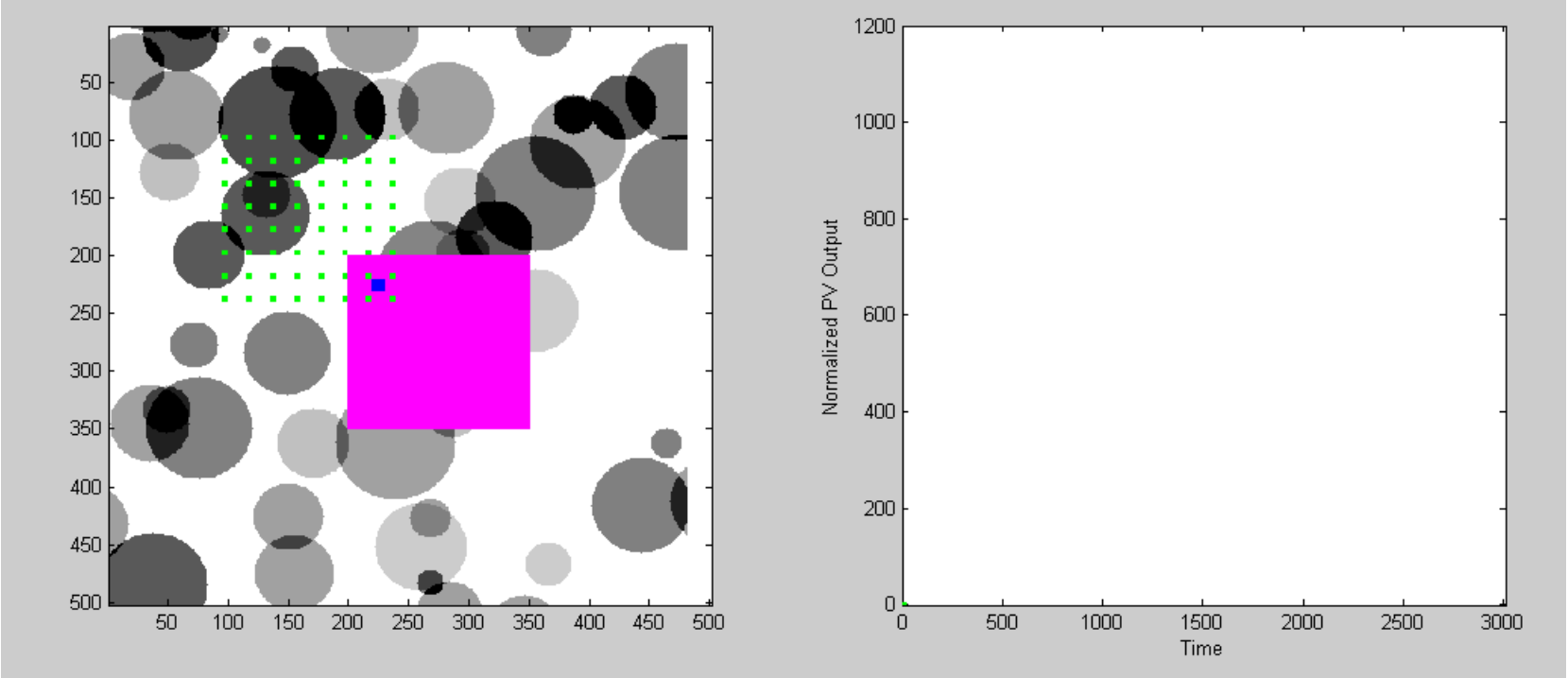
PVCloudSim Model



Parameters: cloud radius = 10 to 100; transmittance = 0.2 to 0.7, cloud coverage = 0.35

(Clouds can overlap)

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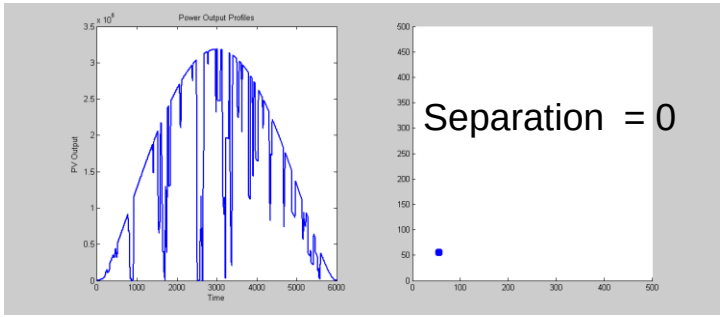
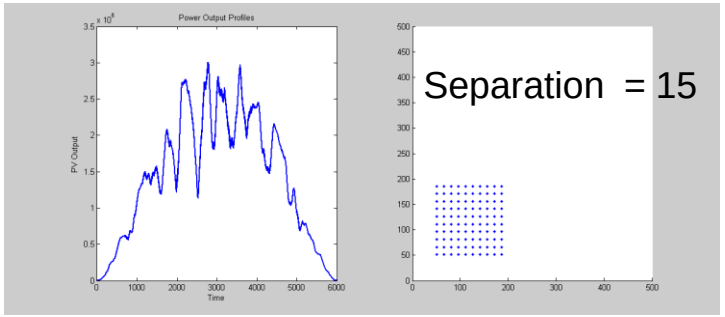
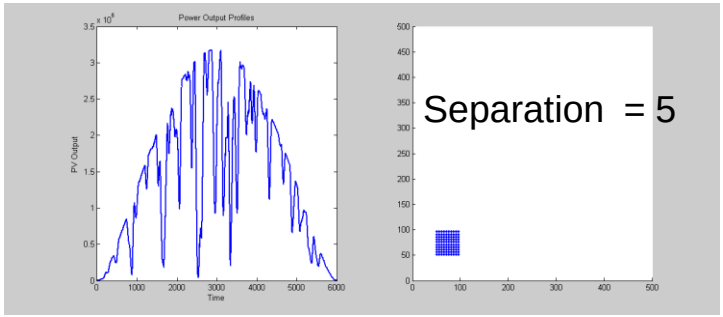
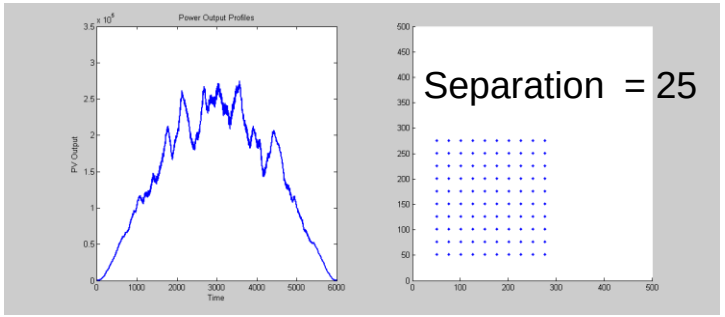
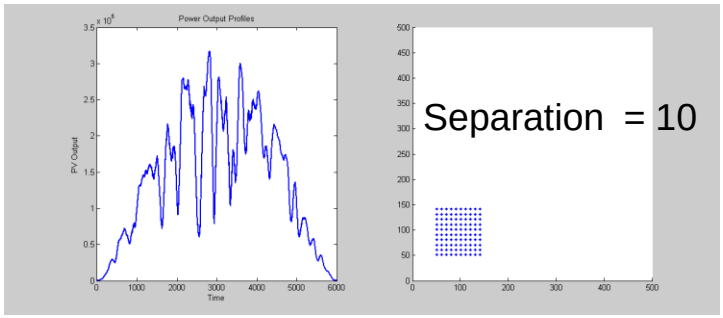
Effect of Geographic Diversity(a)

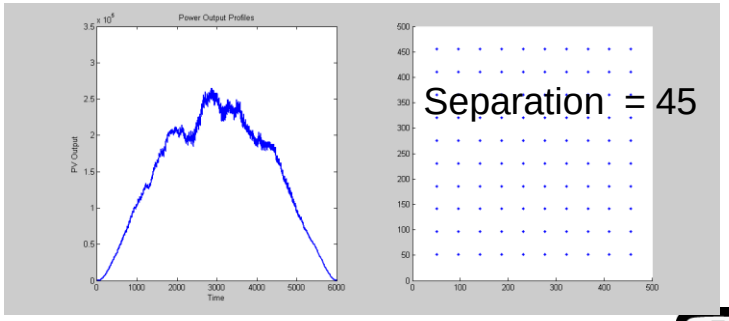












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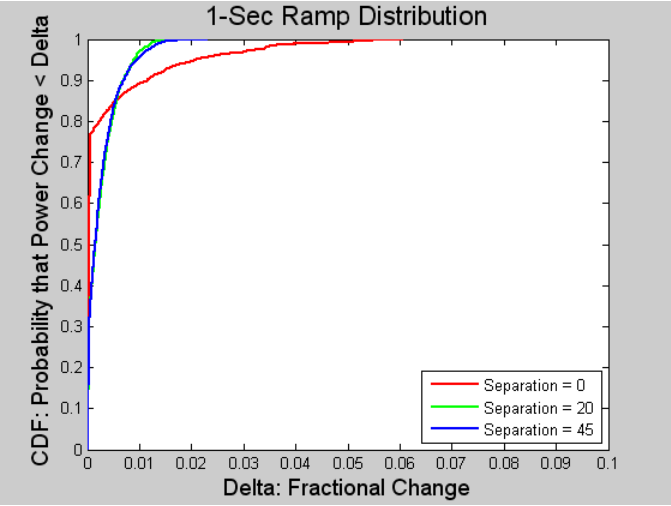
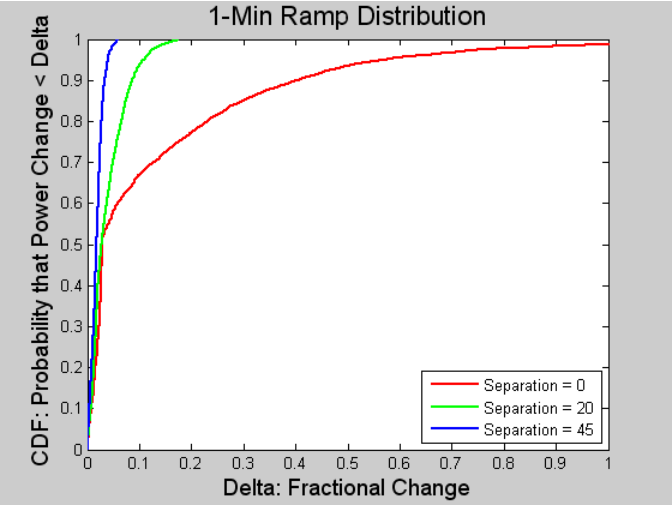
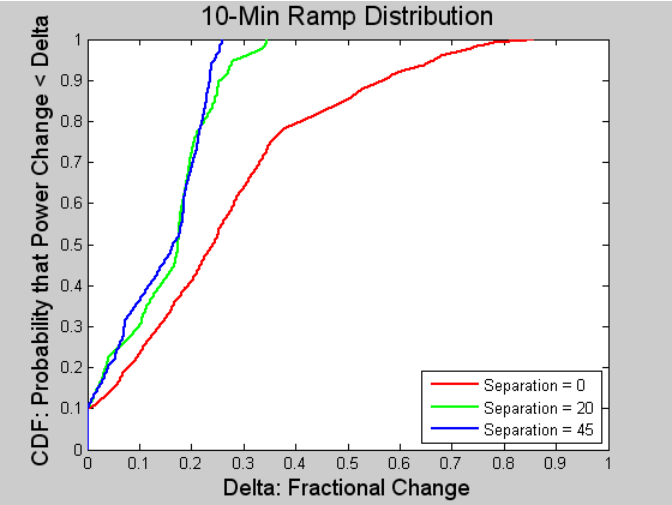
(2) Simulated Ramp Rate Distributions





Large ramps are reduced with geographic separation of PV plants



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Next Steps for CloudSim Model

- Link model parameters to satellite irradiance data, ground based weather data (e.g., METAR network)
  - Cloud size and shape distribution
  - Transmissivity
  - Transit velocity
- Generate cloud field for large regions within a balancing area or entire state
- Define and simulate various build-out scenarios

PV Variability Summary

- **Variability of large plants is modestly reduced from single point (especially very short duration ramps)**
  - **Reduction is limited because large plant output increases with area while variability decreases with increasing separation distance.**
- **Variability of distributed plants decreases significantly with separation distance**
  - **Function of weather and cloud patterns, cloud transit speed, separation distance, etc.**

Conclusions and Next Steps

- **Analysis of existing plant output can be used to define the range of ramps expected in the future on a plant by plant basis.**
- **Cloud models are being developed to represent weather patterns. These models can be used to simulate PV power output from fleets of PV plants and help utilities understand how PV build-out scenarios will affect system reserves and compliance with regulations.**
- **Credible integration studies are possible today.**

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