RENEWABLE ENERGY INTEGRATION CASE STUDIES

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Outline

Ota City, Japan

- **Basic Concepts**
  - Why is integration of variable generation (VG) a challenge?
  - Bulk System vs. Distribution Issues
- **Review of Recent and Current Studies**
- **Define next steps**

Harwich, MA

Freiburg, Germany

What is the Utility's Role

- **Provide high quality, reliable electricity to customers when they demand it.**
  - Generate or procure power to meet system load
    - Integrated resource planning (long term planning)
    - Balance system load and generation (near term planning)
  - Transmit this power to the loads using transmission and distribution resources
    - Transmission and distribution planning
    - Transmission and distribution component upgrades
    - Maintenance of transmission and distribution
- **Protect staff and public from harm**
    - Switching, protection equipment , response to emergency events
- **Private utilities must make a return on investment**
  - Bill customers for services

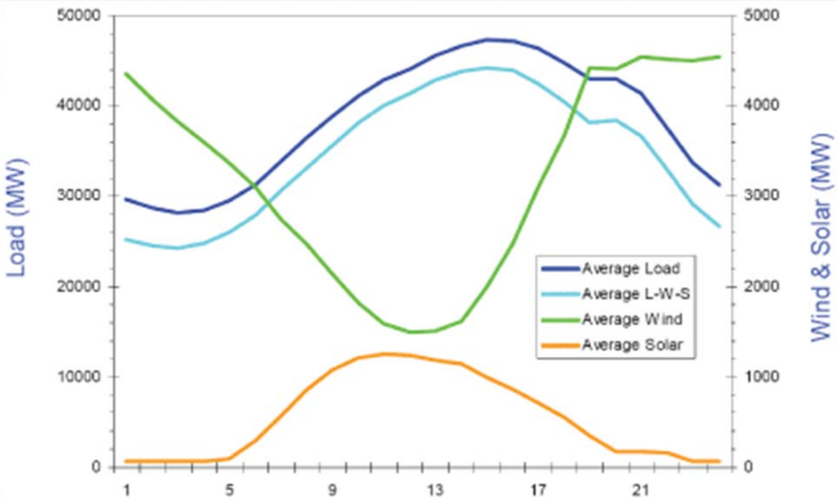
What is Variable Generation?

- **Typically refers to Solar (PV) and Wind**

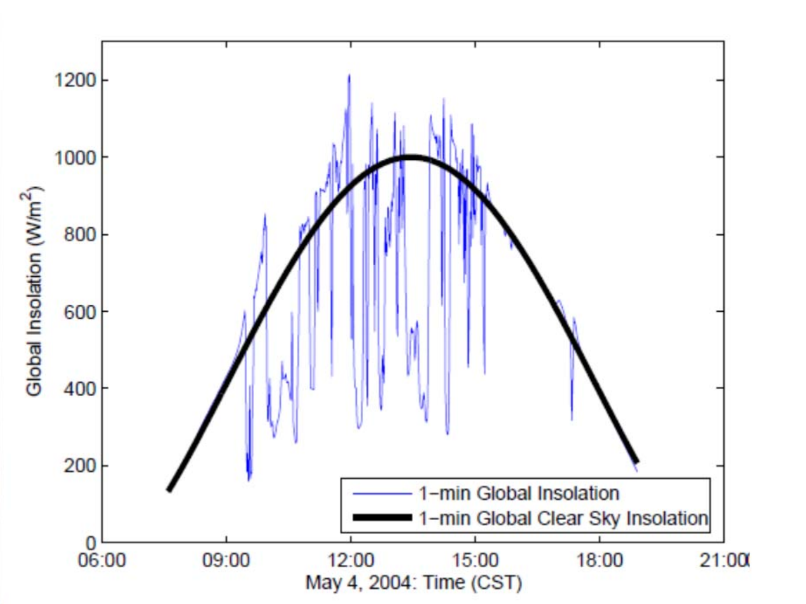
- **Variable**
  - Long-term and short-term patterns
  - Limited ability to control

- **Uncertain**
  - Ability to forecast
  - Accuracy depends on how far ahead the forecast covers

- **Sound familiar? Many of the same characteristics associated with load**



Average PV and wind output patterns in CA

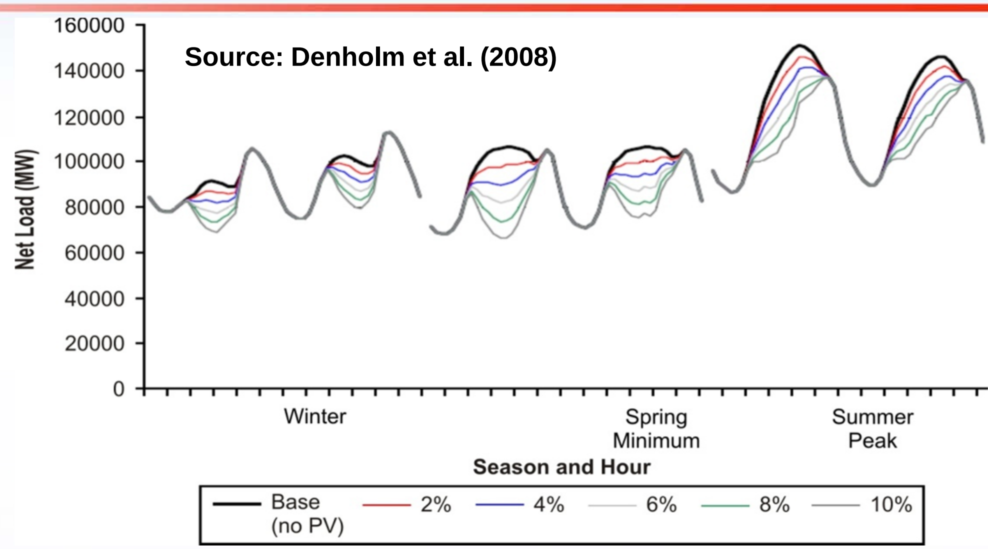


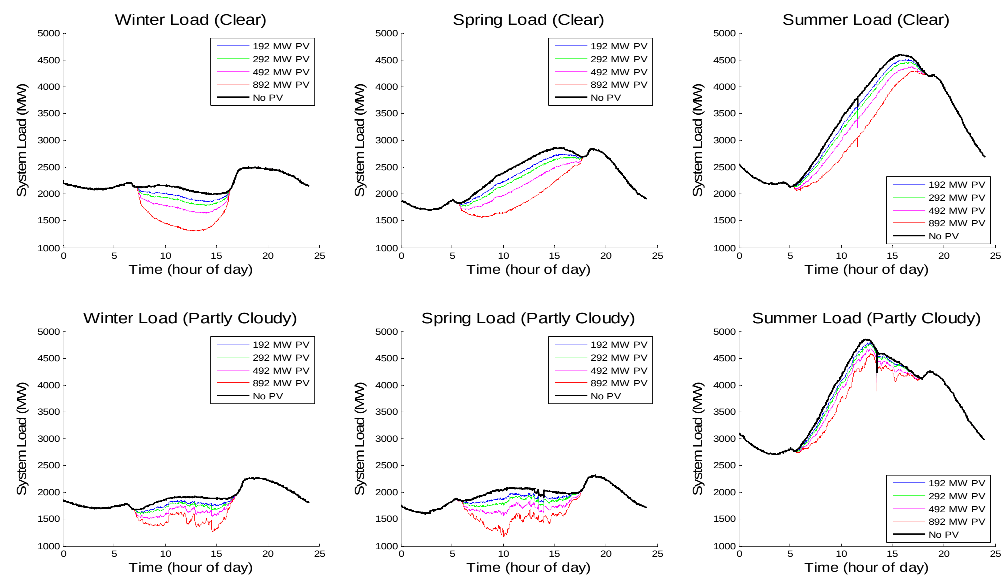
How Does VG Affect Utilities?

- **Variable generation (VG) has traditionally been a must-take resource that affects the load utilities must manage (net load)**
- **At the distribution level**
  - The interaction of variable generation and variable load can alter the normal behavior and performance of components on a distribution feeder (voltage regulators, voltage tap changers, capacitors, etc)
  - Examples: (1) frequency of tap changes may increase leading to reliability and service life concerns, (2) flicker, (3) interoperability between VG components (inverters), harmonics.
  - VG may help defer distribution upgrades due to reducing peak loads on a feeder
- **At the bulk system level**
  - Added variability may increase total variability in load, making it more costly to balance
  - Forecasting VG becomes very important in order to adequately schedule generation and manage resources
  - VG may help defer generation upgrades or addions

PV Generation and Net Load

- **Net Load = Load – VG**
  - VG is assumed to be a “must take” generation
- **During summer peak, PV helps to reduce the peak load**
  - Less fossil generation needed
  - Fewer “peakers” (dirty)
- **During low load seasons (spring and winter in SW) PV can affect operations and planning**
  - Lower temperature, sun position at equinox
  - Affects minimum load
  - Increases the morning ramp
  - Variability increases



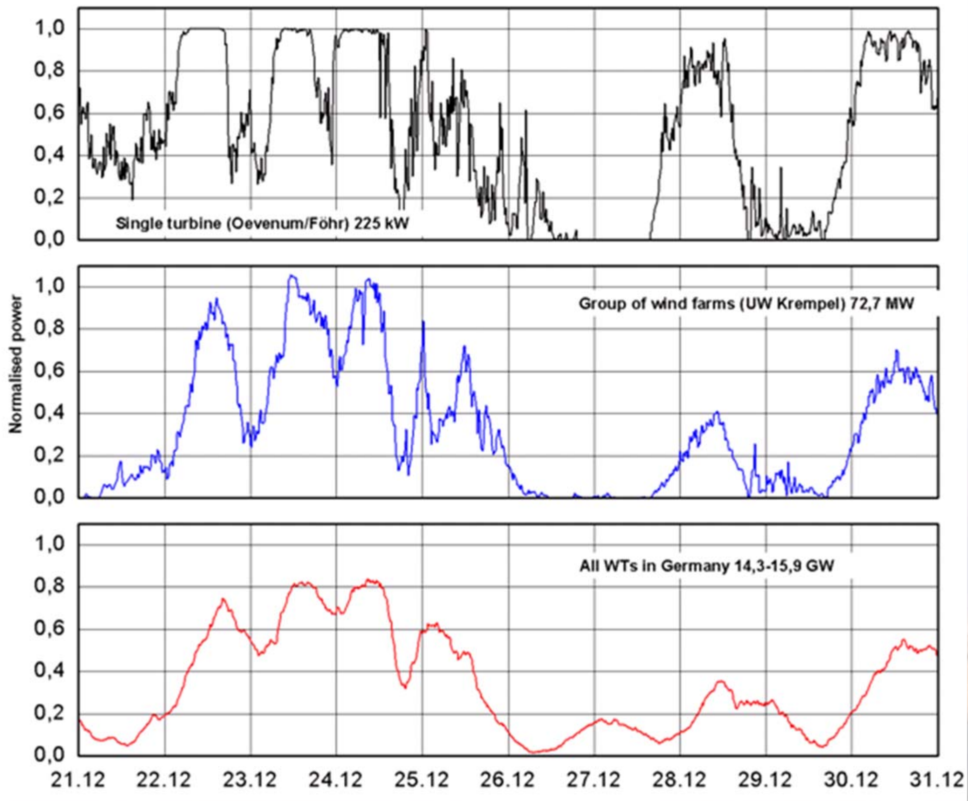


Stein et al. (2011)

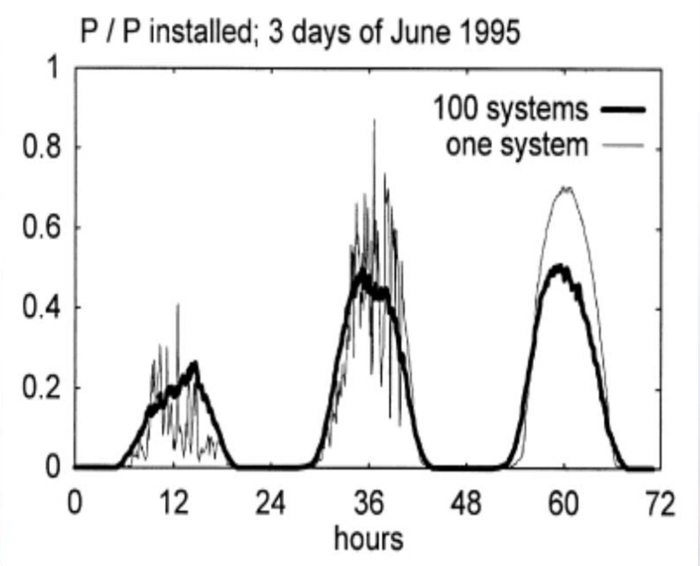
Geographic Smoothing

- **Geographic separation helps reduce variability**
  - Variability does not increase at the same rate as generation capacity
  - At the system level, aggregated variability is what matters

Example for Wind in Germany



Example for Solar PV in Germany



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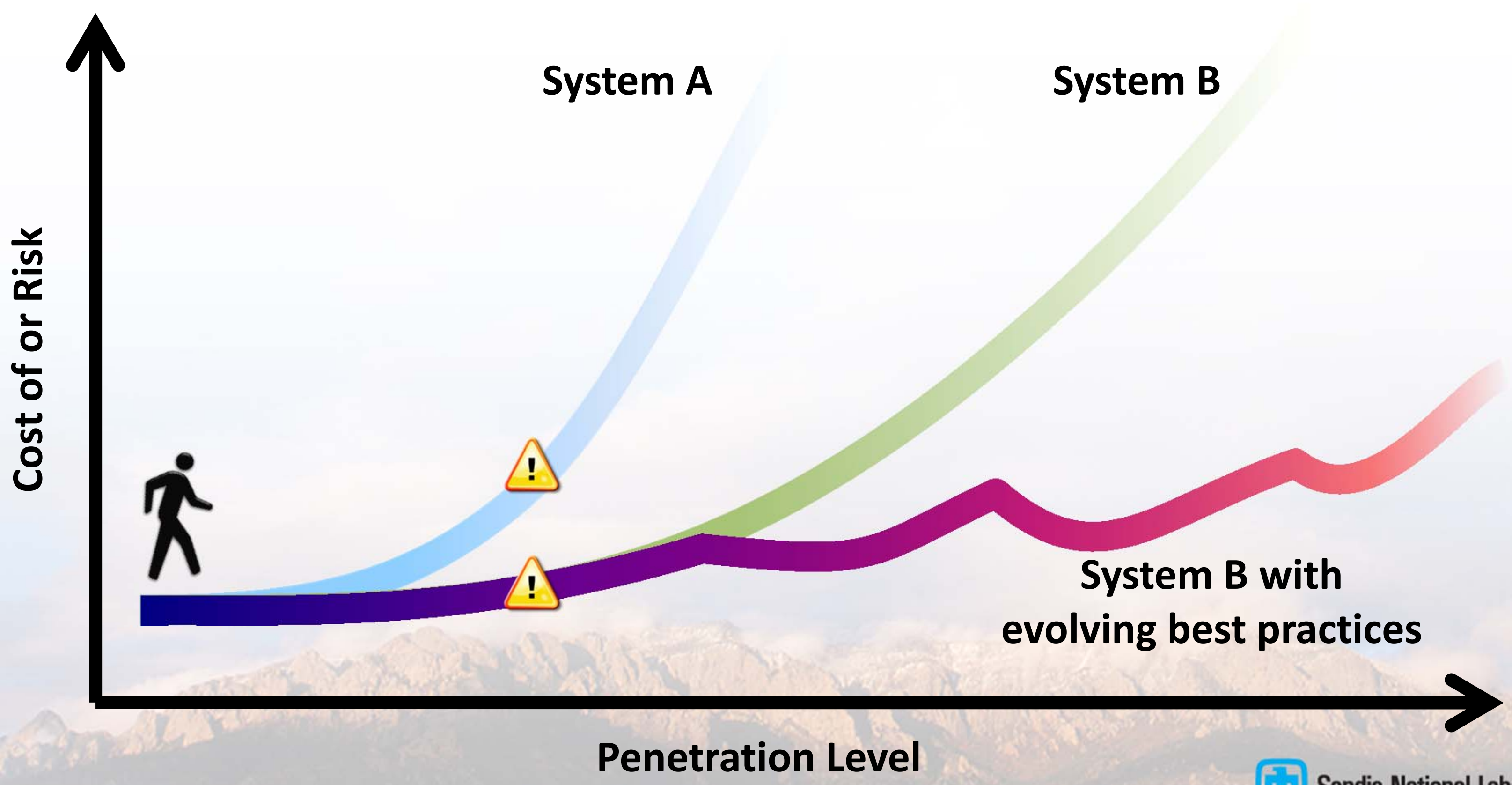
Are There Penetration Limits?

- **There are no <u>absolute</u> technical limits**
  - Impact on cost is very system-specific
  - Depends on resources, load patterns, weather, markets, regulations



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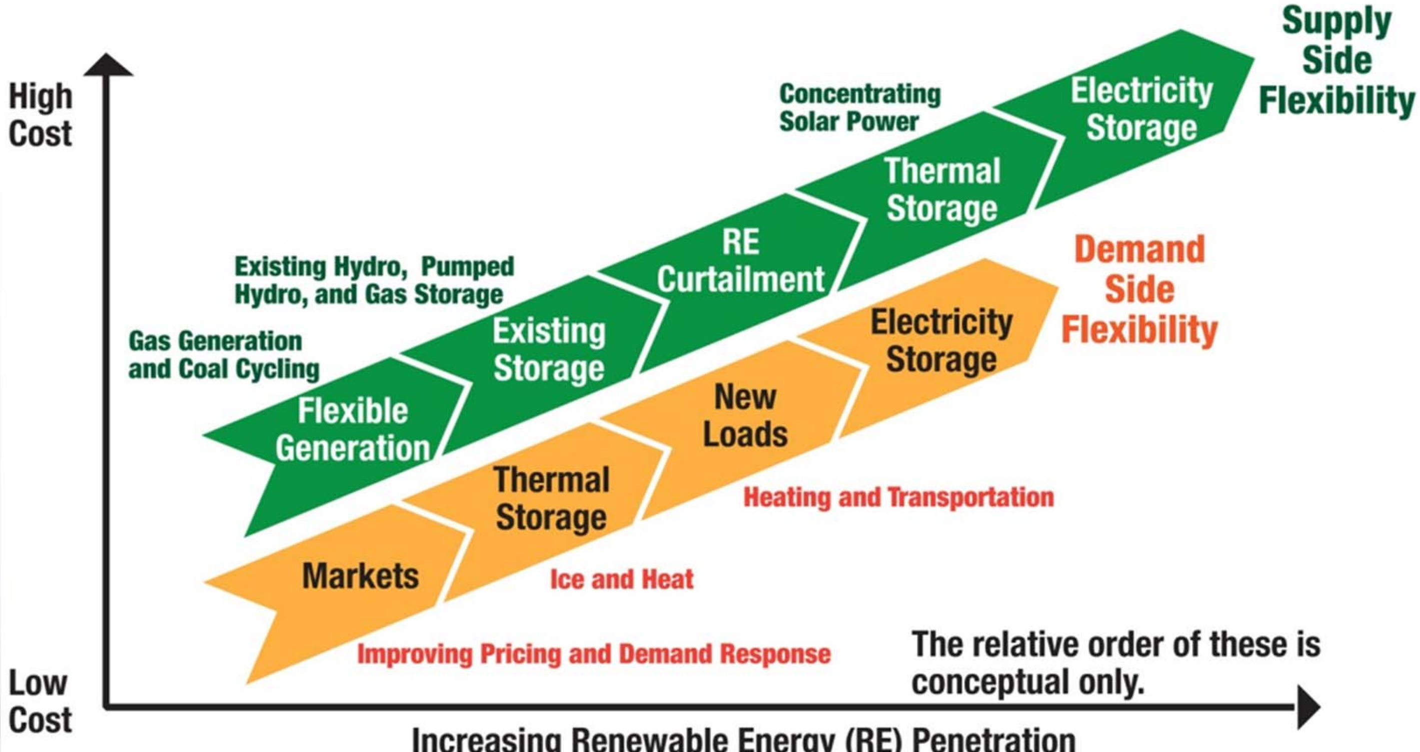
What are the Technical Challenges?

- **Bulk System Issues**
  - How to handle added variability and uncertainty
    - Can the system handle? What is the cost?
  - How to accommodate more VG
    - Technology (grid and VG)
      - **How will the Smart Grid help?**
      - **Can VG contribute to voltage control?**
      - **Can VG output be controlled for reliability reasons?**
    - Performance standards, frequency, contingency
    - Planning and operations best practices
- **Distribution System Issues**
  - Voltage, protection

Integration Solutions and Costs

- Most utilities have only explored the first few solution options (flexible generation, markets)
- High cost, uncertainty, and increased complexity are the main hurdles to overcome



Source: Denholm (2008)

How are impacts assessed?

- **Integration studies help utilities better understand the impacts of and plan for increasing levels of VG on their systems.**
- **There have been several major integration studies but the study methodology is still evolving**
  - Each utility has a unique system and situation
- **Impacts to the distribution system are usually studies separately from impacts to the bulk system (balancing area)**

Distribution Operations Issues

- **Possible impacts depend on factors including…**
  - Feeder characteristics impedance
  - Penetration level, DG location on feeder
  - Type of voltage control and protection
  - Load characteristics

- **Most common operations concerns include…**
  - Customer voltage regulation, power quality
  - Excessive operation of voltage control equipment
  - Protection

Examples of Very High PV Penetration on Distribution System

High Penetration on Feeder

Ota City, Japan: 2 MW PV on single feeder (553 homes, 3.85 kW average PV system)

High Penetration on (Small) System

Lanai , Hawaii: 1.2 MW PV system on 4.5 MW island grid supplied by old diesel generators

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Some Examples of Integration Studies

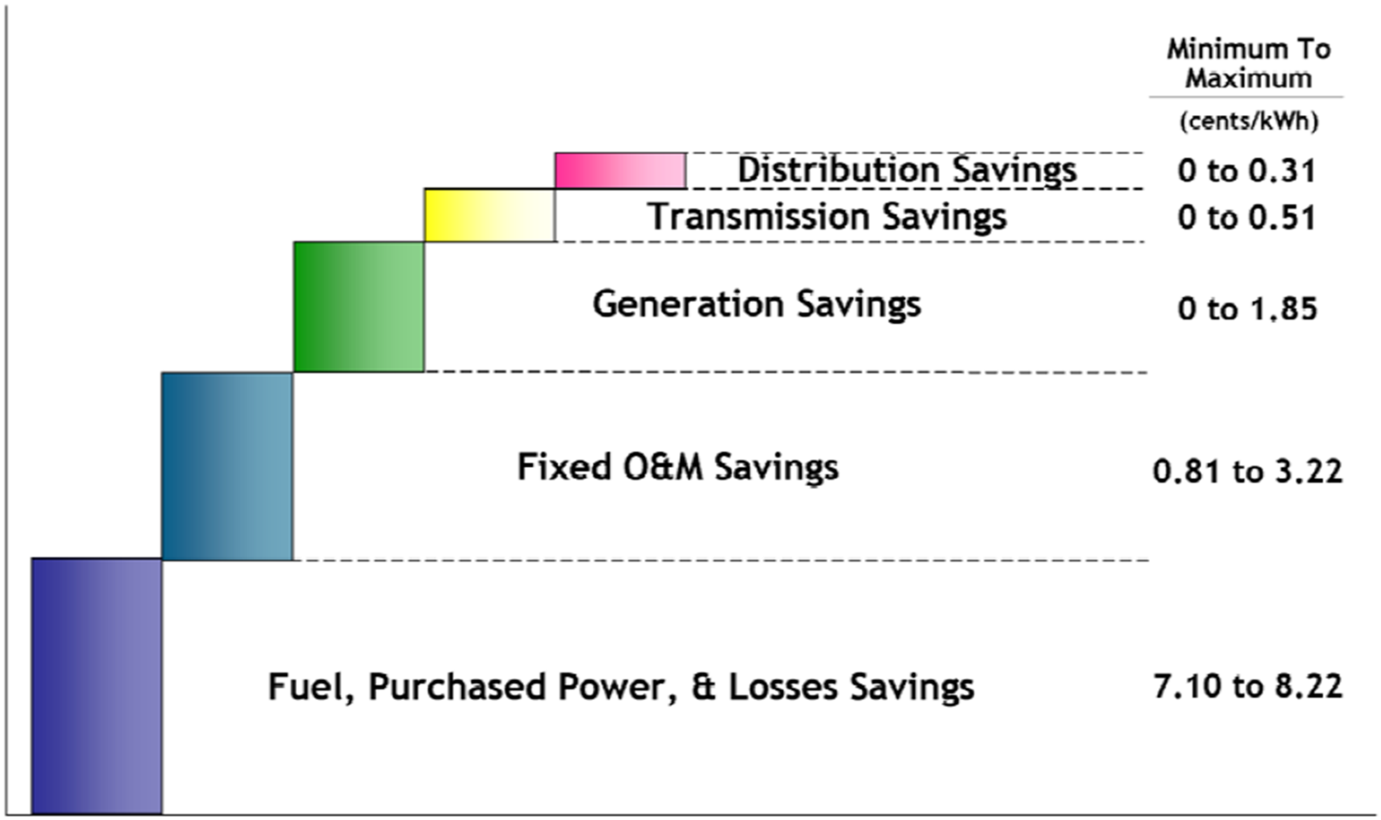
- **Several of these studies are not publically available**
- **Distribution Studies**
  - Distributed Renewable Energy Operating Impacts and Valuation Study (Arizona Public Service, 2009)
  - Distributed Generation Study (NV Energy, 2010)
- **Bulk System Studies**
  - Eastern Wind Integration Study (NREL, EnerEx, 2010)
  - Western Wind and Solar Integration Study (NREL, GE, 2010
  - Operational Requirements and Generation Fleet Capability at 20% RPS (CAISO, GE, 2010)
  - NV Energy Solar Grid Integration Study (in process)
- **General Overview Studies**
  - 20% Wind by 2020 (2009)
  - SunShot Vision Study (in review)

Distributed Renewable Energy Operating Impacts and Valuation Study Results

- **Study focus on Value Determination of distributed renewable generation**
  - Avoided energy costs (based mainly on reduced fuel and purchased costs as well as reduced losses)
  - Reduced capital investment (Deferral of costs for future distribution, transmission, and generation)
  - Consideration of additional externalities (air quality, reputation, experience)
- **Results**
  - For entire distribution system: DG created little value because need to meet peak load when DG is unavailable.
  - For specific feeders: DG created value by deferring upgrades but were very location specific.
  - Transmission deferrals: Large amount of DG is needed to eliminate need for new transmission. Long lead times for transmission planning make value of DG hard to realize (10 year+ timeframe)
  - Generation deferrals: similar to transmission (lots of DG needed to realize value)

Distributed Renewable Energy Operating Impacts and Valuation Study Results

Solar DE Value Buildup



TOTAL SAVING*: 7.91 to 14.11 cents/kWh (79.1 to 141.1 $/MWh)

*Minimum and maximum value shown not reflective of any specific scenario as evaluated in this Study

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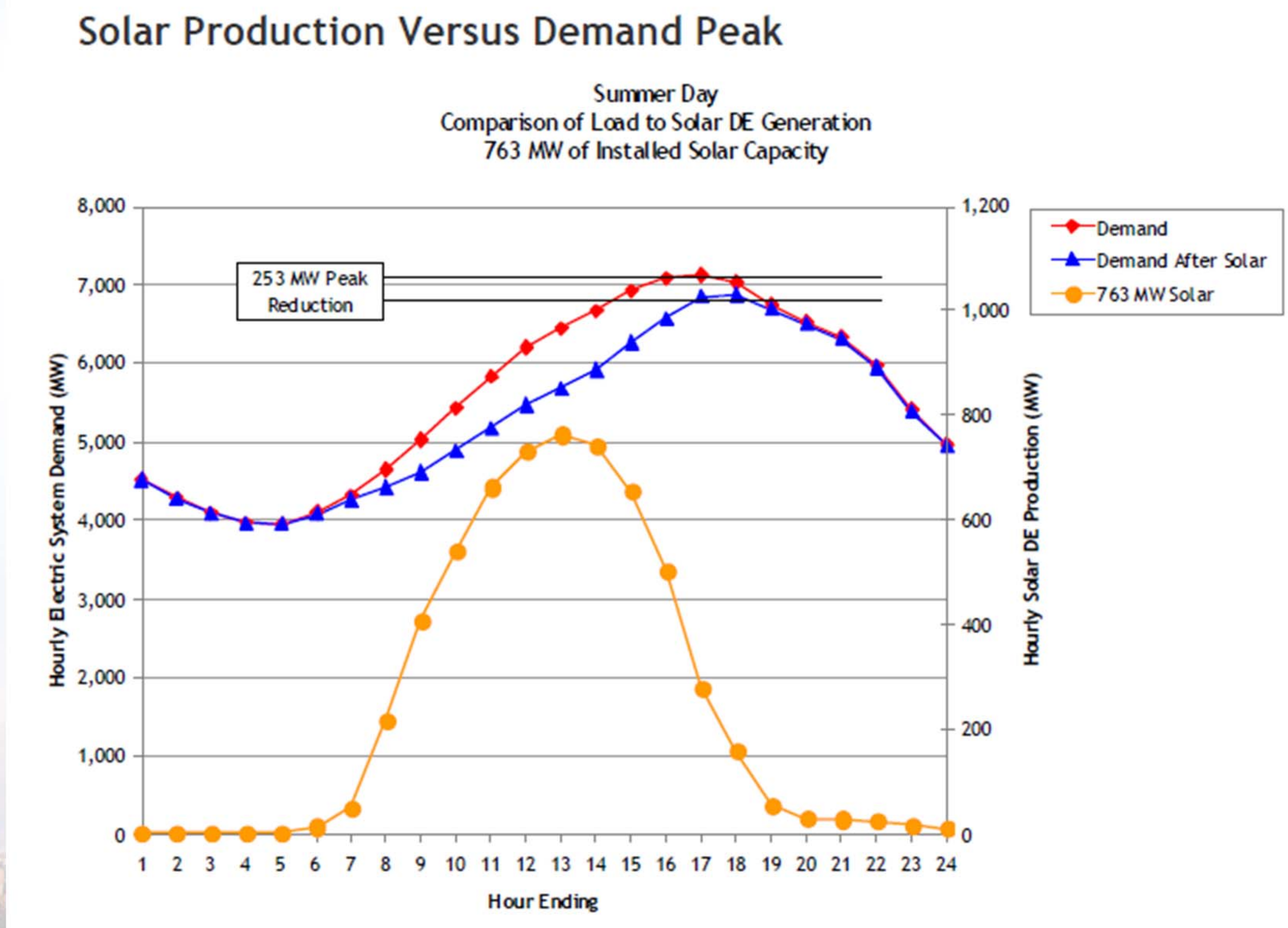
Distributed Renewable Energy Operating Impacts and Valuation Study Results

- **Solar PV peak occurs before the load peak in the early evening**

- **Solar hot water might help to alleviate**



NV Energy Distributed Distribution Study Results

What is the maximum amount of DG from renewable energy that can be integrated on the distribution system within existing operating limits?

Given distribution thermal and voltage limits, what is the maximum amount of DG?

0% 30%

- Most feeders can accept up to 20% or more of DG without violating voltage or thermal limits if DG is uniformly distributed
- When DG systems are strongly clustered, some feeders will potentially experience voltage regulation issues and DG penetration levels for individual feeders will be lower
- Longer feeders also limit the amount of DG that can be installed

Does transmission steady state and dynamic performance impact the amount of allowable DG?

0% To be determined 30%

- Preliminary steady state and dynamic load flow modeling of NVE's Southern transmission system indicates that DG can negatively impact transmission system performance, particularly when large renewable DG is included
- Ongoing studies evaluating integration of large PV will fully address transmission system impacts

Are there other distribution-level technical factors that limit the maximum amount of DG?

0% 30%

- Based on findings for other systems with high DG penetration, NVE should evaluate the impact of clustered DG on power quality before large quantities of inverter-based devices are installed
- NVE also will need to monitor feeder performance and power quality prior to when new large PV is installed with large amounts of small DG at the distribution level

Given generation minimum run and commitment schedules, what is the maximum amount of DG?

0% To be determined 30%

- Under low load conditions, the combination of small DG and large intermittent generation can cause generation to operate at non-optimal levels
- At higher DG penetration, generating operating reserve margins likely will increase, causing added costs.
- Other transmission connected utility-scale wind or solar added to the system will decrease the amount of allowable DG

NV Energy Distributed Distribution Study

Does DG provide benefits to NV Energy?

Does DG provide avoided emissions benefits?

Yes No

- Preliminary results presented in this study do not fully reflect the impact DG will have on generation emission output caused by intermittent DG
- Higher emissions may be created by generation operating at lower efficiency level operates at the margin during periods of light loads
- The value of emissions offsets may vary as new legislation is enacted

Does DG reduce distribution losses?

Yes No

- PV daytime output corresponds to periods of highest losses at the system level, with attendant savings; however, distribution losses on many NVE feeders is low
- On lightly loaded feeders, modest DG penetration can cause losses to increase, particularly on long, rural feeders

Does DG provide fuel costs benefits?

Yes No

- Most fuel savings occur due to the displacement of natural gas generation operating during daytime hours
- At higher DG penetration levels, generation may operate at less than optimum dispatch levels – this will be analyzed in the Utility-Scale PV Integration Study
- Any DG that is net metered will transfer non-fuel costs to other ratepayers

Does DG provide avoided capacity benefits?

Yes No

- There are virtually no generation capacity benefits as PV output at the 8:00pm system peak is zero
- Similarly, most distribution feeder peaks occur during evening or shoulder hours when PV output is low
- The automatic tripping of DG under IEEE 1547 further limits DG capacity benefits at the distribution level

NV Energy Distributed Distribution Study

What are the costs to NV Energy to integrate increasing amounts of DG to the distribution system?

Does DG cause significant <u>system protection upgrade</u> costs to NV Energy?

Yes ← No

- At low DG penetration levels and where DG is uniformly distributed, protection impacts are minimal for most feeders
- At higher penetration levels reverse power flows and high flows will limit the amount of DG that can be installed
- DG may cause fault duty to approach or exceed equipment limits in the North; additional study is needed to confirm which equipment is impacted

Does DG cause significant <u>line size and voltage upgrade</u> costs to NV Energy?

Yes ← No

- Line thermal capacity generally is sufficient
- Local capacity limits should be evaluated for heavy clustering
- For heavy clustering or DG located on long circuits, voltage limits may be exceeded
- Transmission level upgrades may be needed when new large renewable projects are installed along with distribution-level DG. This issue will be analyzed in the Utility-Scale PV Integration Study.

Does DG cause significant <u>costs</u> to NV Energy?

Yes | To be determined | No

- At low DG output or penetration, generation dispatch is minimally impacted
- Under higher DG penetration levels, economic dispatch can be impacted as DG may displace low-cost generation or cause hourly imbalances
- Further, unit commitment schedules may shift due to DG, causing non-optimal generation economic dispatch

Does DG provide net <u>economic benefits</u> to NVE?

Yes | To be determined | No

- Fuel , emissions, and other benefits do not fully offset costs to ratepayers under current rates
- However, these preliminary results do not fully assess the impact of large-scale renewable projects on transmission and power system costs.
- Transmission and power system impacts will be studied as part of the Utility-Scale-Scale PV Integration Study

Bulk System Integration Study Steps

- **Develop generation and transmission scenarios based on future expectations**
  - Economic assumptions (carbon price, RPS, etc.)
- **Develop load and RE resource datasets (synchronized)**
  - Example from NV Energy Solar integration Study
- **Run production cost model to simulate economic dispatch and unit commitment process for scenarios**
- **Important details include:**
  - Locations of loads and generation
  - Size of balancing areas
  - RE forecast availability, frequency, and accuracy
  - Transmission constraints and congestion
  - Additional regulation and contingency required to balance load and generation

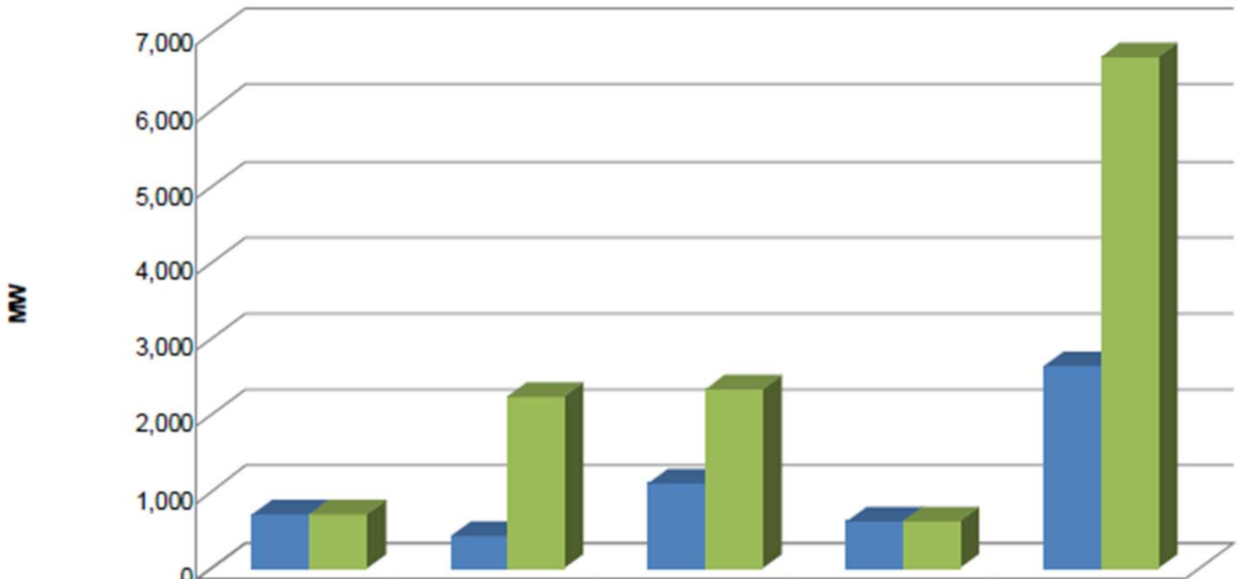
Wind Integration and Transmission Studies

- **Eastern Wind Integration and Transmission Study**
  - http://www.nrel.gov/wind/systemsintegration/ewits.html for details
- **Western Wind and Solar Integration Study**
  - http://www.nrel.gov/wind/systemsintegration/wwsis.html
- **Nebraska Wind Integration Study**
  - http://www.nrel.gov/wind/systemsintegration/nebraska_integration_study.html
- **Oahu Wind Integration Study**
  - http://www.nrel.gov/wind/systemsintegration/owits.html

California ISO Study Results

Goal: Evaluate the operational impacts of a 20% RPS in California for 2010

- **Builds off a 2007 study of impacts of 20% wind integration**



	Biomass/BioGass	Solar	Geothermal	Small Hydro	Wind
2006	701	420	1,101	614	2,648
2012 (expected)	701	2,246	2,341	614	6,688

www.caiso.com/2811/281176c54d460.pdf

CAISO Study Results

- **Key Results and Findings**
  - Operational requirements for wind and solar integration is different
  - Solar introduces problems during the morning and evening load ramps
  - Solar and wind together lessen operational requirements due to the lack of correlation between the two resources.
  - Decreases to off- and on-peak use of conventional generation ("thermal units"), which makes them less profitable and more expensive. (29-39% reduction in revenue)
  - Load-following ramp rates increase by 30-40 MW/min
  - Load-following hourly capacity increases by almost 1 GW (morning and evenings)
- **Recommendations**
  - Improve utilization of existing generation fleet's operational flexibility (minimize self scheduling)
  - Wind and solar participation in economic dispatch markets
  - Improve/develop day-ahead and real-time operational forecasting (regulation and load following requirements)

CAISO Regulation Capacity Results

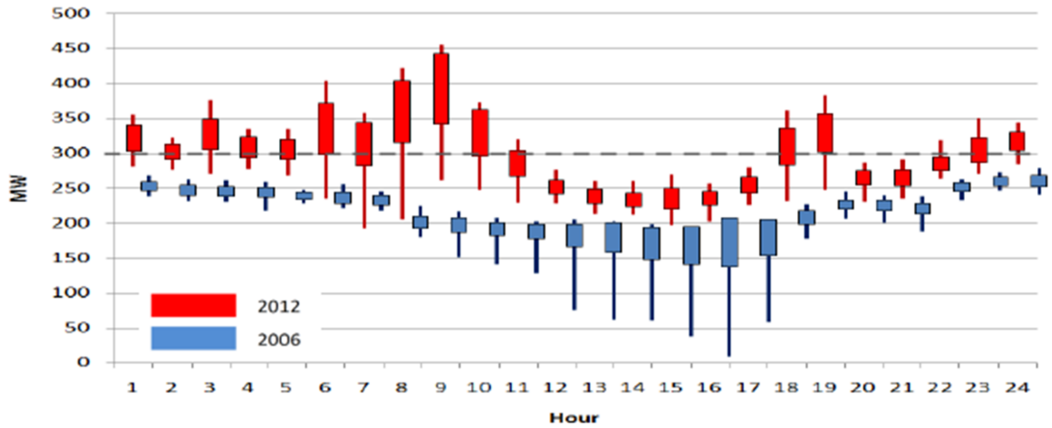


Figure ES-9: Simulated Regulation Up Capacity Requirement by Operating Hour, Summer, 2006 and 2012

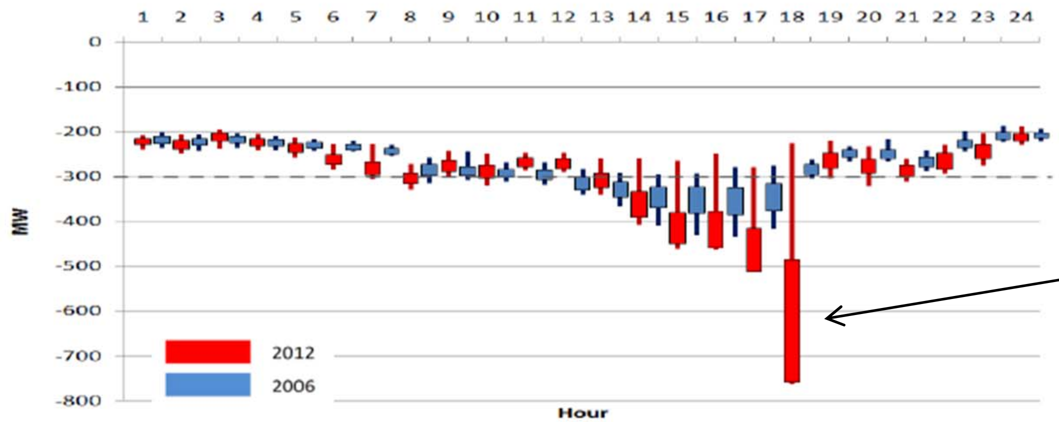


Figure ES-10: Simulated Regulation Down Capacity Requirement by Operating Hour, Summer, 2006 and 2012

Solar ramps in morning and evening

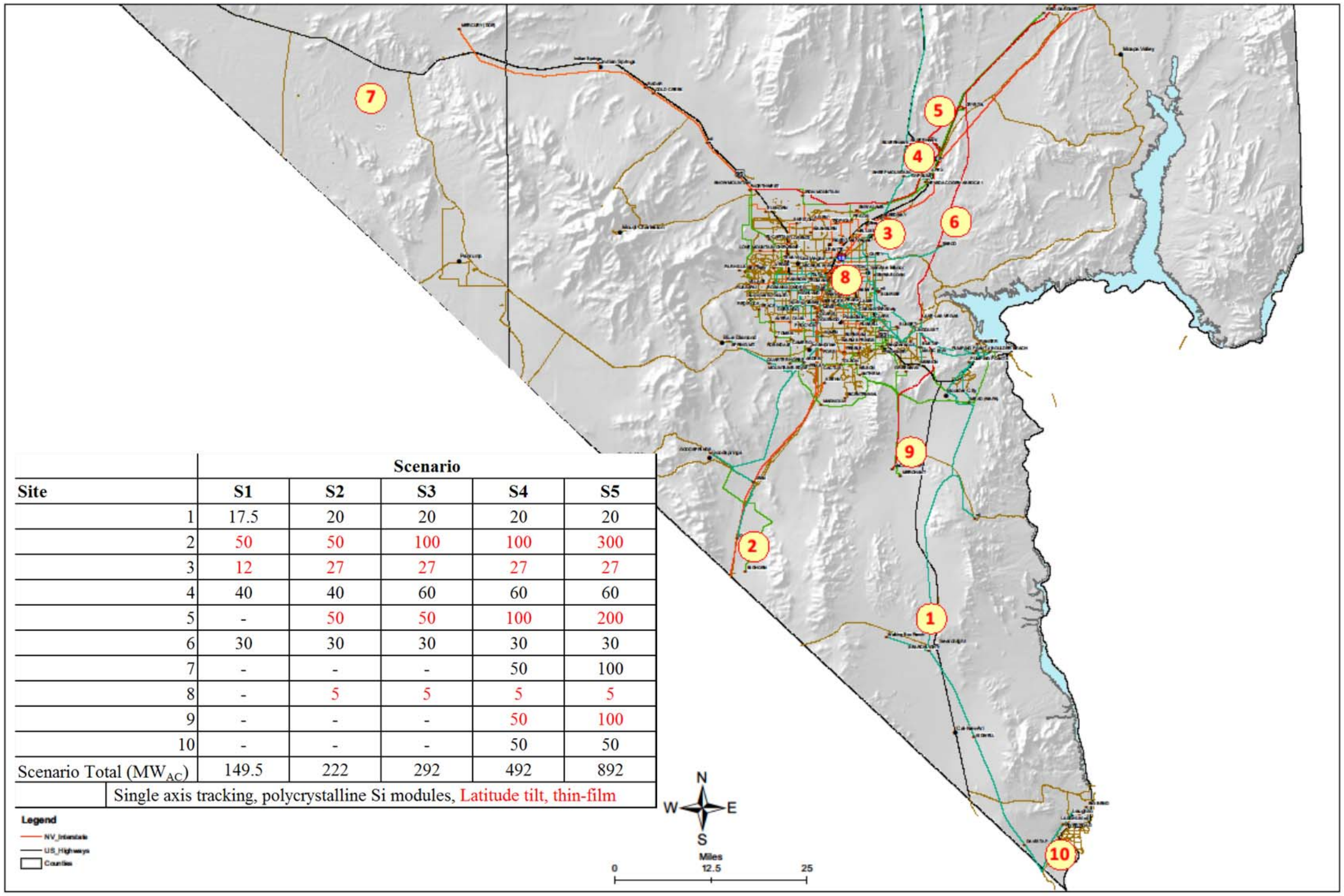
Wind typically ramps up at 6PM

www.caiso.com/2811/281176c54d460.pdf

NV Energy Solar Grid Integration Study

- **NV Energy is conducting a Solar PV Grid Integration Study**
  - Define impacts on utility operations (integration costs) of large PV plants in Southern Nevada.
- **Navigant Consulting is performing the study.**
- **Pacific Northwest National Lab (PNNL) is providing estimates of regulation and load following requirements.**
- **Sandia is contributing the estimates of the PV output profiles for the plants being considered, including power forecasts.**
- **Study will be completed by the end of the summer 2011**
- **Next few slides cover Sandia's generation of PV output profiles for study.**

PV Plant Locations for Study



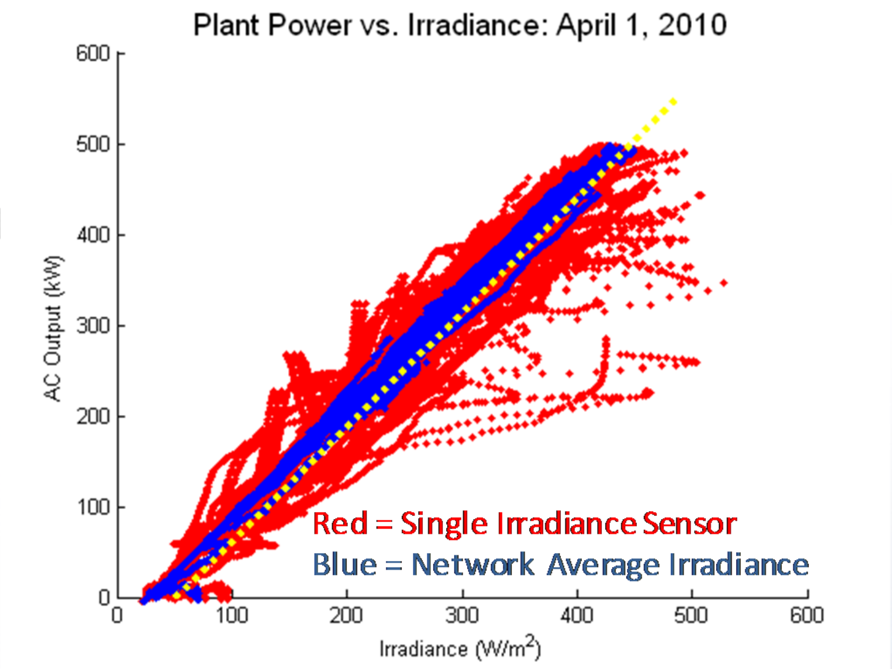
Site	Scenario				
	S1	S2	S3	S4	S5
1	17.5	20	20	20	20
2	50	50	100	100	300
3	12	27	27	27	27
4	40	40	60	60	60
5	-	50	50	100	200
6	30	30	30	30	30
7	-	-	-	50	100
8	-	5	5	5	5
9	-	-	-	50	100
10	-	-	-	50	50
Scenario Total (MW_{AC})	149.5	222	292	492	892
	Single axis tracking, polycrystalline Si modules, Latitude tilt, thin-film				

Data Sources

- 1- hour satellite irradiance at each of the ten sites from Clean Power Research's SolarAnywhere data
- 1-min irradiance data from six Las Vegas Valley Water District (LVVWD) sites in Las Vegas
- Upper air wind speed from NOAA weather balloon at Desert Rock, NV
- Air temperature and wind speed data from McCarran International Airport, Las Vegas

Solar Output Modeling Approach

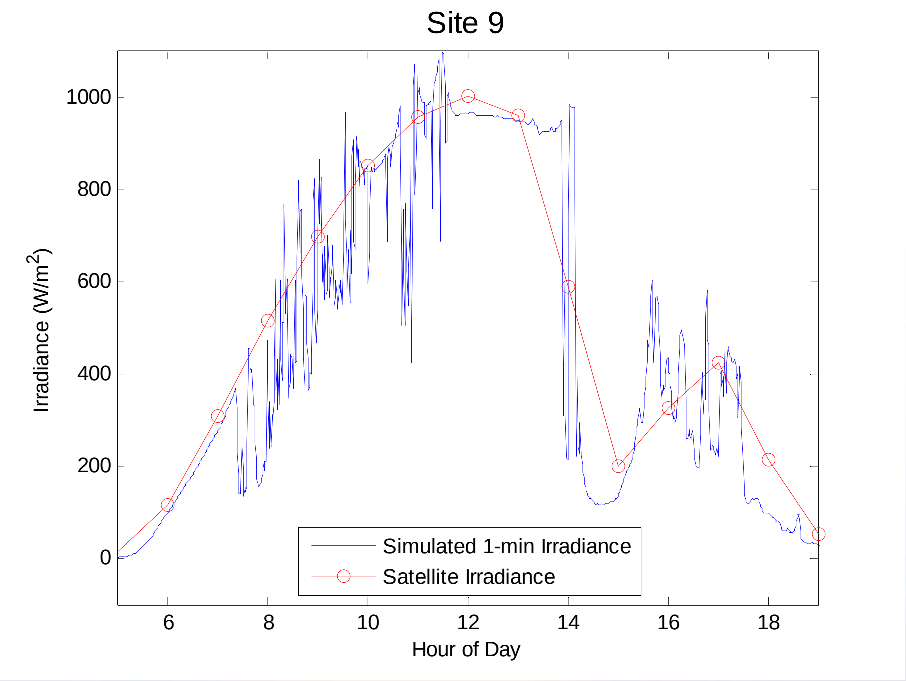
1. **Estimate 1-min irradiance at each site**
2. **Convert point irradiance to 1-min spatial average irradiance over plant**
3. **Calculate 1-min AC power output from plant**



from Kuszmaul et al., 2010

1. Estimate 1-Min Irradiance

- **A library of 1-min irradiance days was created from LVVWD sites (>5,000 days)**
- **Hourly averages were calculated for each day**
- **Least-squares routine identified best fitting days in library to match day at each location**
- **The same library day was prevented from being assigned to more than one site for each day of the year.**

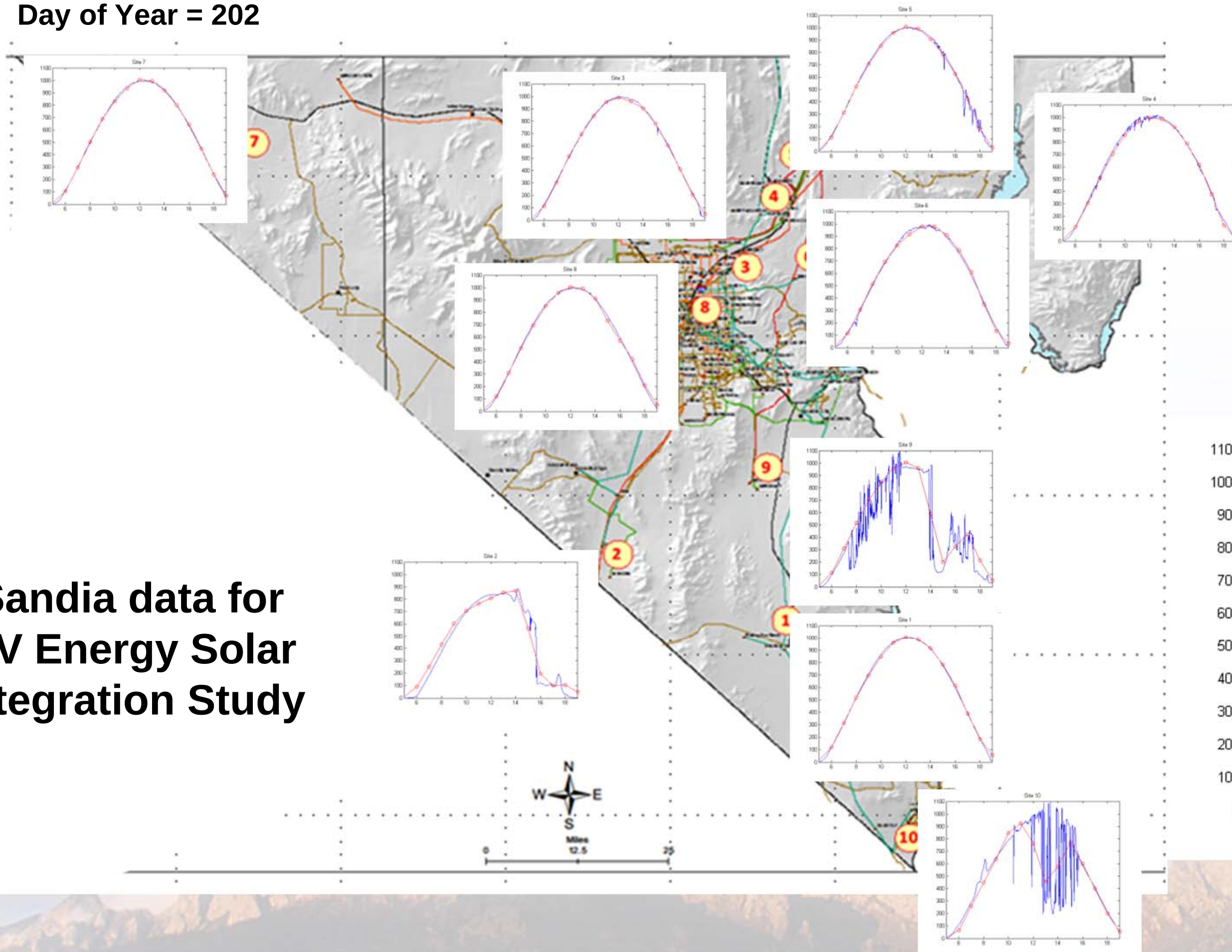


Matching 1-min ground irradiance with 1-hr satellite data

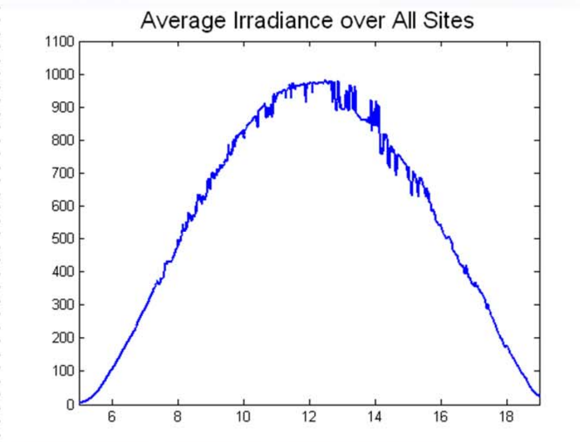
Example 1-min Irradiance Across Study Area

- **Simulation of PV Output**

Day of Year = 202



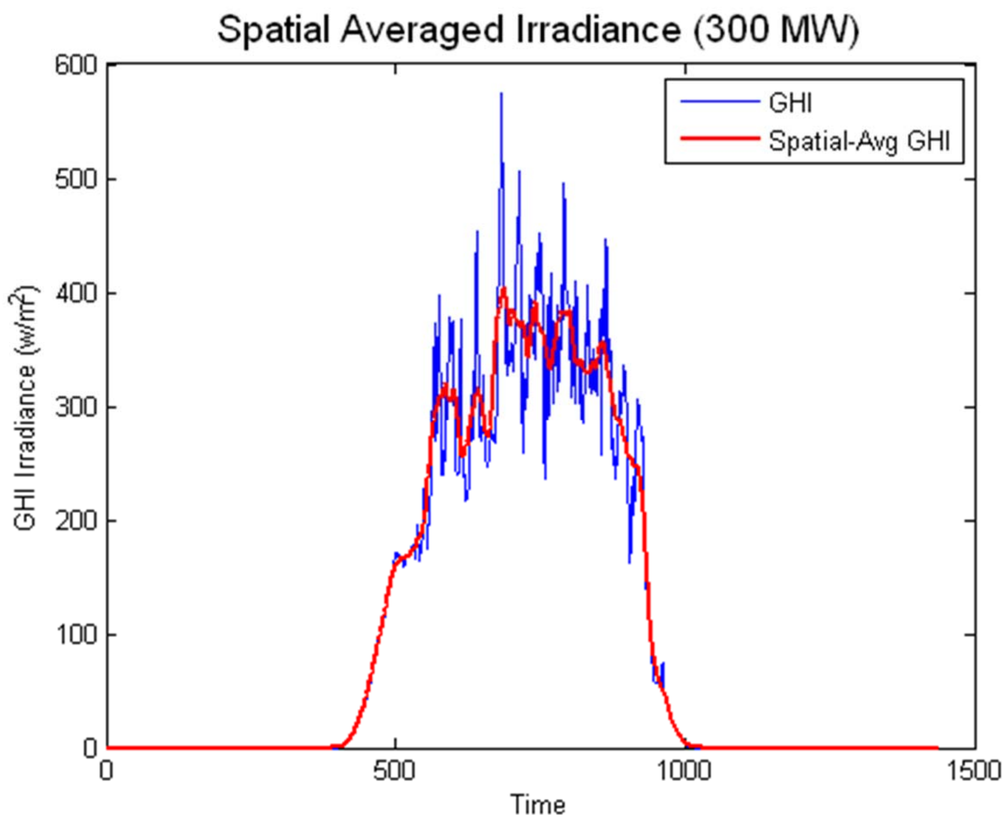
This example shows model represents days when only part of domain has clouds.



Sandia data for NV Energy Solar Integration Study

2. Spatial Average Irradiance over PV Plant

- **Spatial average of irradiance over plant is estimated as a moving average irradiance (after Longhetto et al., 1989)**
- **Averaging window = the time for clouds to pass over plant**
  - Plant size varies with module technology (efficiency)
  - Cloud speed varies with time, as measured



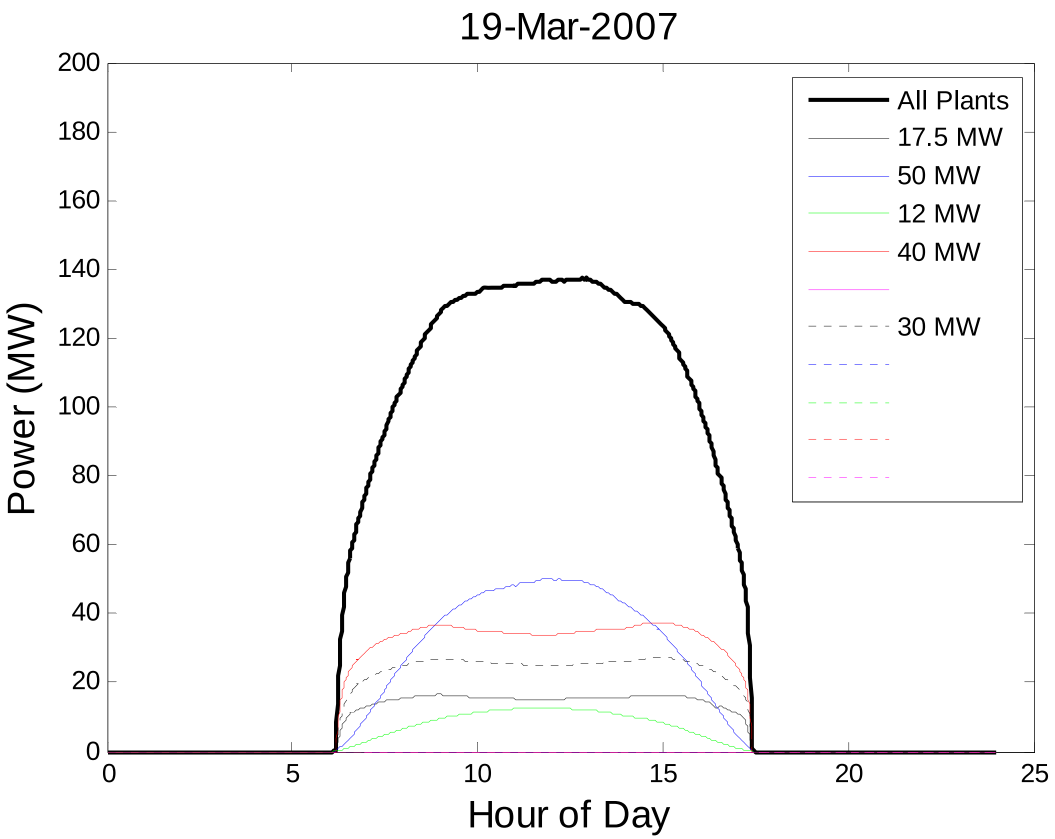
Effect of geographic smoothing within a plant

3. Calculate AC Power from Plant

- **Sandia PV Array Performance and Inverter Models were used to calculate system output**
  - These models account for:
    - Module technology characteristics (c-SI vs. thin film)
    - Temperature , angle of incidence and spectral effects
    - Inverter efficiency curves
- **Irradiance incident on array was estimated using**
  - DISC model (Maxwell, 1987) for DNI estimation
  - Perez (1990) model of diffuse irradiance on tilted plane
- **Air temperature was estimated using lapse correction for site elevation, wind speed from LAS airport**

Example Results: PV Plant Output

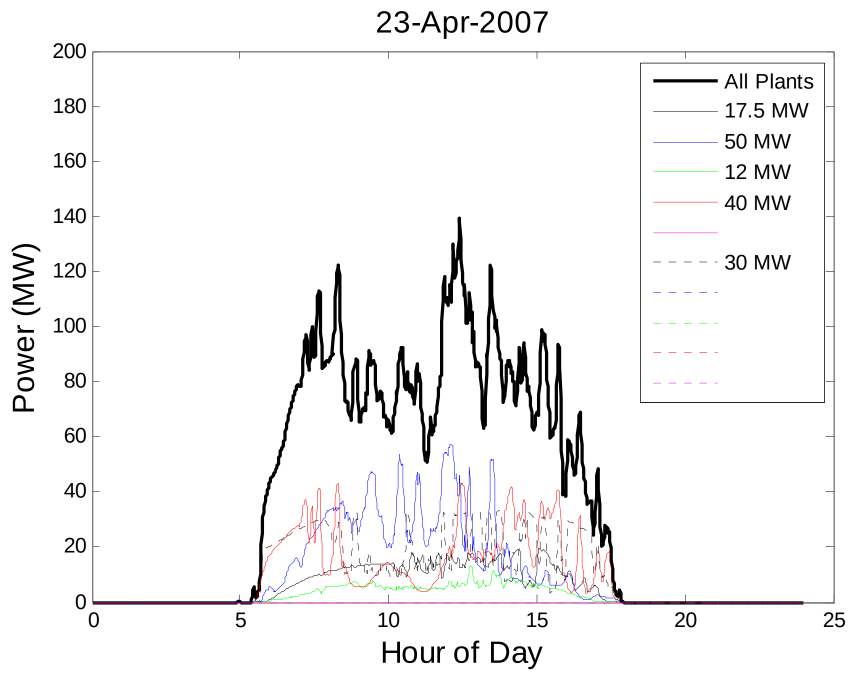
S1: 149.5 MW (5 plants)



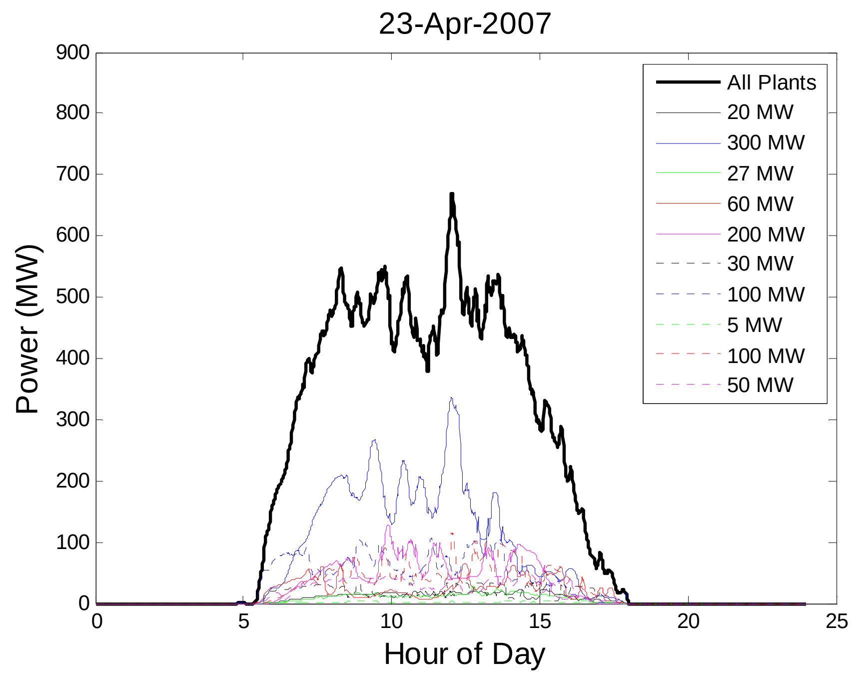
- **Output profiles reflect differences between systems**
  - Module technology
  - Plant capacity
  - Fixed tilt vs. tracking
  - Temperature differences
  - Changing cloud speeds

Example Results: PV Plant Output

S1: 149.5 MW (5 plants)



S5: 892 MW (10 plants)



Apparent reduction in
Relative variability,
But look at y-axis…

General Integration Conclusions

- **Integration studies are needed to assess the system impacts of changing the mix of generation on the grid**
  - Regional differences are very important
  - Synchronized load and RE generation is important
  - Market design is quite important (flexibility)
  - Large balancing areas are very helpful
  - Accurate forecasts are important for planning
- **There are no hard integration limits, just cost and policy constraints**
- **More technical work needs to be done to develop rigorous methods to assess penetration limits for specific feeders**
  - Current approach is ad hoc and very conservative (e.g., 15% rule)
- **Increasing flexibility in the way the grid is operated is usually the best first step.**
- **Demand response (load shifting) offers real benefits, if realized**
  - Business models need to be developed and tested
  - Becomes very important if electric vehicles take off (large load growth possible)

Questions and Discussion

Ferrisburgh Solar Farm, Vermont

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