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Renewables Grid Integration: Achieving High Penetration

New Mexico Legislative Council Science, Technology and Communications Committee

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Presentation Outline

- Wind and Solar Generation Potential
- Penetration Levels
- Distribution System Impacts
  - Example: Voltage Control
- System-Level Impacts
  - Integration Cost
  - Variability and Uncertainty
- Technical Benefits to the Grid
- Conclusions

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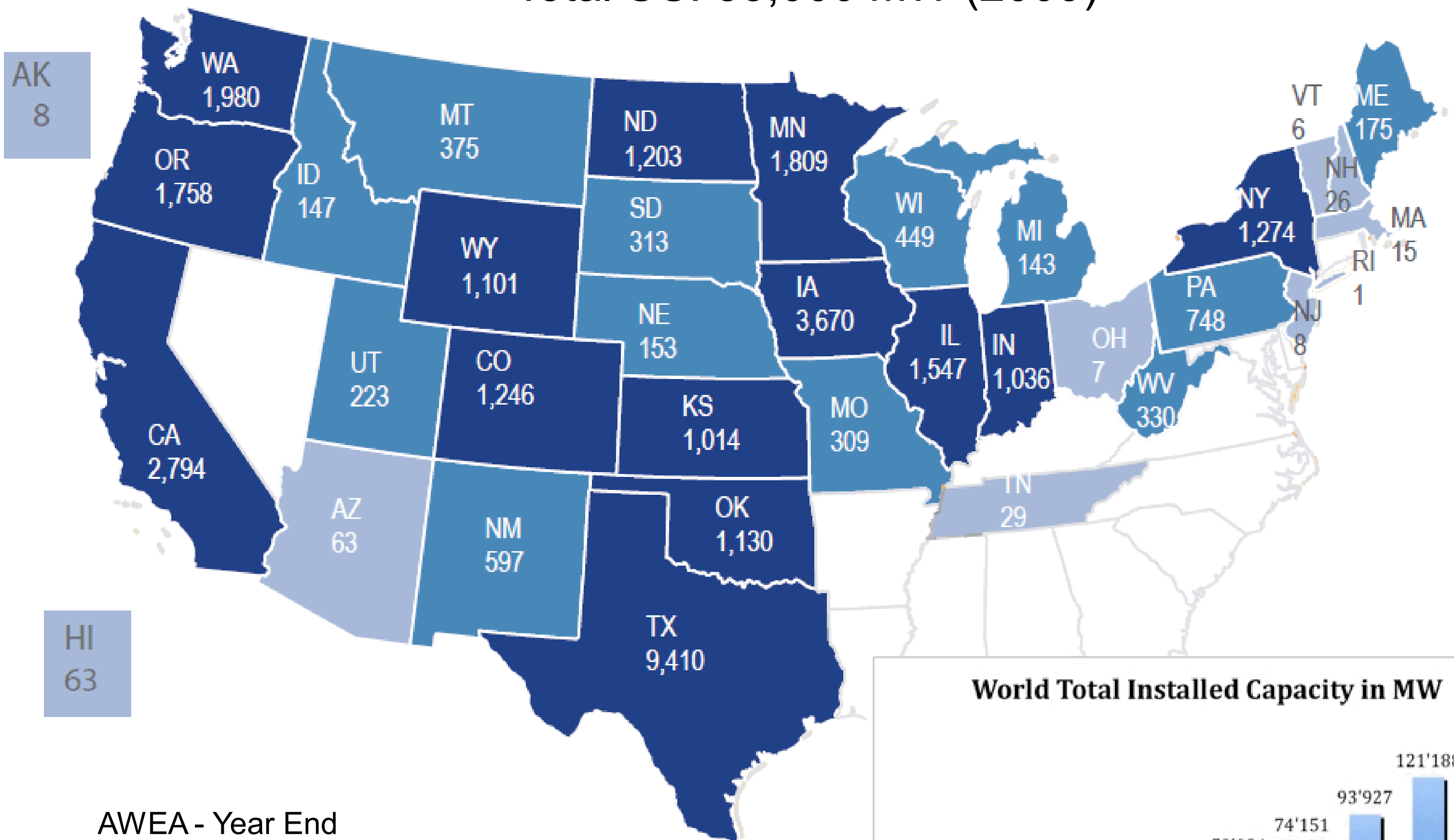
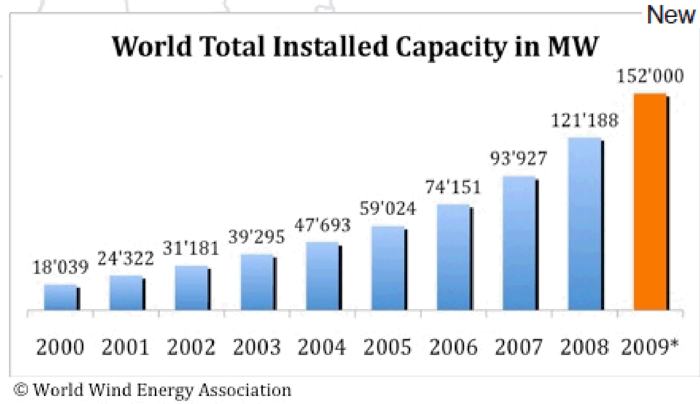
Wind Generation Potential

Total US: 35,000 MW (2009)



State	Added in 2009 (MW)
Texas	2,292
Indiana	905
Iowa	879
Oregon	691
Illinois	632
New York	568
Washington	542
North Dakota	488
Wyoming	425
Pennsylvania	388
Oklahoma	299
California	277
Utah	204
Kansas	199
Colorado	178
Missouri	146
Maine	128
South Dakota	126
Montana	104
New Mexico	100

AWEA - Year End
2009 Market Report



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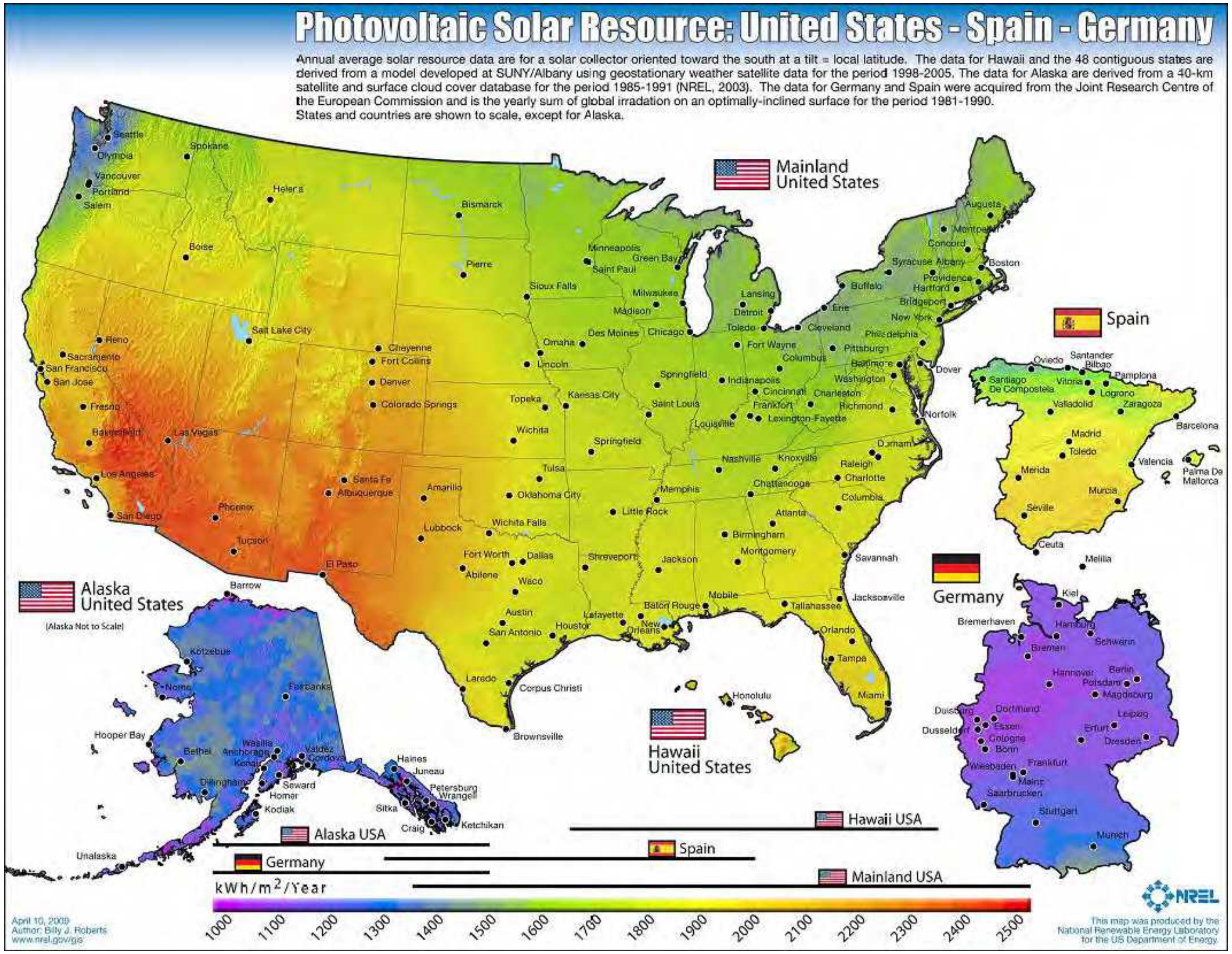
Solar Generation Potential



Top 10 States for New Grid-Tied Solar Electric Installations in 2009*

Capacity Installed in 2009			Cumulative Capacity in 2009		
1	Calif.	220	1	Calif.	1,102
2	N.J.	57	2	N.J.	128
3	Fla.	36	3	Nev.	100
4	Ariz.	23	4	Colo.	59
5	Colo.	23	5	Ariz.	50
6	Hawaii	14	6	Fla.	39
7	N.Y.	12	7	N.Y.	34
8	Mass.	10	8	Hawaii	27
9	Conn.	9	9	Conn.	20
10	N.C.	8	10	Mass.	18
	Others	29		Others	78
Total		**441 MW**	**Total**		**1,653 MW**

* Includes all grid-tied PV and CSP.

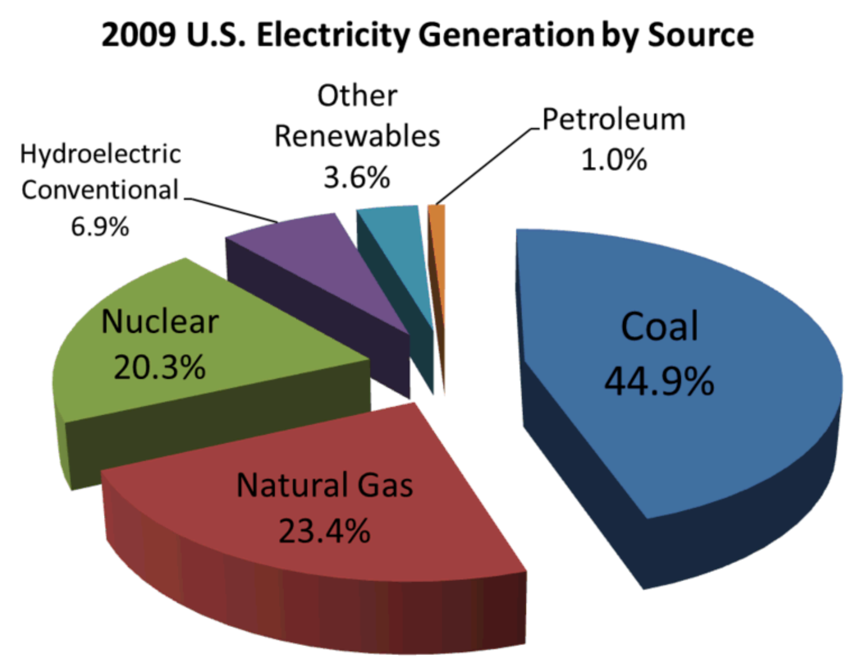
Top Countries for New Solar Electric Installations in 2009

	Capacity Installed in 2009	Cumulative Capacity at End of 2009
Germany	3,800 MW	9,677 MW
Italy	700 MW	1,158 MW
Japan	484 MW	2,628 MW
United States	481 MW	2,108 MW
Czech Republic	411 MW	465 MW
Belgium	292 MW	362 MW
France	285 MW	465 MW
Spain	180 MW	3,595 MW
Total	**~6,900 MW**	**~21,500 MW**

SEIA - US Solar Industry Year in Review 2009

Renewables In The Big Picture

- By energy produced (2009), 69% of electricity comes from fossil fuels
- Only 4% comes from "Other Renewables"
  - Wind (mostly)
  - Biomass
  - Geothermal
  - Solar
- High penetration levels in some parts of the system
- Can we do better overall?



Source: EIA

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System "Limits"

- There are no absolute technical "limits"
  - Cost and risk determine practical limits
    - **What is the cost and who is willing to pay?**
    - **What is the risk and who is willing to bear?**
  - There are technical solutions (often costly) to mitigate reliability and safety impacts
- However, there are technical challenges!
- How much renewable generation can be integrated at a reasonable cost and risk?
  - It depends on many factors!

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Penetration Level

- Penetration level is a way to quantify amount of renewable generation deployed on the system
  - For distribution system deployment
    - **Renewable capacity / peak load (most common)**
    - Renewable capacity **/** minimum load , station capacity, feeder capacity
  - For system-wide deployment
    - **Renewable energy / total load energy over one year (most common)**
    - Renewable capacity **/** peak load or total generation capacity

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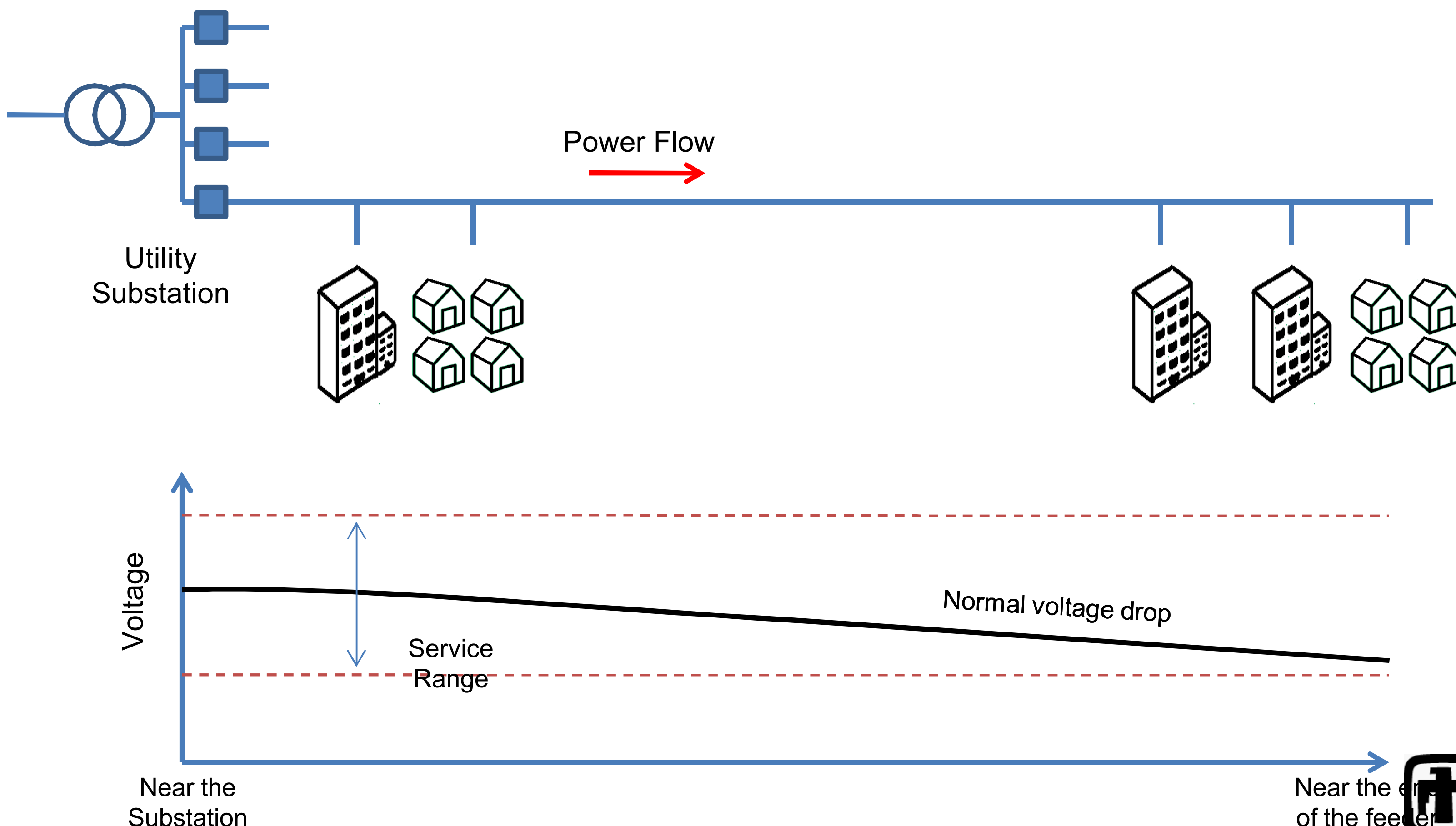
Distribution System Impacts

- Renewable deployment in distribution systems is principally solar PV
- Depending on many factors, high penetration PV in distribution systems could lead to…
  - Customer voltages that are too high or hard to control
    - Voltage raise most likely to encountered first, especially in long feeders
    - Variability can cause excessive operation of voltage control equipment
    - Impact depends on where the solar generation is connected
  - Degradation on protection performance
  - Increased likelihood of electrical “islands”
  - Flow in excess of feeder/regulator/transformer capacity

Voltage Raise Issue

- Voltage along the feeder must be maintained within service limits (standards)



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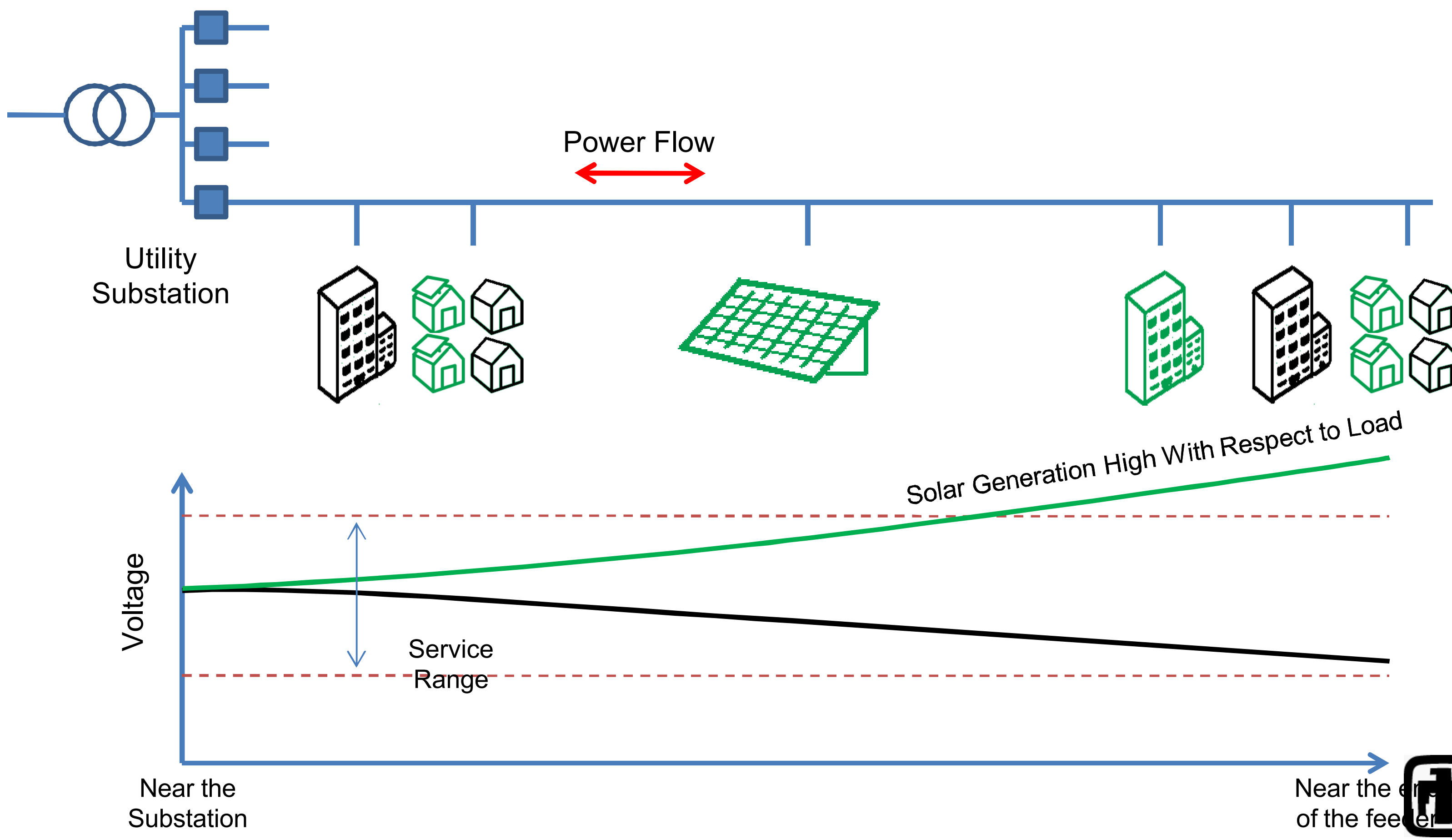
Voltage Raise Issue

- High amounts of PV generation (or other DG) can cause voltage to raise above service limits



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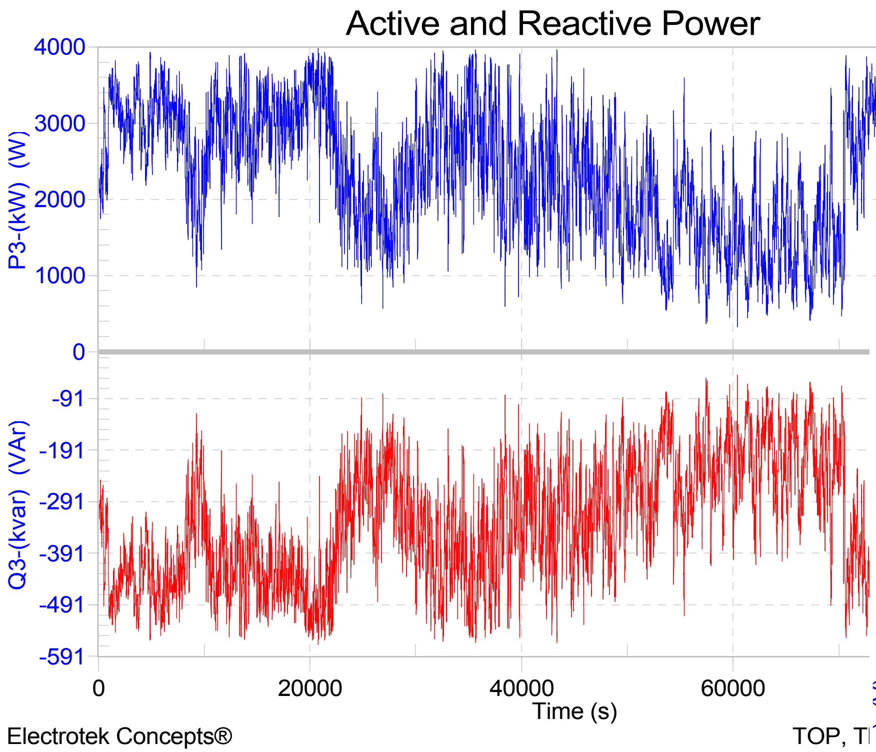
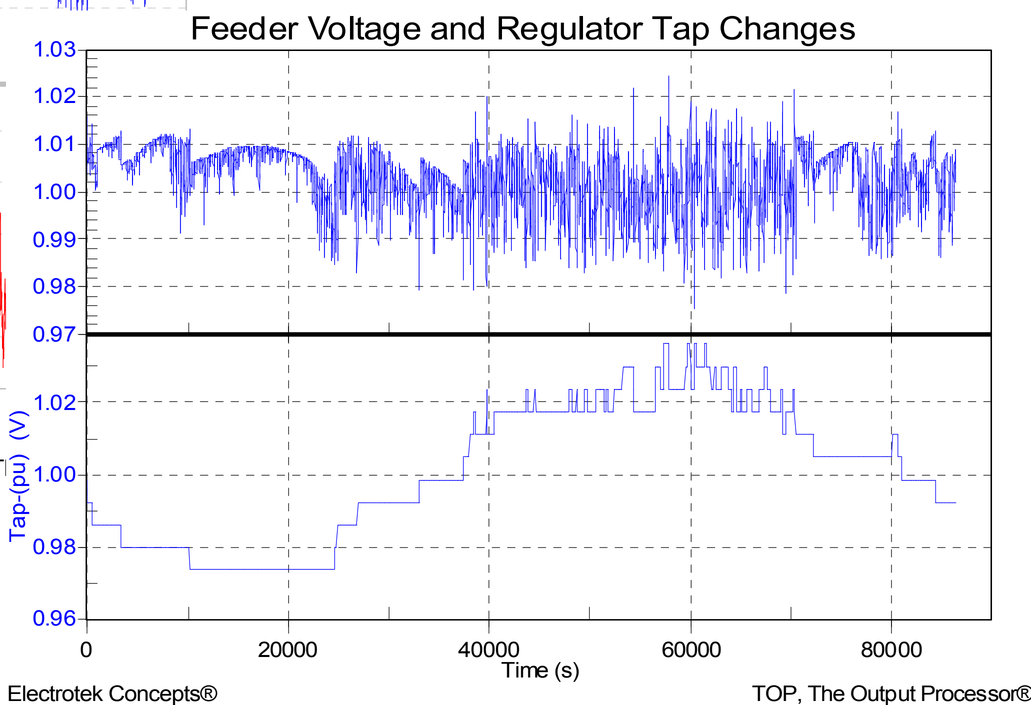
Voltage Control Issue

- Long feeder, large DG (wind) at end of feeder
  - Simulation shows excessive voltage regulator tap operations

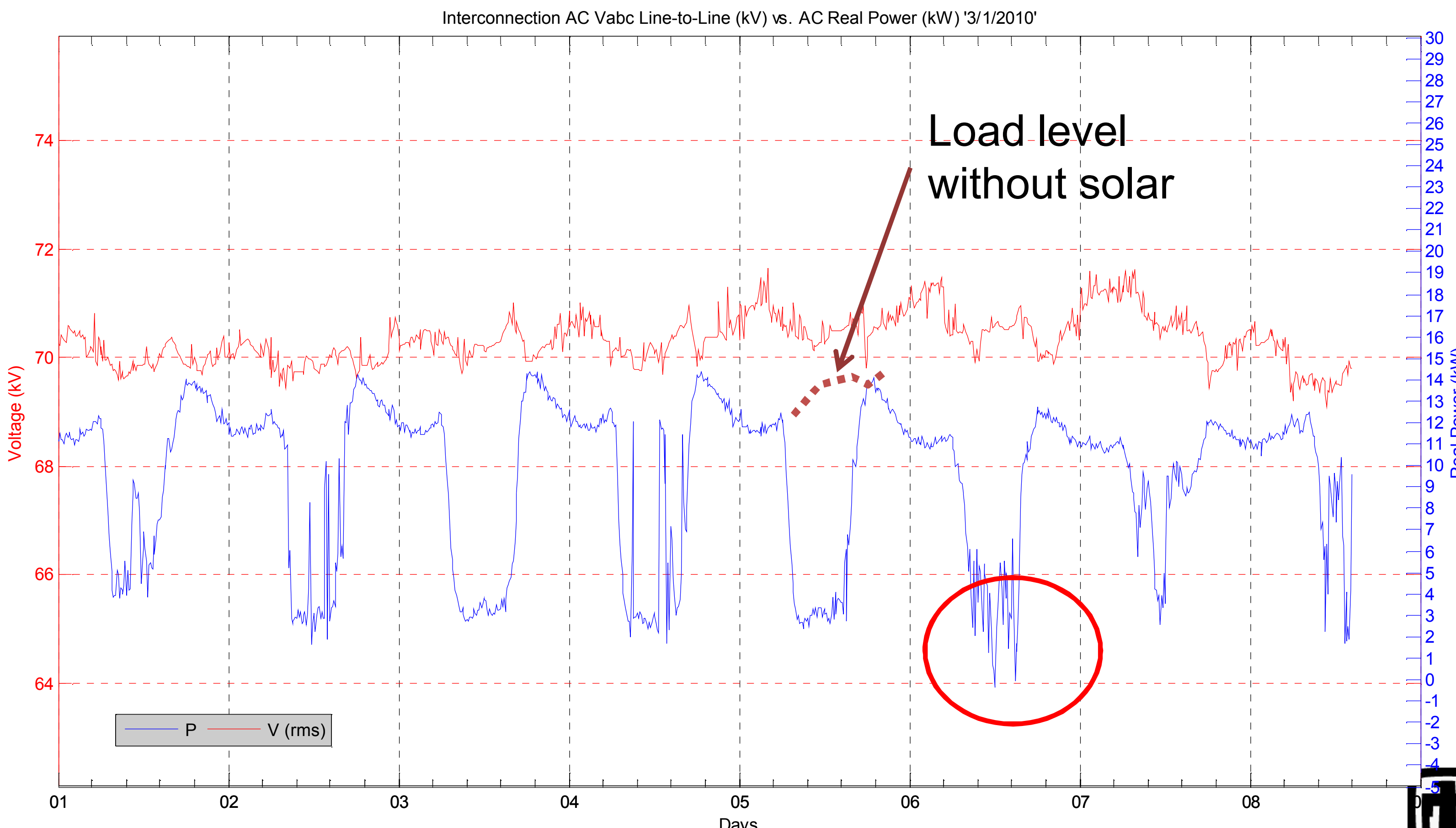


Source: EPRI



Voltage Control Issue

- Short feeder, large DG (PV) close to station
  - Voltage at end of feeder varies more, but no issues!



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Voltage Control Issue

- Possible technical solutions
  - Locate large solar generation closer to substation or connect directly to station with dedicated feeder
  - Operate voltage regulators in "DG mode"
  - Allow PV generators to control voltage or power factor
- More expensive alternatives
  - Upgrade feeder circuit with large conductor
  - Disconnect or reduce solar output when feeder or customer voltage is too high
  - Apply energy storage

System-Wide Impacts

- System-level concerns
  - PV variability and uncertainty could make it more difficult and costly to operate generators
  - A large amount of solar generation may trip during a system disturbance (voltage ride-trough issue)
  - System may become less stable as a large amount of conventional generation is displaced

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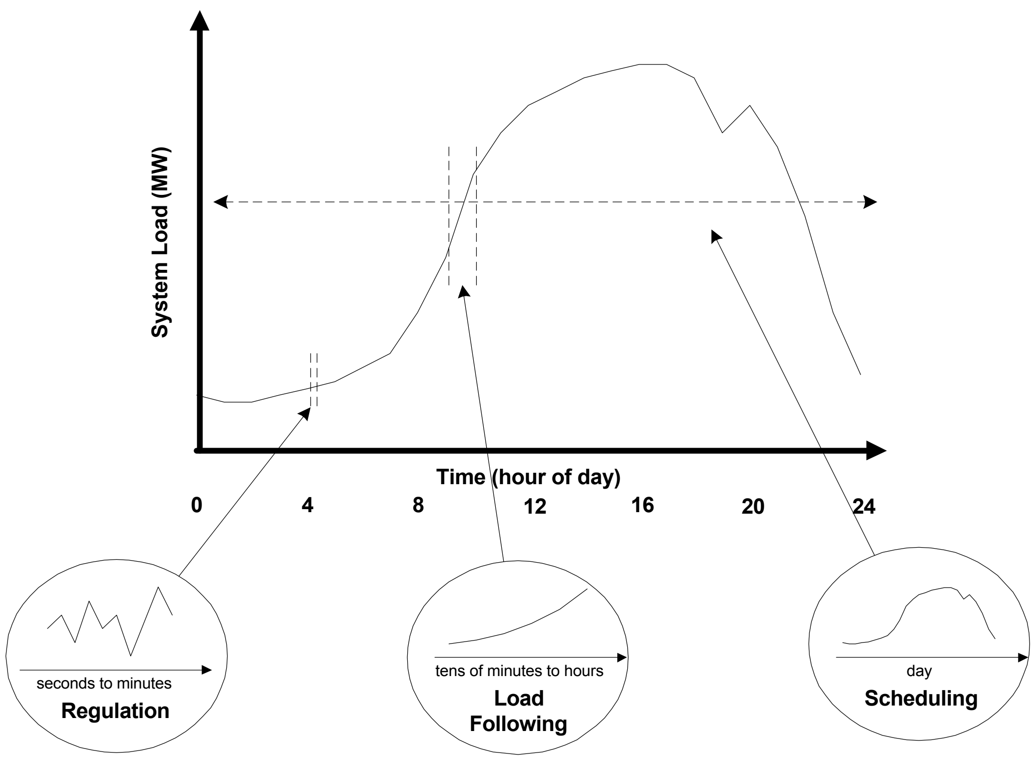
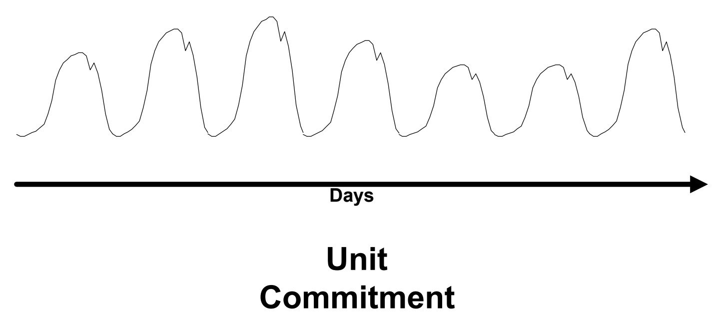
Integration Cost

- System is good at managing variability and uncertainty associated with the load
- Additional variability & uncertainty from renewable generation can increase operating cost

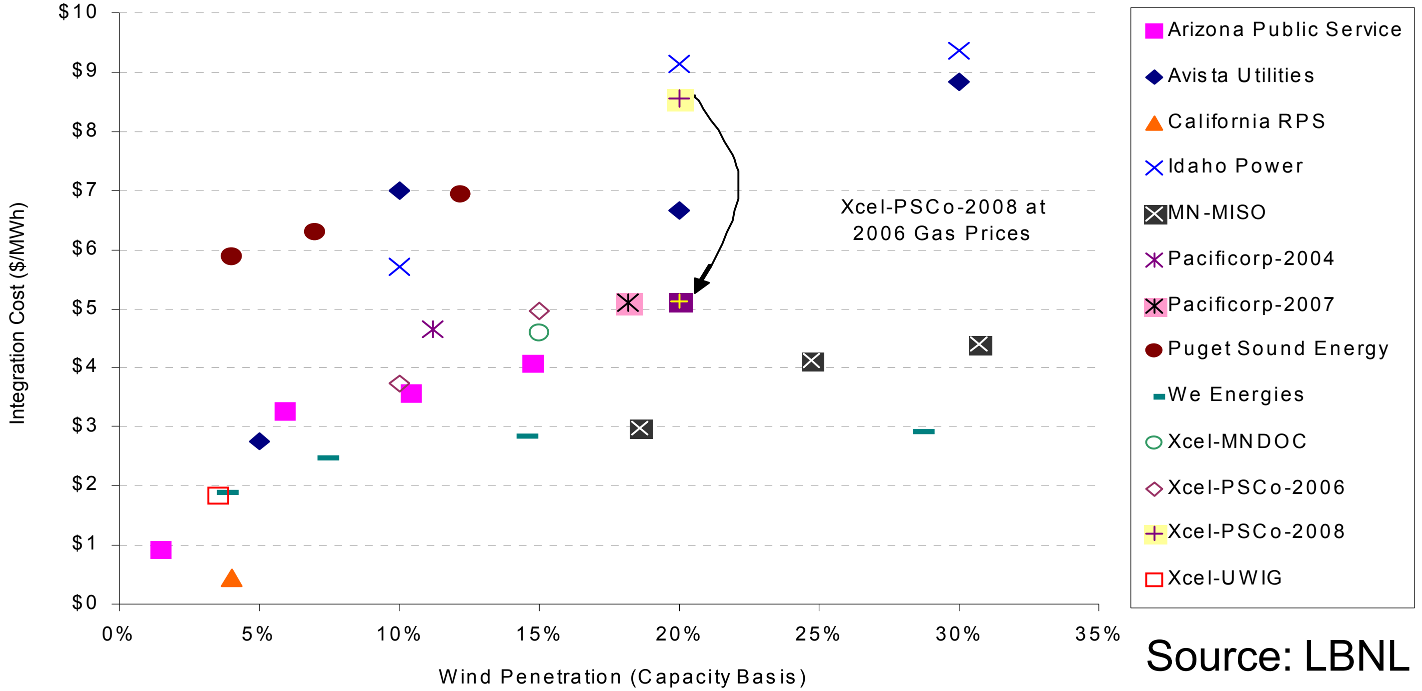




Integration Cost

- Impact of adding variability and uncertainty is called "integration cost"
  - Factors: Penetration level, system conditions and additional variability/uncertainty

Summary of Integration cost for large-scale wind



Source: LBNL

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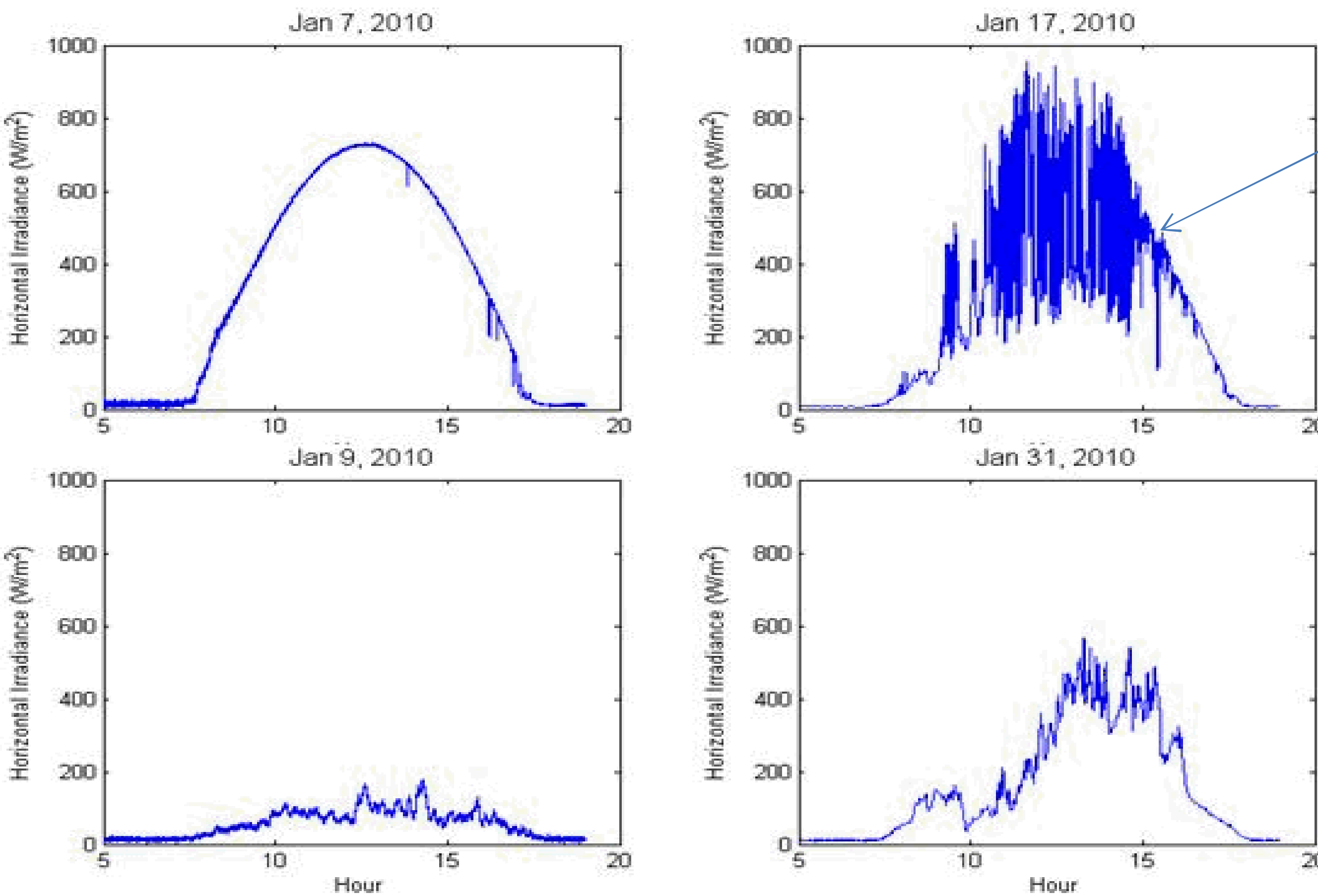
Solar Variability

- Solar intensity (irradiance) at a given location can vary a little or a lot depending on sky conditions (clouds)



Note: irradiance is not a good indication of short-term variability from large plants or geographically-dispersed plants.

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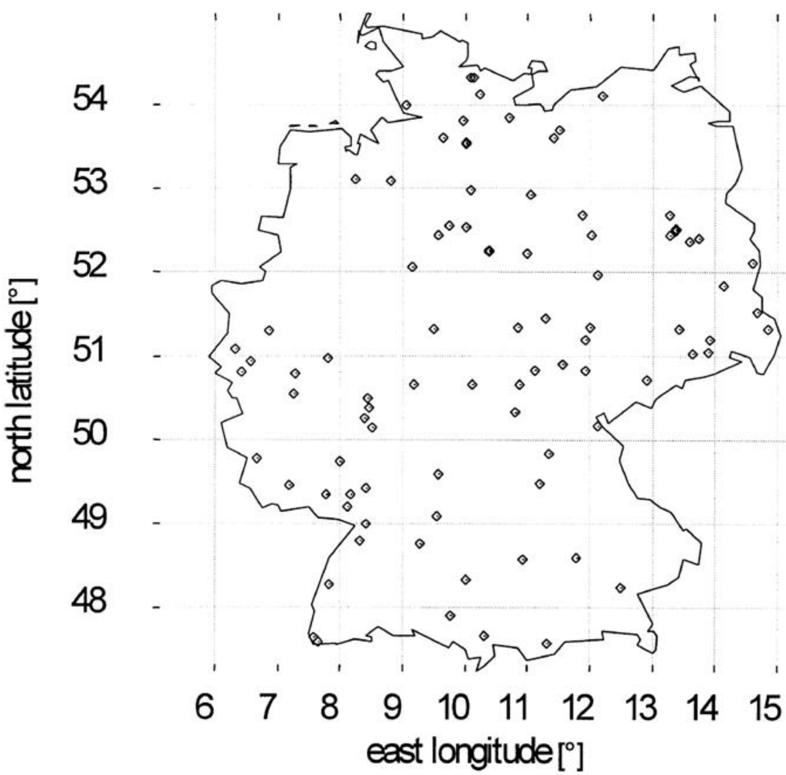
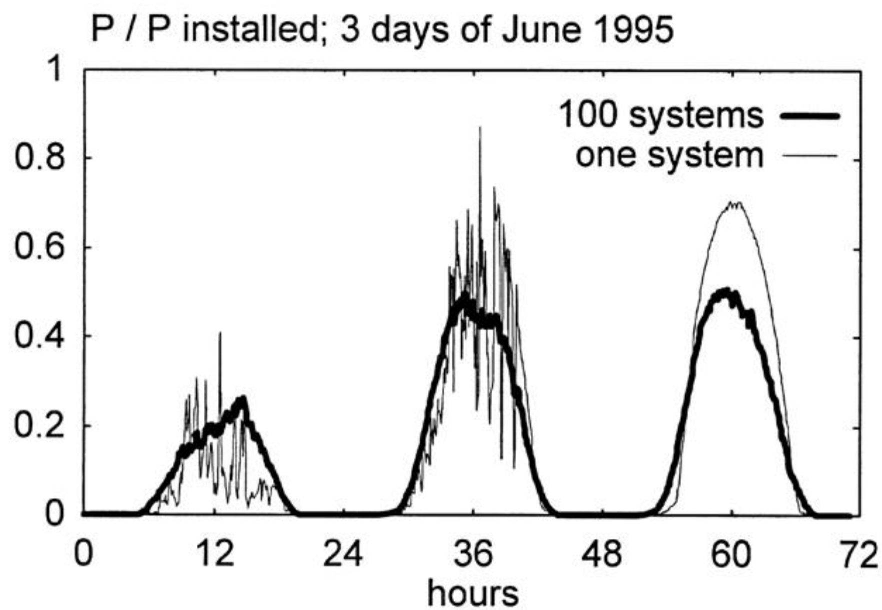
Solar Variability

- Geographic diversity greatly reduces variability (both solar and wind)
  - Example for residential PV systems in Germany





(Wiemken et al. 2001)

Integration Cost

- Technical solutions
  - Geographical dispersion
  - Manage generation resources over wider footprint
  - Use state-of-the-art forecasting
  - Increase flexibility of conventional generation
  - Increase participation in well-functioning electricity market
  - Tap load response potential
- Less cost-effective
  - Curtail variable generation when needed
  - Large-scale energy storage

Examples of Very High Penetration

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

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

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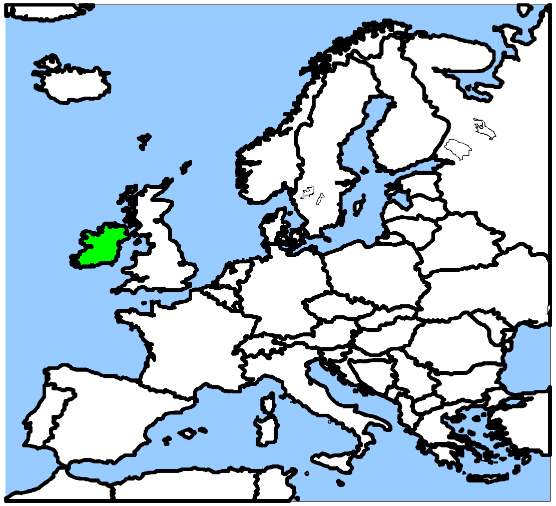
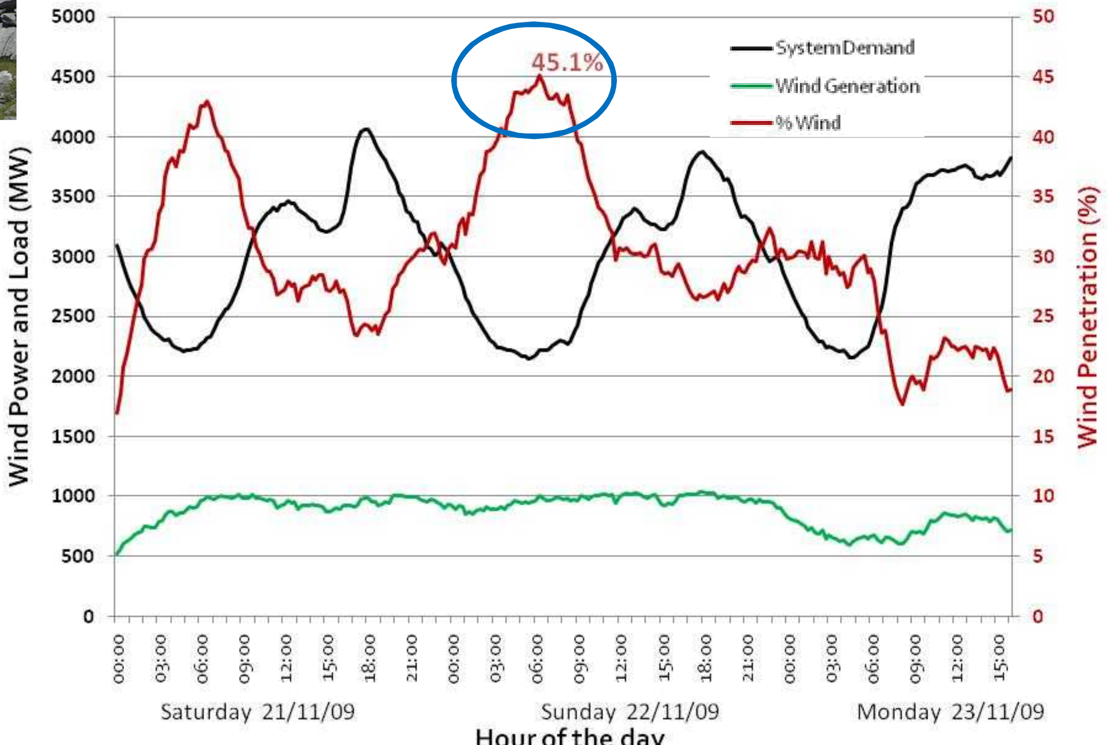
Examples of Very High Penetration

Ireland: >1 GW wind capacity in 7 GW peak load island system



Penetration level by energy approaching 15%

Instantaneous penetration level approaching 50%



Source: Mark O'Malley

Laboratories

Technical Benefits to The Grid

- Renewable generation could support grid reliability, performance, and efficiency… to some extent
  - Off-load distribution and transmission lines and transformers; reduce losses (depending on location!)
  - Help manage voltage and maintain system stability
  - Serve load
- By combining it with modern technologies (Smart Grid concepts, Energy Storage, etc), the technical value to the grid can be increased

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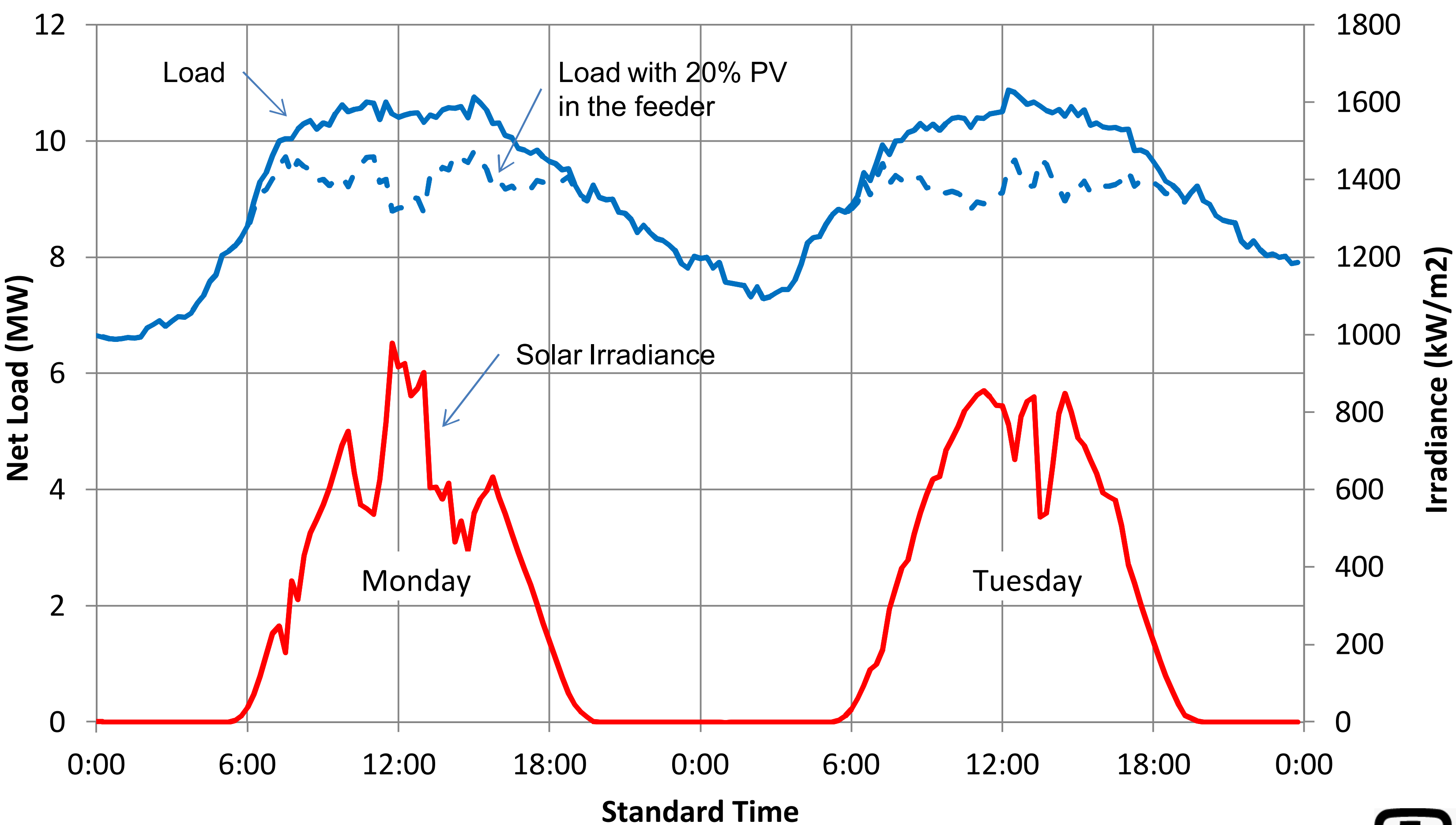
Reduce Station/Feeder Loading

- In the SW, PV output matches commercial load peak…



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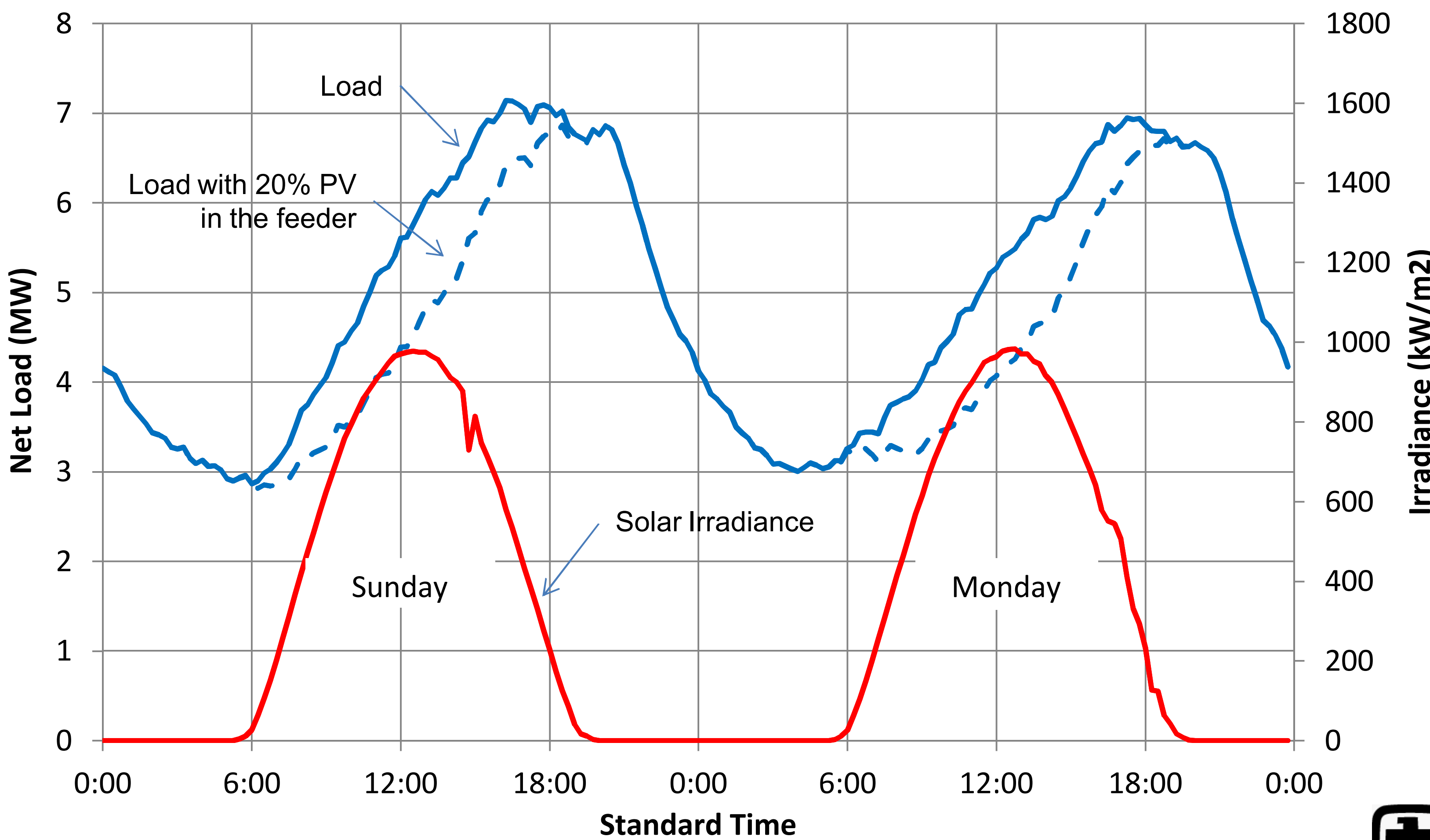
Reduce Station/Feeder Loading

- … timing is less optimal for residential load peak



Conclusions

- Actual impacts of high penetration renewable generation depends on many factors
  - Penetration level
  - Characteristics of the system
  - Degree of variability and uncertainty of renewable generation
- Most common technical issues:
  - Distribution system deployment: voltage management
  - System-wide deployment: managing variability and uncertainty
- There are no absolute technical limits, but there are technical challenges