Understanding Distribution-Level Integration Challenges

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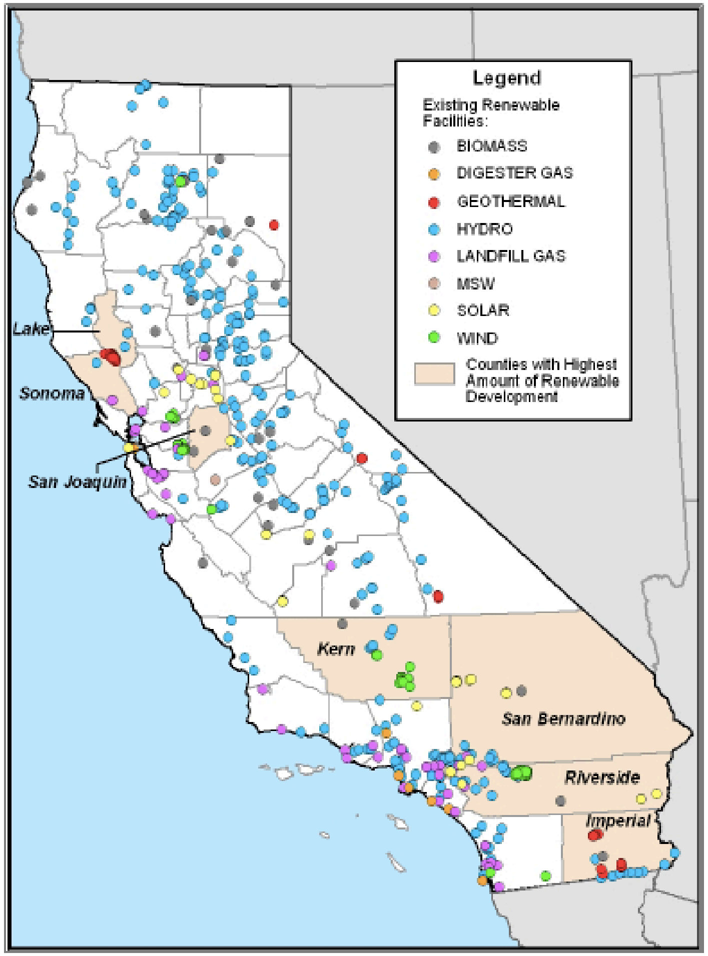
California – Renewable Energy Goals



- **20% by December 2013**
- **25% by December 2016**
- **33% by December 2020**

- **20,000 megawatts of renewable generating capacity by 2020**
  - 12,000 MW of localized electricity generation
  - 8,000 MW of utility-scale generation

- **Need to develop a strategy that minimizes interconnection costs and time**

RE Interconnection – Technical Concerns

Wind and Large Solar (Bulk System Connected Generation)

- **Steady state and transient stability analysis**
- **Load/Generation Coincidence (Peak Load and Variability of Source)**
- **Regulation Requirements**
- **Integration with Automatic Generation Control (AGC)**
- **Incorporation of renewable resource forecasting**
- **Examine current operating practice and new concepts to enable high penetration;**
  - frequency responsive (create regulating reserves)
  - demand side coordination

Distributed Solar and Small Wind (Distributed Generation)

Issues listed above, plus

- **There are a number of technical factors that effect the amount of distributed energy integrated into a distribution system:**
- **Voltage Regulation**
- **Fault Current (System Protection Coordination)**
- **Equipment V/I Ratings (Continuous and Transient Conditions)**
- **Power Quality (Harmonics, Flicker, DC Injection)**
- **Unintentional Islanding**
- **Equipment Grounding**
- **Unbalanced System Loading**
- **Integration with Local Loads and Storage**

- Most technical concerns at the bulk level have been solved with modern inverters and grid codes
- Technical concerns at the distribution level have been identified, but solution set is not standard and small RE have not been fully integrated into planning and operations

Interconnection concerns are real and solvable

e.g., specific to: equipment, design, location, application, etc.

Distribution Integration Issues

- The current electrical grid is designed to move electricity in one direction, from central-station generators to substations to customers.

- However, as more distributed generation is added to the system, power generated by these resources may exceed demand and flow backward into circuits or substations, requiring new protection and control strategies to avoid damaging the electric system.

- There is a high variability in distribution system design, construction and sometime operating practice. This does not make a standard solution easy.

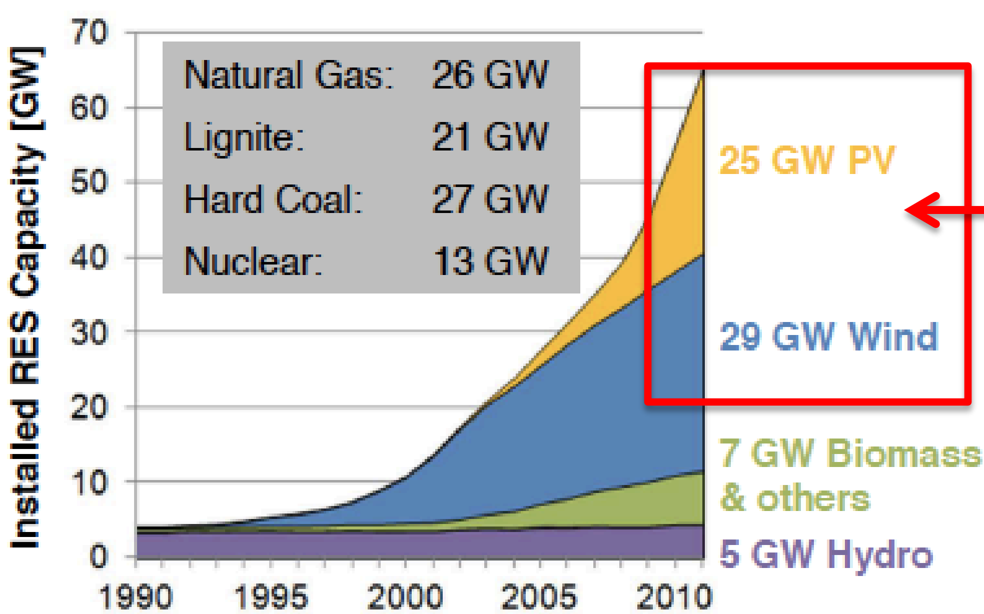
- There are an increasing number of requests for interconnection and the need to reduce the complexity, expense, and length of time associated with that process.

Learn from Experience – The German Example

PV Status Quo in Germany – Development of Renewable Energy Sources

The installed capacity of renewable energy sources (RES) has grown by over 1200 % over the last 20 years in Germany.

Growth of RES in Germany 1990 - 2011



PV Facts

Electricity from PV:

- 2011: 19 GWh (about 3 % of overall generation)

Feed-in Tariff:

- PV < 10 kWp: 19.31 ct/kWh
- Electricity price: approx. 25 ct/kWh

Growth goal 2020:

- Approx. 40 GWp

Over 50 GW of installed variable generation capacity

Source: BMU (2012), Umweltbundesamt (2012)

Jan von Appen, Martin Braun, Thomas Stetz
"Preparing for High Penetration of Photovoltaic Systems in the Grid"
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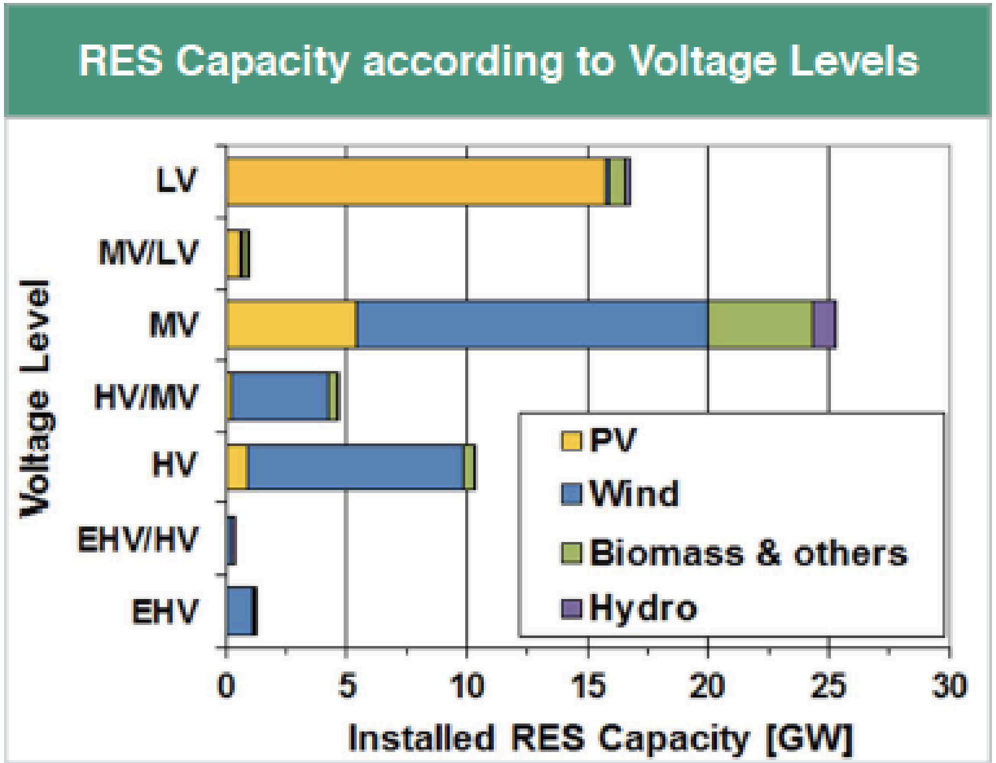
PV in Germany is mostly DG

PV Status Quo in Germany – Distribution of RES in the Grid

Over 1,000,000 PV systems are already installed. The majority of these systems is installed in the low voltage grid.



Source: DGS (2012)

Amount of overall PV capacity in LV grid:

- ~ 69%
- PV plants with less than 100 kWp

Amount of overall PV capacity in MV grid:

- ~ 26 %
- PV plants greater than 100 kWp

Germany
80M people
80MW peak
1M PV systems
25GW PV

California
37M people
60MW peak
150K systems
3GW PV

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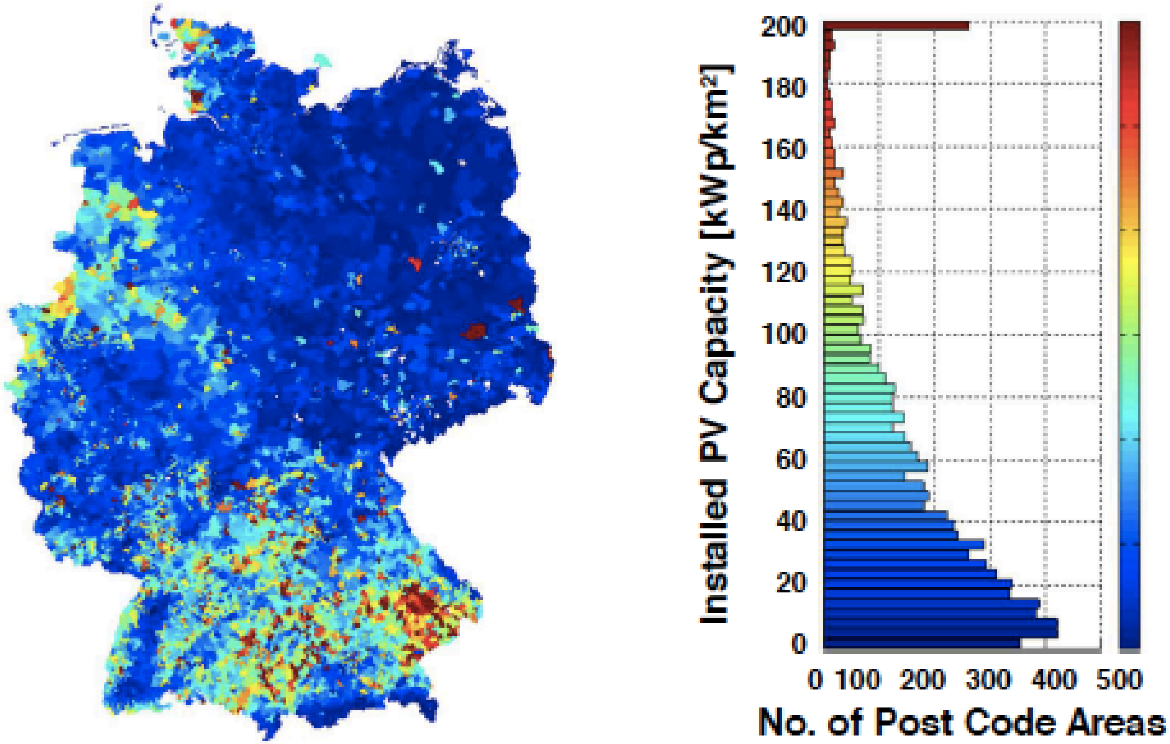
PV in Germany is mostly in the South

PV Status Quo in Germany – Geographic Distribution of PV in Germany

Certain regions in Southern Germany host over 200 kWp per km², while the German average lies around 39 kWp per km² (Sept 2010).



Source: Stetz, Braun, et al. (IWES, 2012)

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German Solar Production - May 25, 2012

theguardian

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Environment › Solar power

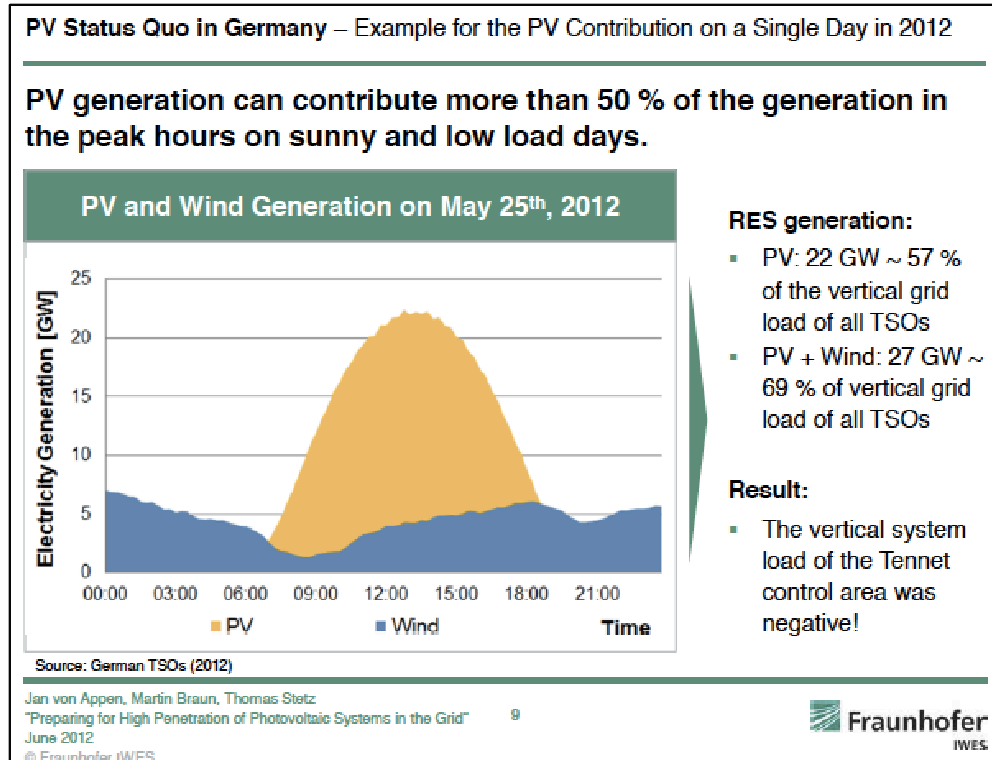
Solar power generation world record set in Germany

Plants produced 22 gigawatts at midday hours on Friday and Saturday, meeting half country's electricity needs on second day

Reuters
guardian.co.uk, Monday 28 May 2012 13.03 EDT
Comments (130)

Solar panels stand on the roofs of the Sun Ship part of the Freiburg Solar Settlement in Freiburg im Breisgau. Photograph: Harold Cunningham/Getty Images

http://m.guardian.co.uk/environment/2012/may/28/solar-power-world-record-germany?cat=environment&type=article



PV Status Quo in Germany – Example for the PV Contribution on a Single Day in 2012

PV generation can contribute more than 50 % of the generation in the peak hours on sunny and low load days.

RES generation:

- PV: 22 GW ~ 57 % of the vertical grid load of all TSOs
- PV + Wind: 27 GW ~ 69 % of vertical grid load of all TSOs

Result:

- The vertical system load of the Tennet control area was negative!

Source: German TSOs (2012)

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Germany – Integration Issues

Impact on the Grid – Reverse Power Flow

PV generation can cause reverse power flows on distribution lines and lead to high voltage magnitudes.

Distribution Grid in "Sonderbuch"

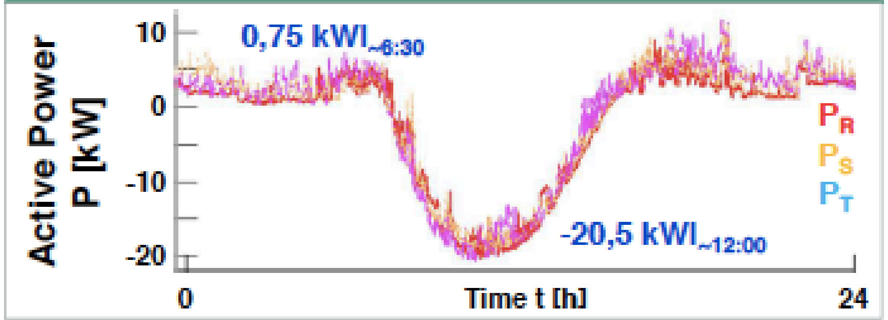
Grid information:

- Low voltage system with 80 households
- Peak load: 130 kWp

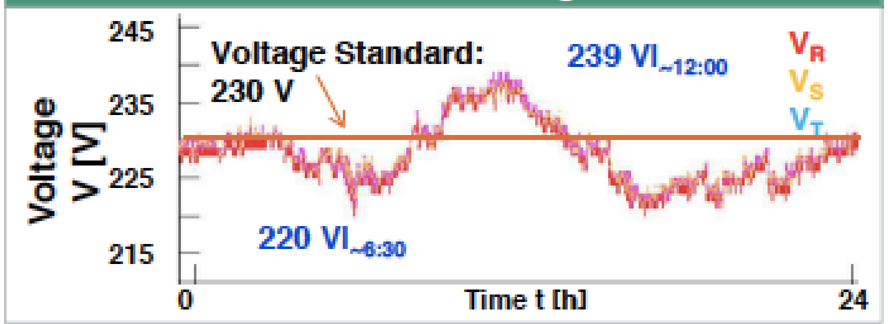
PV capacity:

- 1,200 kWp
- 60 Systems

Active Power Flow



Measured Voltage



Source: Eilenberger, Braun (University of Stuttgart, IEH, 2012)

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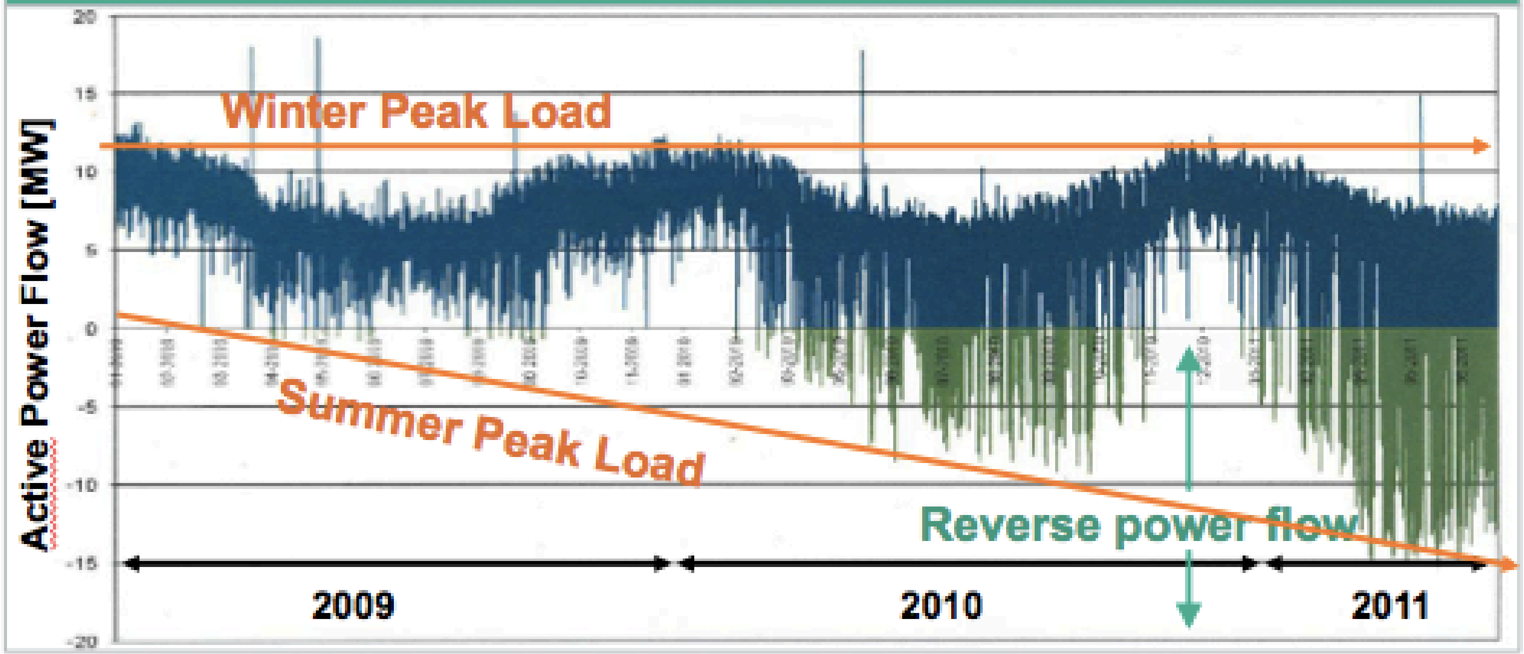
Germany – Integration Issues

Local Impact on the Grid – Additional Power Flow

Transformation from Consumption to Supply Grid within 2 Years!

Active Power Flow at a Substation (01/01/2009 – 06/30/2011)



Source: E.ON Bayern AG (2011)

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Smart Grids Week 2012, Bregenz © Fraunhofer IWES

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Germany - Summary

- High incentives and goals promoted distributed solar deployment in Germany
- Low PV system prices continue to drive market
- Extremely simple and standardized interconnection process helps deployment
- German utilities are able to rate-base the cost of distribution system upgrades
- High penetrations have demanded changes in PV system design and operations
- Germany has updated interconnection guidelines and inverters to require volt/VAR capability, trip setting variations, fault ride through capability and ability to remotely curtail system output
- Germany has a goal of 80% RE by 2050 – will need to make significant system upgrades to achieve this level

NREL – working with CA Utilities

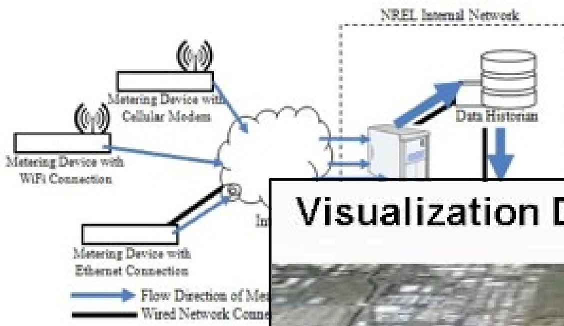
- **Working with the CA IOUs, Sandia, and EPRI on developing better screens for simplified interconnections**
- **Working with CA IOUs, Sandia, and EPRI on distribution modeling and screening methodology**
- **Southern California Edison**
  - Evaluating high penetration PV case studies
  - Testing inverters with advanced functionality
  - Modeling high penetration PV system impacts
- **Sacramento Municipal Utility District**
  - Evaluating high penetration PV case studies
  - Developing visualizations for impact studies
- **San Diego Gas & Electric**
  - Evaluating high penetration case studies

NREL - Energy Systems Integration Facility

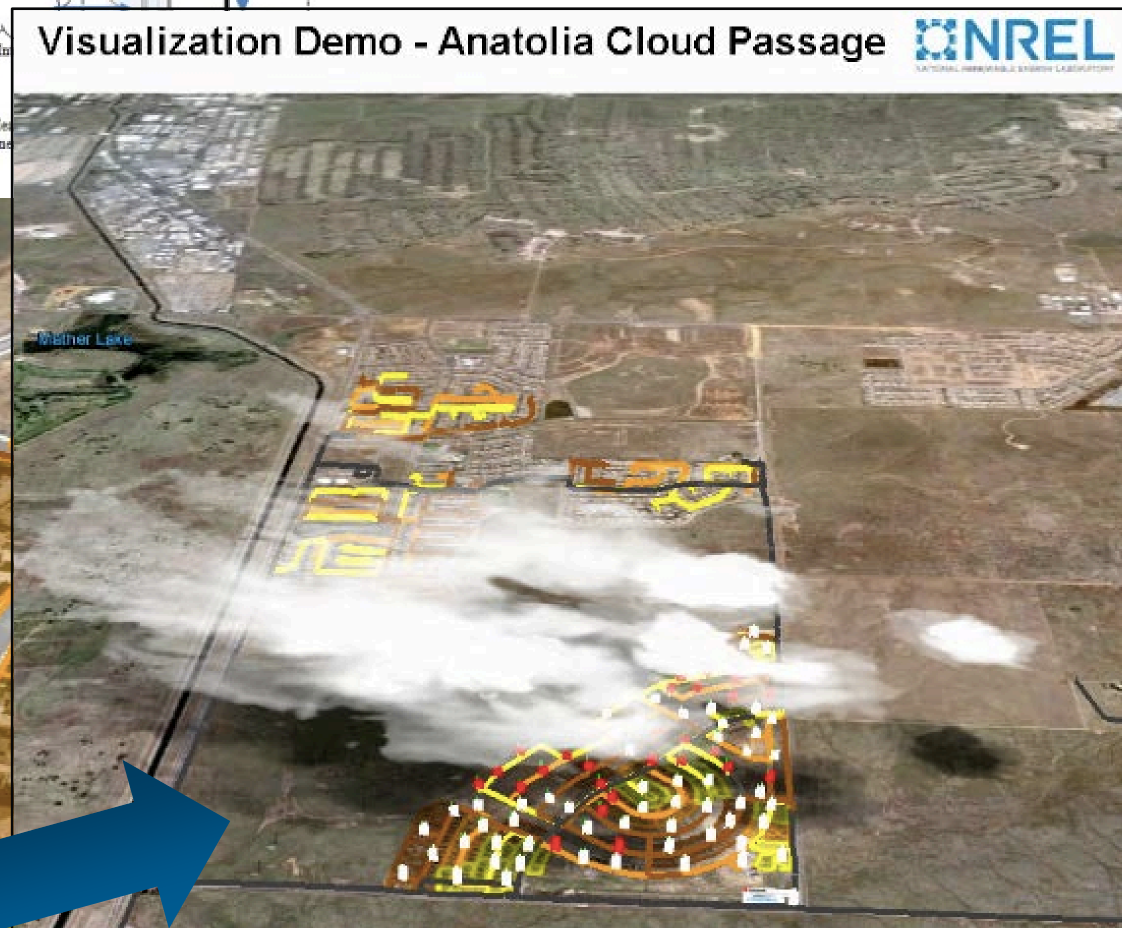
- Provides a technology user facility for conducting research and development of clean energy technologies in a systems context at deployment scale
- Provides a High Performance Computing, Data Center, and Visualization capabilities that can be used to inform development and integration of clean energy technologies

A unique national asset for Energy Systems Integration R&D, testing, and analysis.

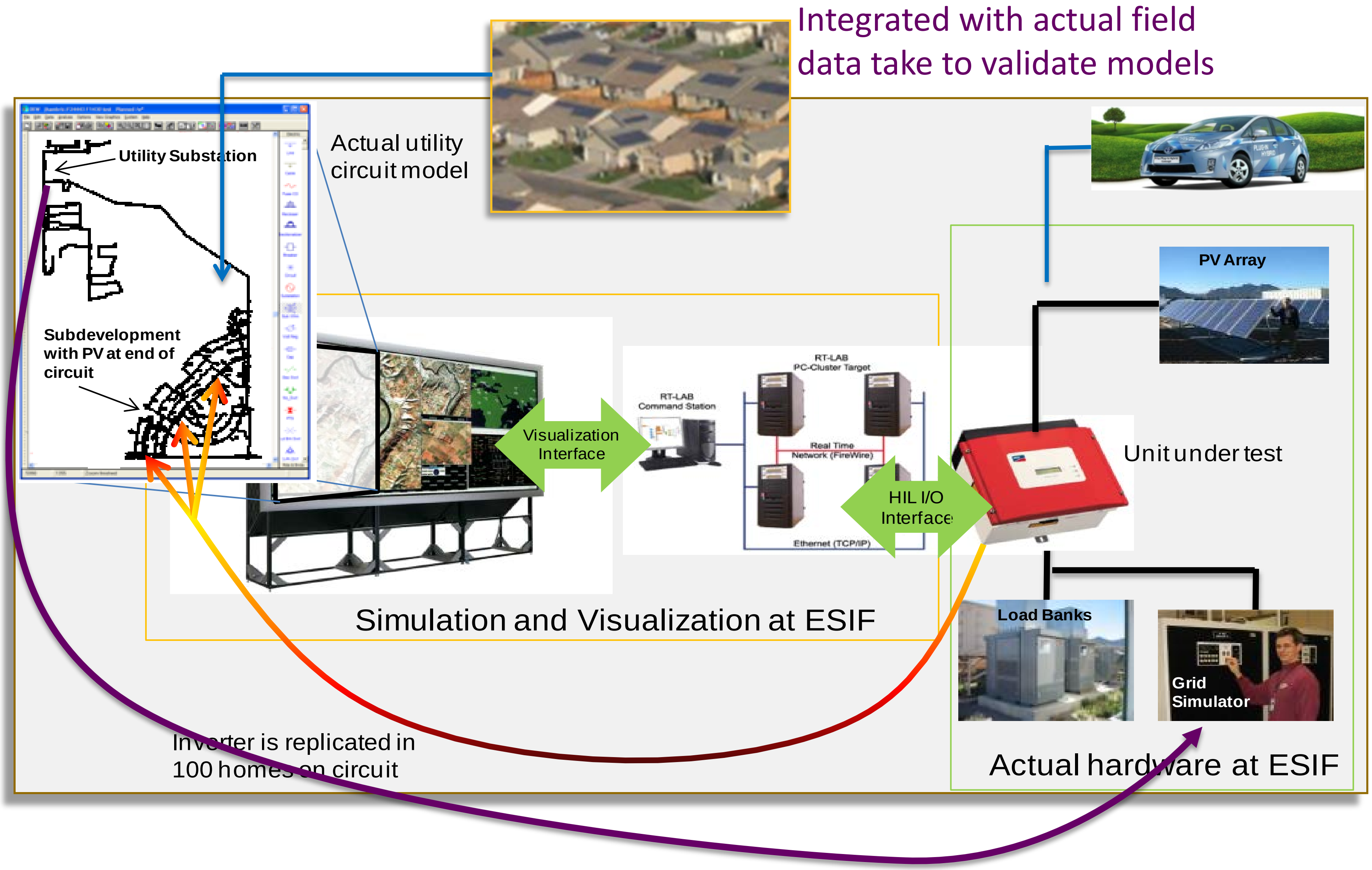
ESIF - Power System Visualization



NREL is working with SMUD on visualizing impact of DG deployments



ESIF - Power Hardware-in-the-Loop (PHIL)



Integration Solutions

- **Technology Solutions**
  - Distribution system upgrades – need clear definition on who pays for what. May not be the least expensive solution – need optimal cost from a systems perspective
  - Inverter technologies with advanced functionality (volt/VAR control, fault ride through, remote communications, power curtailment) - All have been proven in the lab but need testing in a larger system-wide context
  - Standardized control and communications interfaces are needed to provide remote control for contingencies – needs to be secure
  - Standard methods to identify best locations for integration are underway
  - Integration of local load control and energy storage will help reach higher penetration levels

- **Standards and Regulatory Solutions**
  - Update Interconnection requirements to include advanced inverter functionality
  - IEEE 1547, UL 1741, SGIP, WDAT, Rule 21 – need to be updated
  - Streamline interconnection process based on rigorous screens – let low impact system connect quicker
  - Streamline and digitize permitting process

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Thank you

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For more information on NREL Integration Projects and ESIF:

http://www.nrel.gov/eis/facilities_esif.html

For more information on Solar in Germany:

Martin Braun, Thomas Stetz, and Jan von Appen

Fraunhofer IWES Website:

www.iwes.fraunhofer.de

Backup Slides

From "SCE Experience with PV Integration" by George Rodriguez

http://www1.eere.energy.gov/solar/pdfs/hpsp_grid_workshop_2012_rodriguez_sce.pdf

Typical Distribution Upgrades

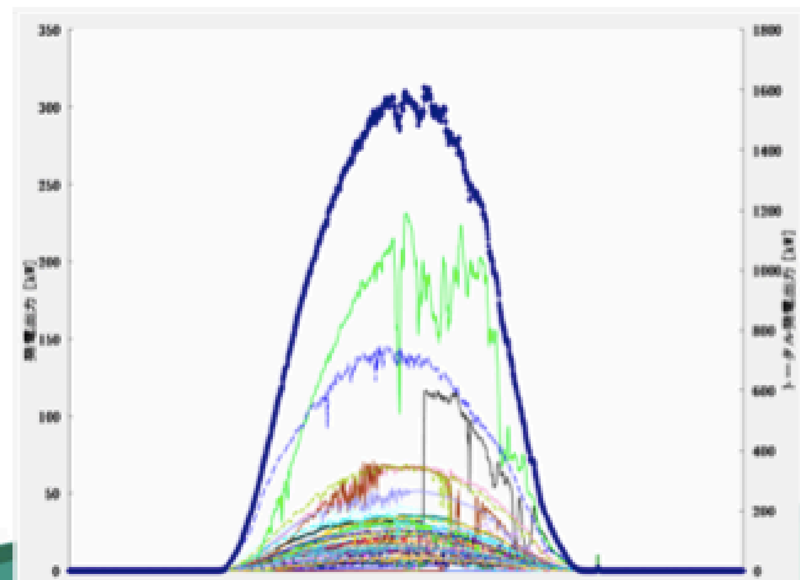
- Areas with low penetration
  - Switching devices
  - Line extensions
- Areas average penetration
  - Cable/Conductor upgrades
  - Protection devices
  - Voltage regulating devices
- Areas with **high penetration**
  - New distribution circuits
- Areas with **very high penetration**
  - Substation transformer upgrades
- Areas with **extreme penetration**
  - Sub transmission/transmission upgrades

Possible Interconnection Changes to Improve SPVP Integration

- Penetration Level
  - Originally 15 % circuit rule would have limited SPVP to 1-2 MW per circuit
  - Latest studies allow for up to 8 MW on a circuit if near the substation
  - Dedicated circuits needed if PV exceeds circuit capacity.
  - Costly ($100K/site) Remote Controlled Disconnect Switches current requirement. Inverters can be controlled via internet if deemed reliable
- Active Voltage Regulation –
  - Rule 21, Para D2a – prohibits the generator from any active voltage regulation –
  - Utilities don't want DG units to control voltage is because our "not smart" grid has no way to monitor & control customer generation.
  - Customers will want to be paid for their services and we have no CPUC approved way to do this.
  - Possible solution is to have utility owned generation - even DG- to be treated and considered differently from customer or IPP units.
- System Disturbance Ride-through
  - Rule 21, Para D2b3 – has tight voltage limits which basically prevent any ride thru of a distribution system disturbance.
  - PV systems may have value during disturbances that we want to keep them on-line

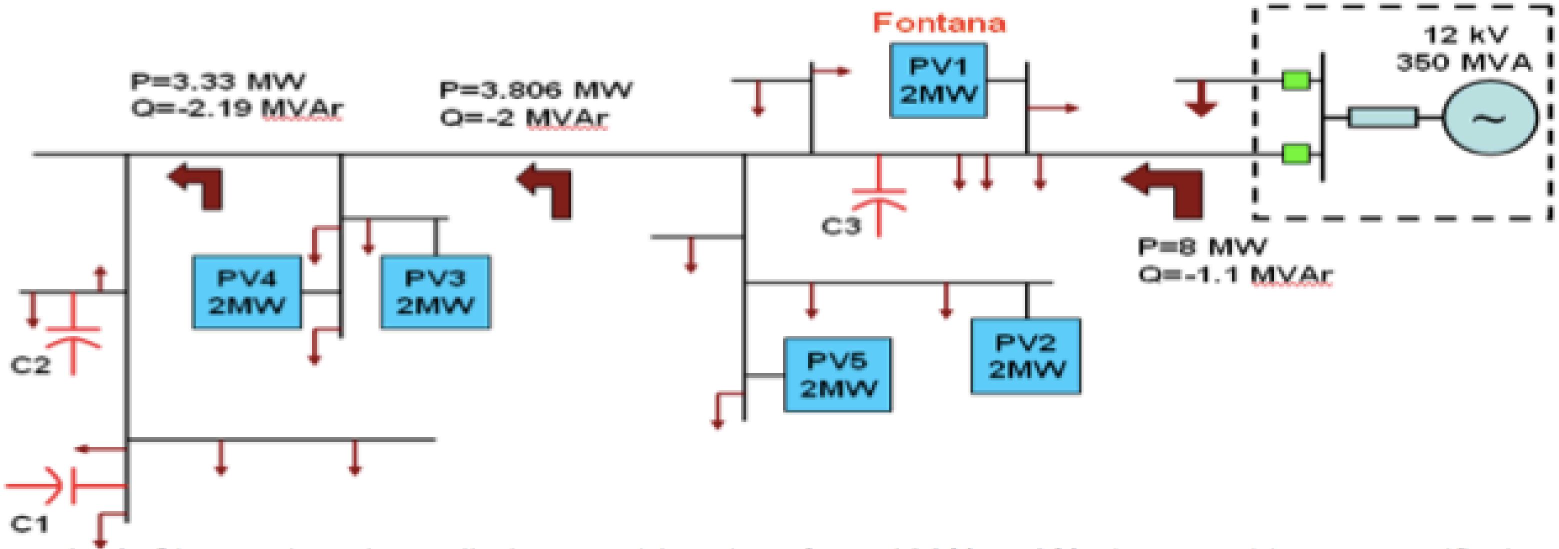
- Harmonics – Concerns over harmonics from PV Inverters seemed to have allayed, Further study may be needed to guarantee this concern.
- Intermittency – SCE / NREL Study may allay concerns.
  - Overall distributed PV "smoothing effect" reduces impact

Smoothing Effect of Multiple PV



High Penetration of PV Systems

SCE Feeder Transient Studies are being conducted



Scenario 1: Change in solar radiations sudden drop from 100% to 0% change with pre-specified ramp up/down rates

Scenario 2: Load rejection Disconnecting adjacent feeder load

Target studies:

- Impact on feeder flow (P & Q)
- Impact on feeder voltage
- Impact on short circuit capacity of the feeder
- Interaction with capacitor banks