Solar Grid Integration
Industrial Research Perspectives

Kathleen O'Brien, GE Global Research

March 8, 2011

Global Research: market-focused R&D

- First US industrial lab
- Began 1900 in Schenectady, NY
- Founding principle … improve businesses through technology
- One of the world's most diverse industrial labs

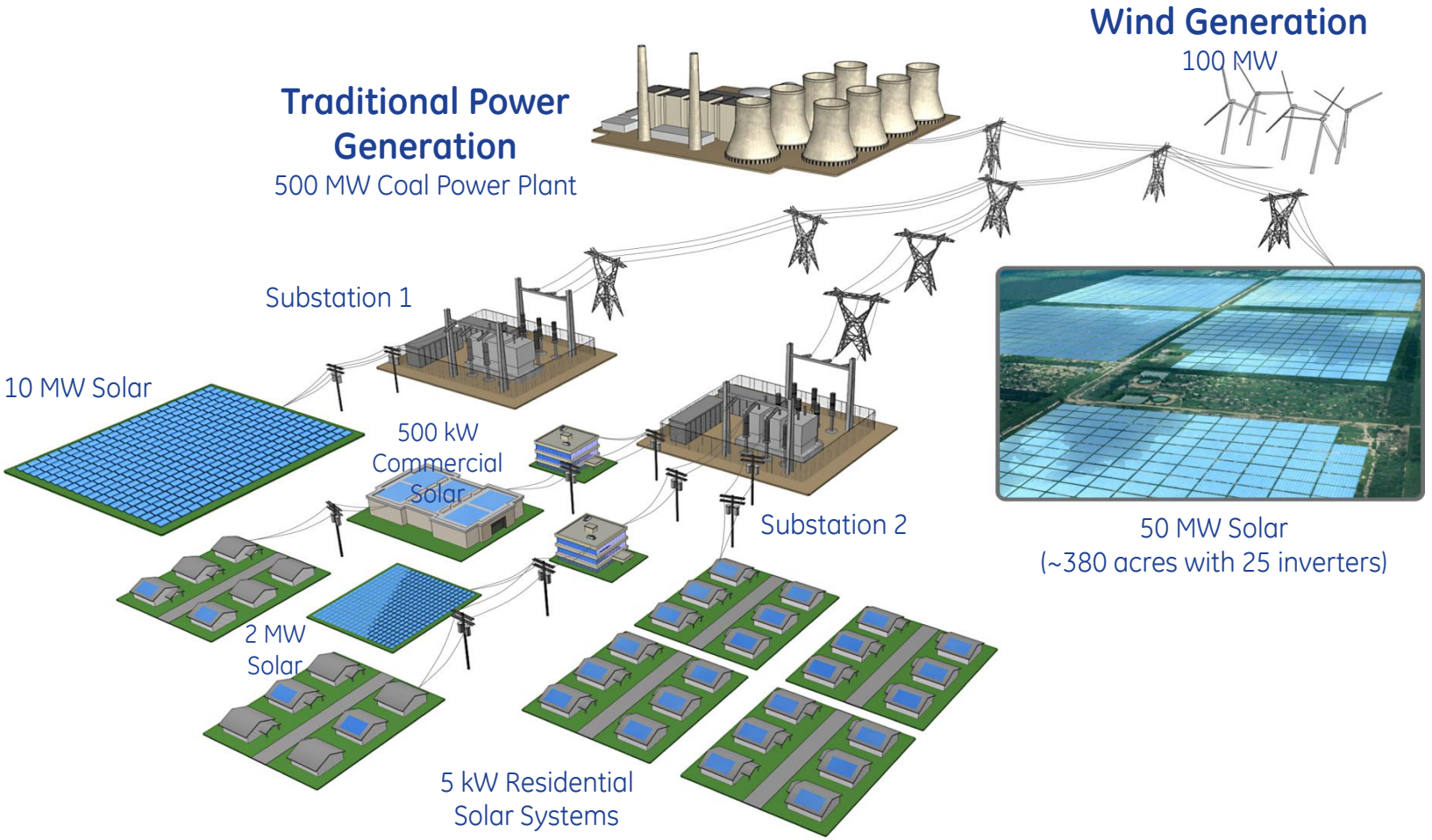
Cornerstone of GE's commitment to technology

Role of Global Research

- Delivering core technologies for new products + productivity
- Discovering new technology opportunities
- Establishing foothold in advanced technologies
- Spreading technology across businesses
- Developing world-class talent
- Connecting with the world's technology

imagination at work

Solar Power Generation



Wide variety of power levels and grid connections

PV Generation Segmentation

1. Behind the meter - commercial and residential

- Small scale makes interconnection studies generally infeasible – tends toward plug & play applications
- not yet recognized as a significant grid resource
- This is the target of UL 1741 and IEEE 1547 standards

2. Utility-scale plants for wholesale generation

- **Distribution connected < ~10 MW**
- **Transmission connected >30 MW**

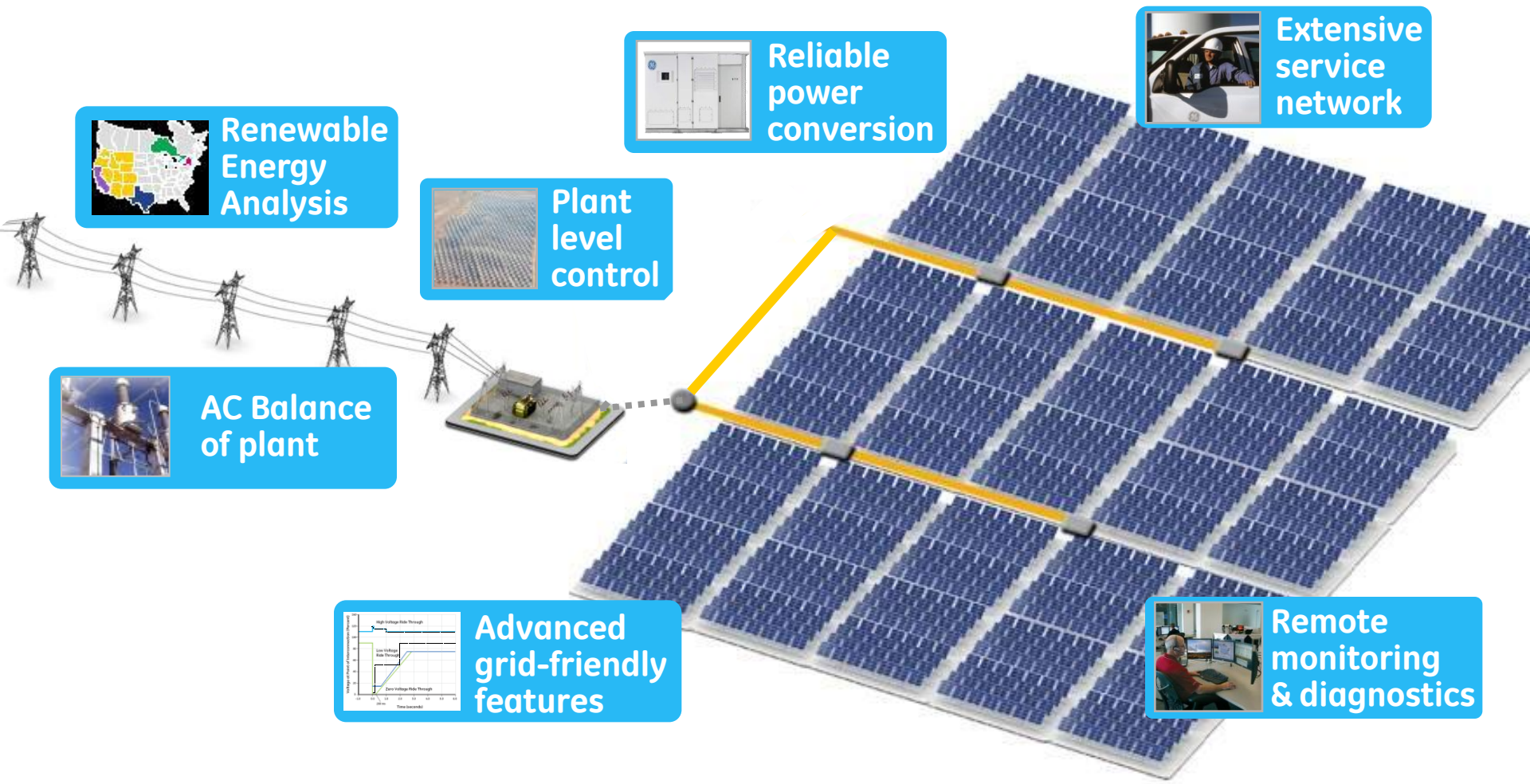
- Large enough to impact the grid – needs to mitigate its own impact where feasible
- As a grid resource, needs to provide its share of grid support
- Scale justifies engineering effort and system investments
- UL 1741 and IEEE 1547 conflict with these goals

imagination at work

Source: Reigh Walling – GE Energy Consulting

Distinct interconnection requirements

Essential PV power plant features



Power conversion & grid interface key to system wide reliability

GE Utility-Scale PV Provides Grid Support

- Reactive power
  - Voltage regulation
  - Mitigate voltage impacts of inherent variability
  - Contribute to grid needs

- Disturbance ride through
  - Avoids consequential loss of generation assets due to a grid fault

Arizona Public Service – 500kW Plant

Evaluating effects of high levels of PV on a distribution feeder (up to 44%)

- Arizona Public Service Site
- GE 700kW Inverter at STAR test-site and on mixed-use Flagstaff, AZ feeder
- Started May 2010 / Flagstaff June 2011

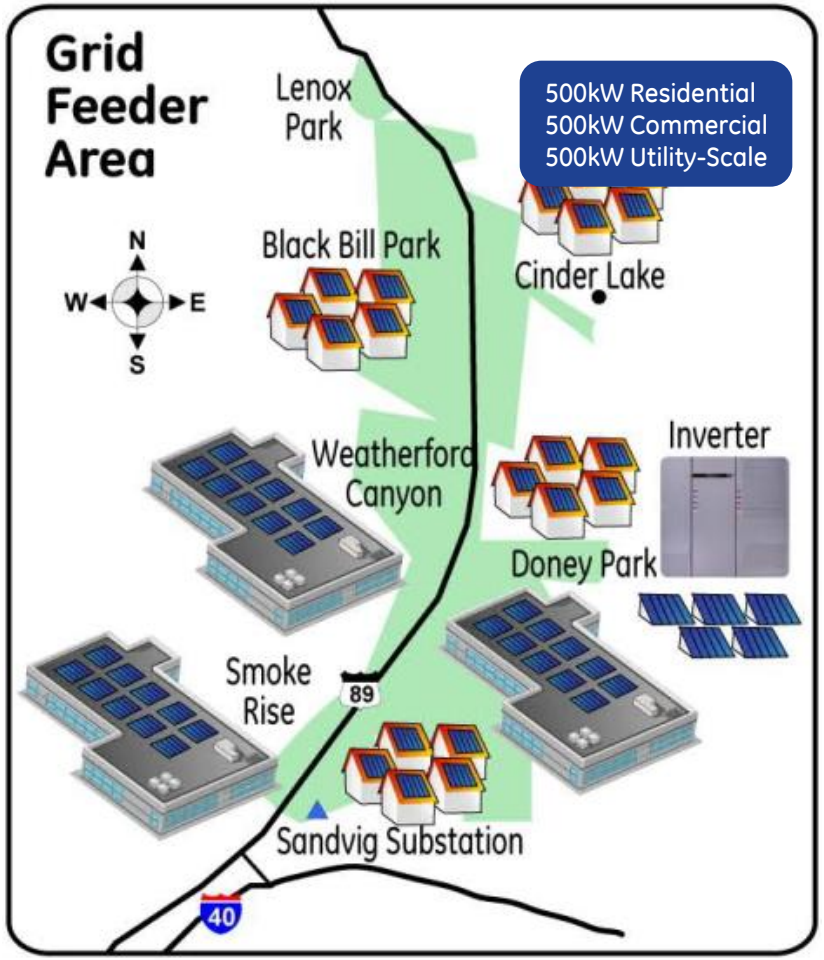
Objectives

Determine system impact of distributed PV

- Net load cycles
- Equipment wear

High resolution performance data - inverter and plant controls

- Variability analysis
- Forecasting accuracy
- Voltage regulation capabilities
- Protection scheme issues
- Interaction w/ adjacent equipment



DOE Grant#: DE-EE0002060: High Penetration of Photovoltaic Generation Study - Flagstaff Community Power (APS,

imagination at work

Window into the Future of Locally High Penetration Solar

Research Interests - Variability

- **Large plant variability** – What effects do changes in insolation have on plants spread out over large geographic areas. How does this compare to the effect on smaller plants?

- **Regional variability** – What are the characteristics of variability between large plants? What is the correlation between energy produced at plants located at a defined distance from each other?

- **Load variability** and solar plant power production – correlations and effect on existing utility equipment

- **VAR support** to mitigate variability impact on feeder voltage – comparison of different methods.

- **Data collection** – Temperature, wind speed, insolation, forecast vs. production, second to hourly data.

Research Interests – Power Delivery

- **Ride-through:**

Disturbance ride-through behavior – Comparison to established wind methods with application to distribution grids.

Methods for achieving ride-through at less than full power.

- **Plant/Controls:**

Dynamic stability in clusters of power converters – effects of different grid conditions

Distributed vs. centralized – Distributed hardware (dc/dc or dc/ac) for utility-scale solar. Distributed control for utility scale solar. Are the benefits limited to smaller-scale plants?

Communications and SCADA – Advanced communication capabilities and potential use with DMS/EMS systems. Impact on large dispersed plants.

- **Reliability:**

Inverter reliability monitoring – methods for determining failure mechanisms without customer generation data.

Research Interests – Protection & Storage

- **Protection:**

Islanding protection – transfer-trip vs. active anti-islanding, advanced islanding detection (synchrophasors etc.), failure modes

What short-circuit current contribution requirements should be in place at high-penetration?

Open-circuit overvoltage – Advanced control solutions, transfer-trip

Advanced protection schemes – coordination and use of solar within "Smart-Grid" advanced protection schemes for distribution systems.

- **Energy storage:**

Value, location, technology, control, and function. Determination of potential as facilitator for increased PV penetration based on cost and function.

Interaction with other generation (wind etc.) and energy storage. Is this needed/beneficial to the system or not?

Thank-you

imagination at work

Standards, Regulations

IEEE Standard 1547™

- IEEE 1547 sets uniform rules for DG interconnection
  - Adopted by many state regulatory commissions
- DG may not regulate utility voltage (i.e., must run at fixed p.f.)
  - Intended to avoid coordination issues with utility regulation schemes
  - Complicates the ability of a PV to mitigate the voltage variations that it causes
- DG may not continue to energize an "island"
  - Distribution feeders are radial, faults are common
  - Intended to avoid equipment damage and safety issues
  - Functional requirement, diverse solutions allowed
- DG must trip in response to abnormal voltage or frequency

Underwriters Laboratory UL 1741

- Intended as a test standard for plug & play PV meeting IEEE 1547
- Requires built-in island detection functionality
  - Inherently rules out any of the other anti-islanding measures allowed by IEEE 1547
  - Diametrically opposite of a ride-through capability
- Required "resonant circuit" tests are onerous for conducting tests on utility-scale inverters
- Only UL standard for PV
- Regulators and financiers demanding UL compliance

Source: Reigh Walling – GEE EA&SE