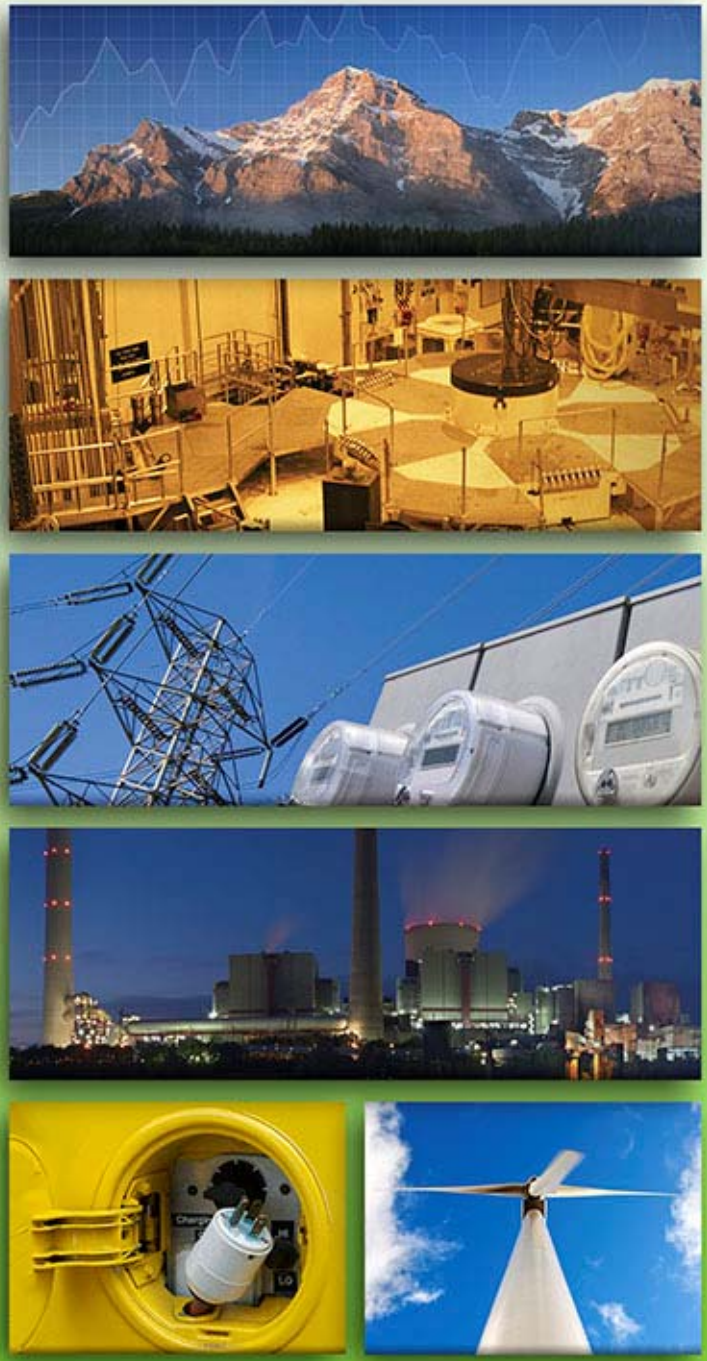


EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Historical Perspective on Grid Integration of Distributed Generation

Tom Key, EPRI
tkey@epri.com

4th International Conference

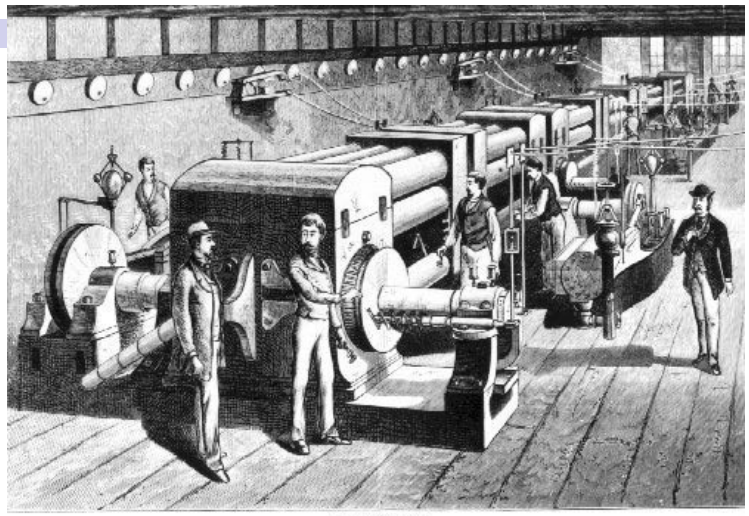
Tutorial on Grid Codes
December 6, 2010

Topics

- Early Electric Power Systems
- Modern Distributed Generation
- Demand for Uniform Interconnection Standards
- Serious Distributed PV Power
- Questions about Grid Integration
- Changing Expectations and Rules for Distributed Generation

Distributed generation is not a new thing

- **First 25 years – in 1900 most customers were within 5-miles of their power station**
- **Powered areas operated as electrical islands, < 10MW and not interconnected.**
- **Co-generation was common.**
- **Next 80 years evolved the centralized power system employing transmission lines, larger scale, better economy, away from cities, efficiency improvement, power dispatch and diversity advantage.**

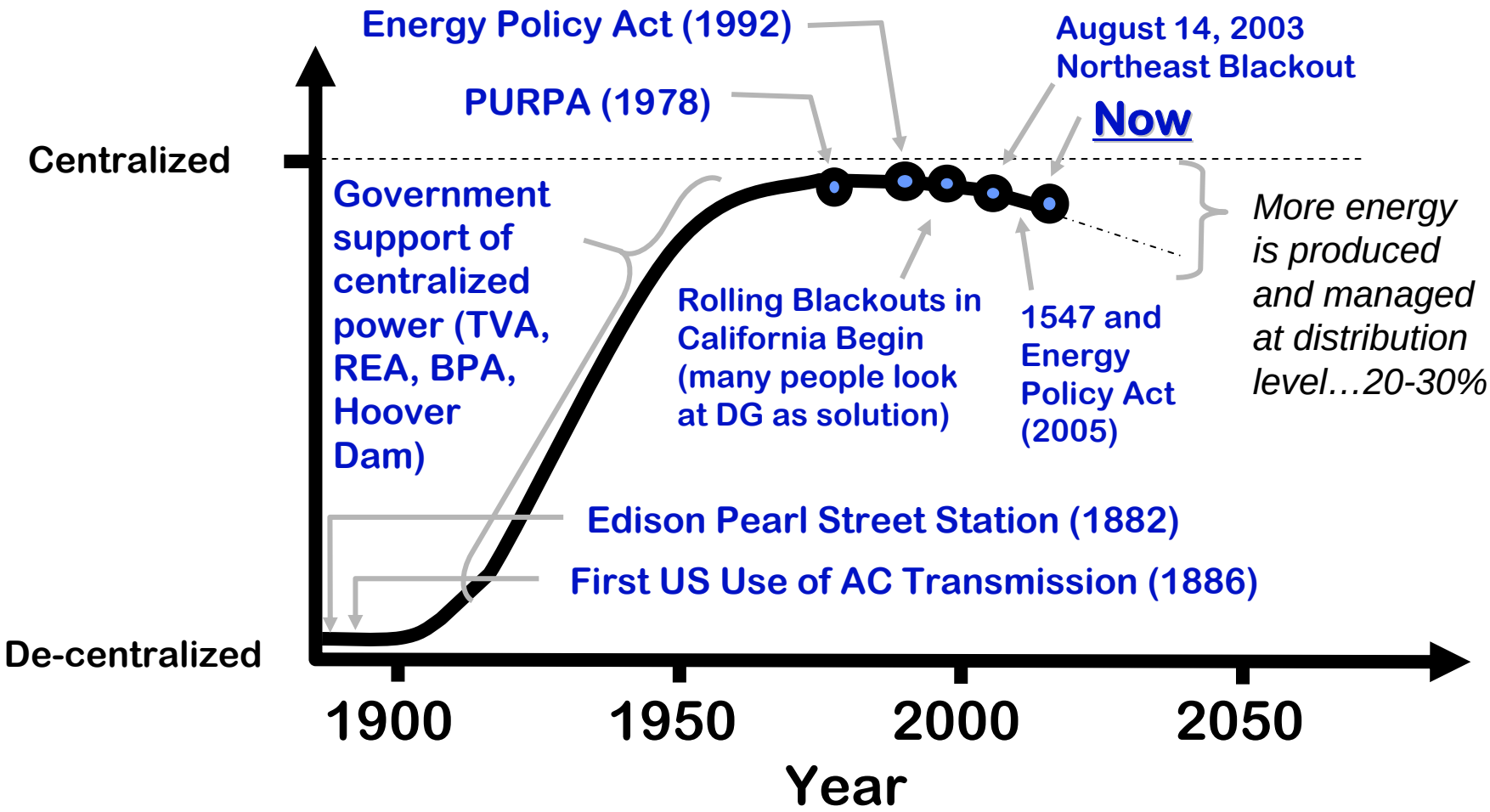


THE DYNAMO ROOM.
FIRST EDISON ELECTRIC LIGHTING STATION IN NEW YORK.
U.S. DEPARTMENT OF THE INTERIOR, NATIONAL PARK SERVICE, EDISON NATIONAL HISTORIC SITE

Edison's Pearl Street Station in 1882 – each generator was about 100 kW DC:

- Heat rate 138,000 BTU/kWh and efficiency ~ 2.4%
- Electricity cost US$.24 cents/kWh, $4.21/kWh in today's dollars

History of Electric Power Development in USA



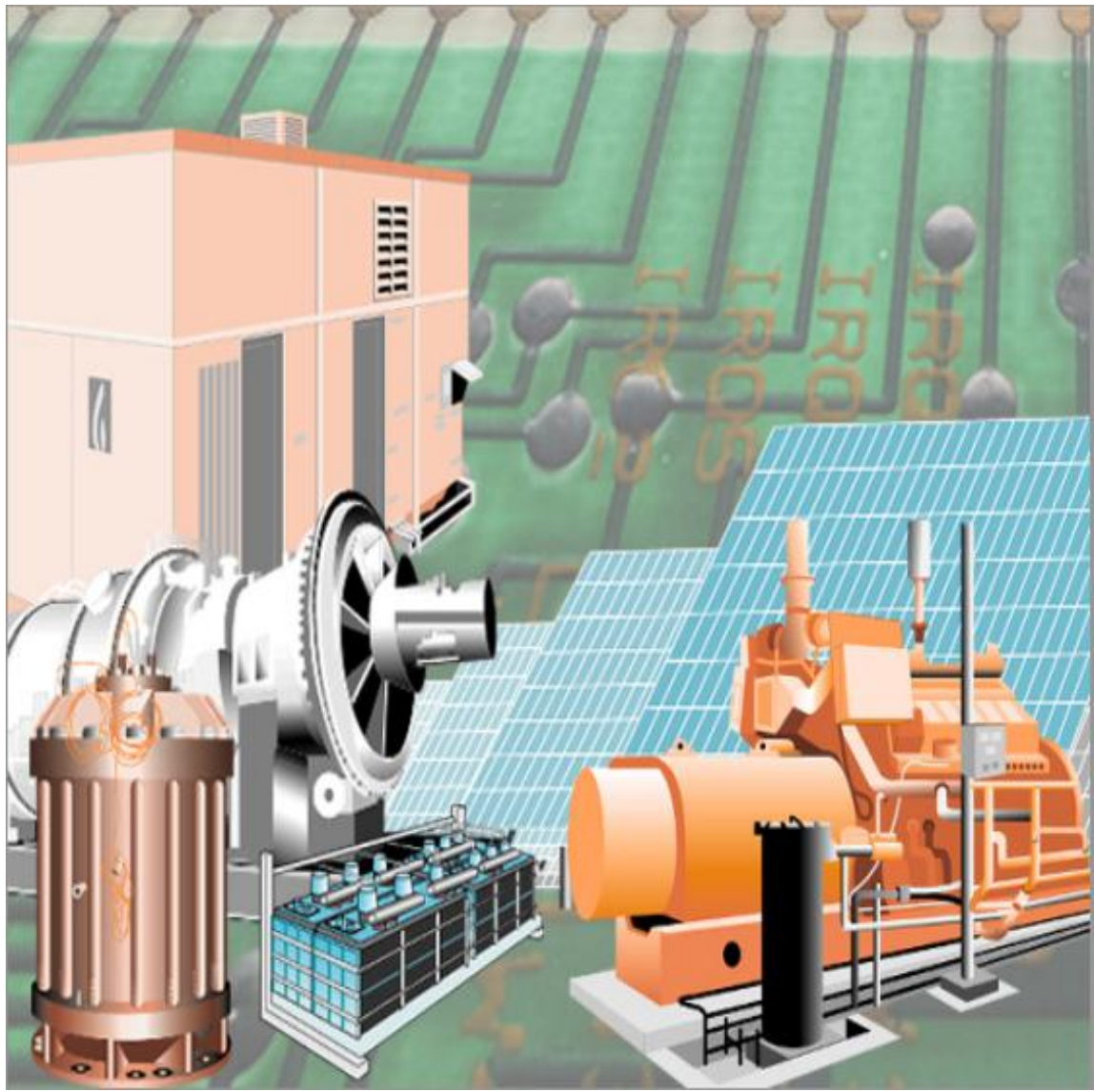
Distributed Energy and Power Conditioning Resources

Generators

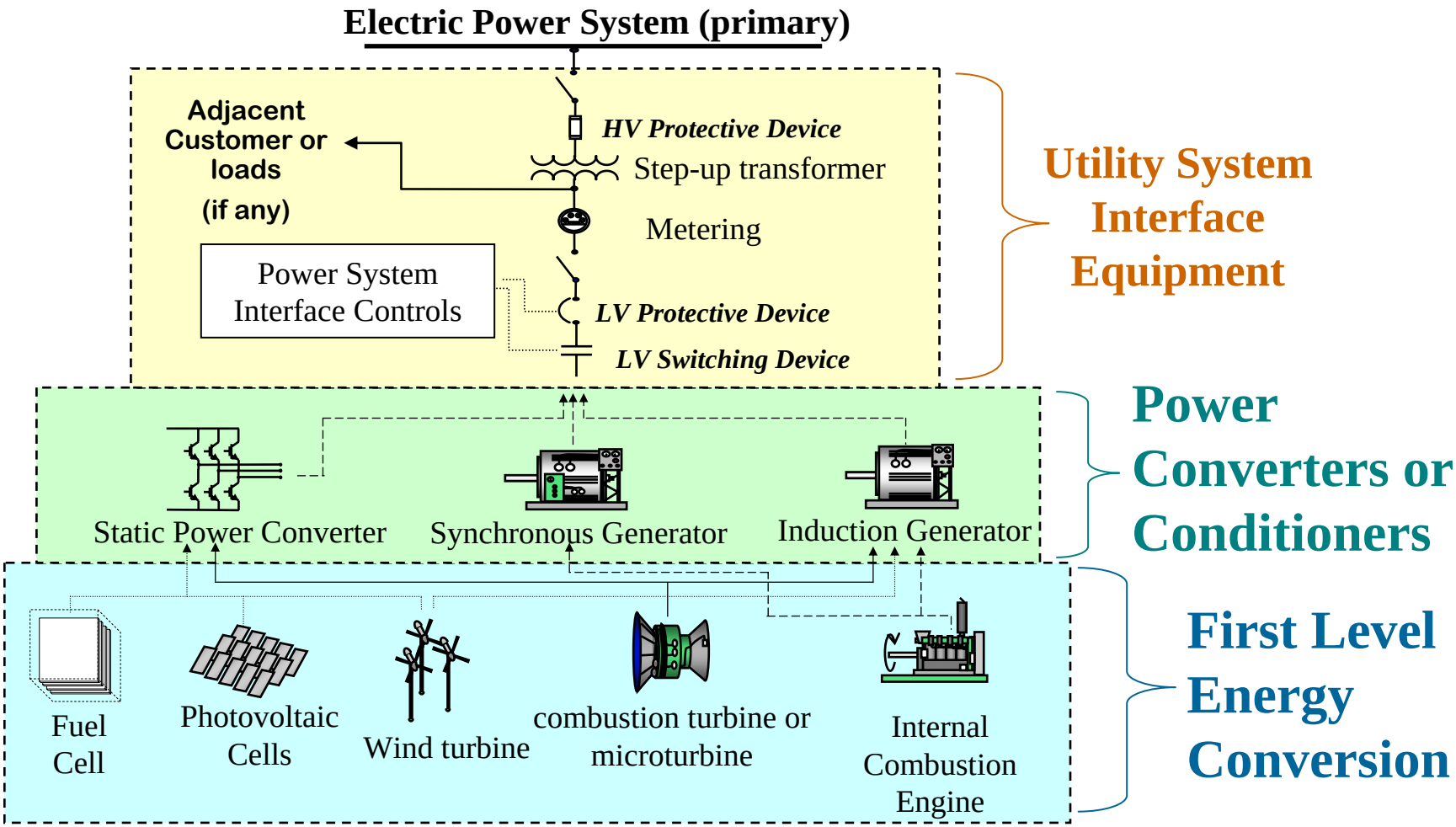
- IC Generators
- GT Generators
- Micro turbines
- Small wind turbines
- PV systems
- Fuel cells

Storage Devices

- Batteries
- Capacitors
- Flywheels



Three Levels of Typical DG Plant



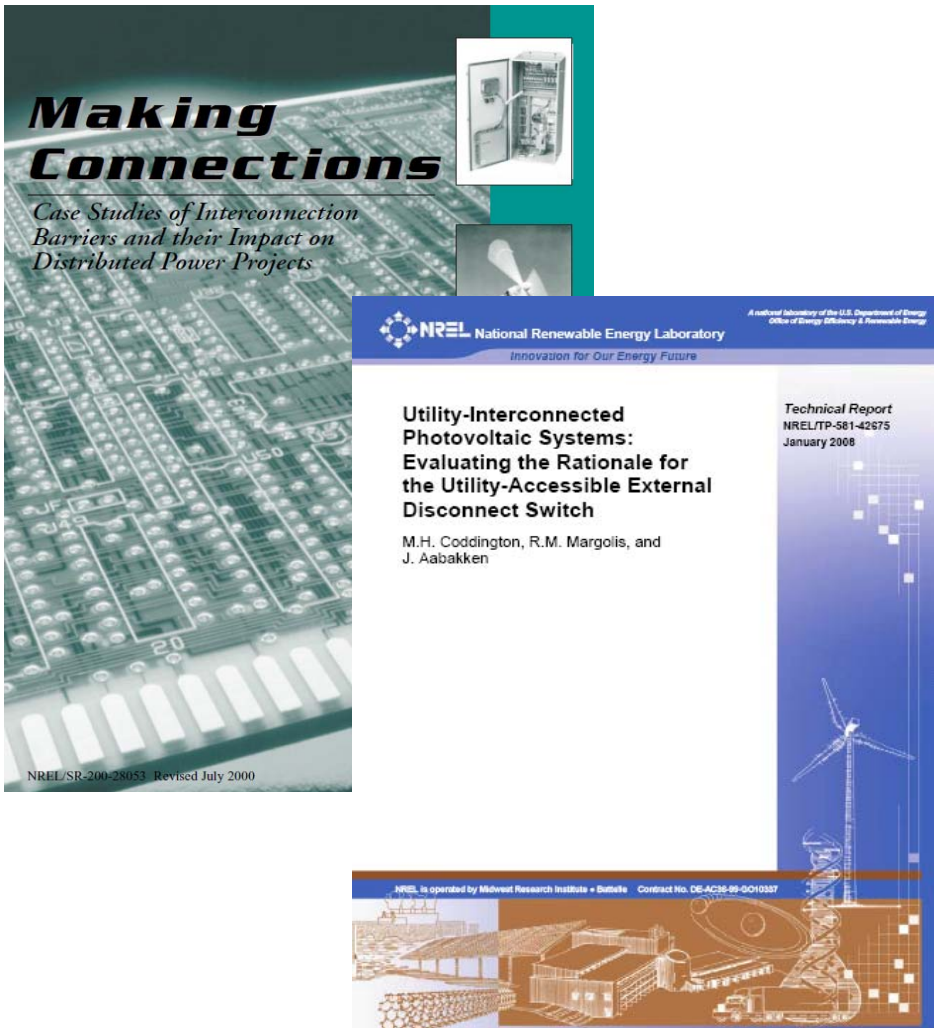
Early work on inverter integration with the Grid

Codes and Standards

- NEC Article 690, PV System Installations, 1984
- IEEE 929 - for Utility Inter- face of PV Systems, 1988
- IEEE 1001 – Recommended Practice for Grid “Integration”, 1989
- IEEE 1547 and UL 1749 – Std Interconnection, 2003

Tom Key, Sandia Lab, July 1987

Pressure to make uniform requirements, codes and standards (for connection and installation)



NEC 690 – *Key High Points for Interactive Non-Backup PV Systems*

- 690.2… *Definitions*
- 690.4… *Installation*
- 690.5… *Ground Fault Protection*
- 690.7… *Maximum Voltage*
- 690.8… *Circuit Sizing & Current*
- 690.9… *Overcurrent Protection*
- Section III… *Disconnecting Means*
- Section IV… *Wiring Methods*
- Section V… *Grounding*
- Section VI… *Marking*

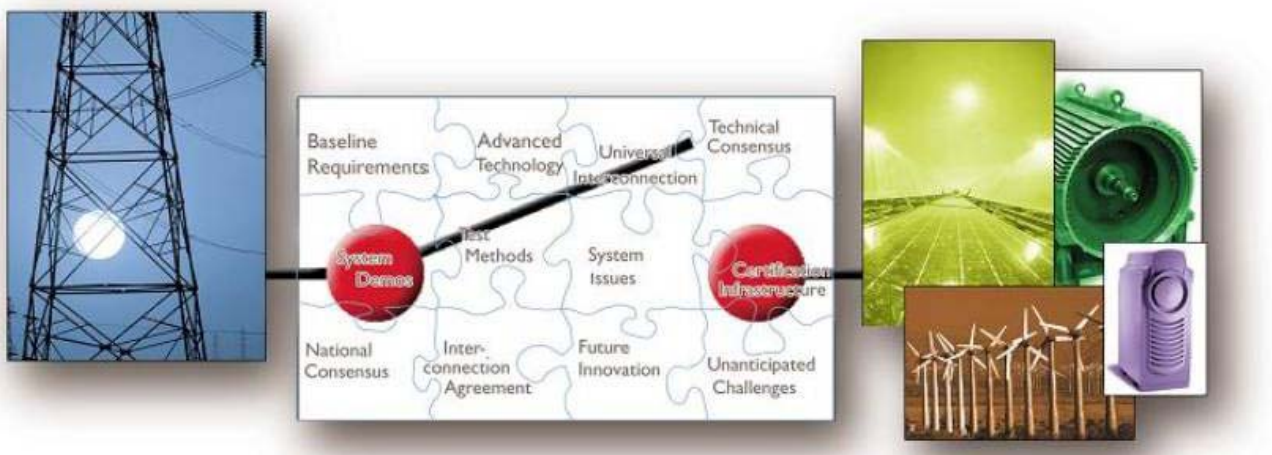
2005 Energy Policy Act requires use of IEEE 1547 Interconnection Standard

Concept Check

DG "Integration" is larger picture dealing with the whole power system and total aggregate affects of DG on power system design, planning and operations… voltage control and energy.

VS

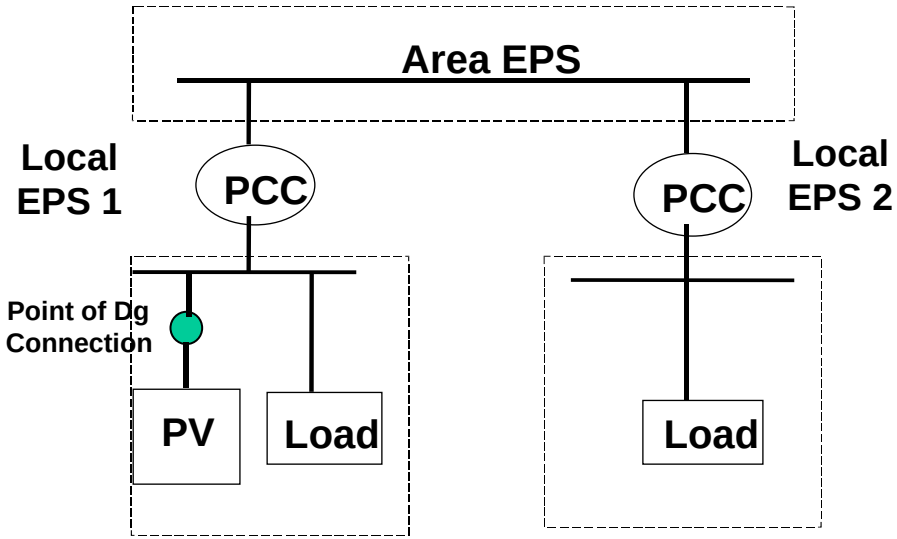
DG "Interconnection" Deals with the relays, switchgear, grounding and interface issues that are specific to the DG at the DG PCC. A subset of the idea of integration, and also the focus of IEEE 1547



IEEE 1547 Assumes DG is Not Significant

Significance Factors

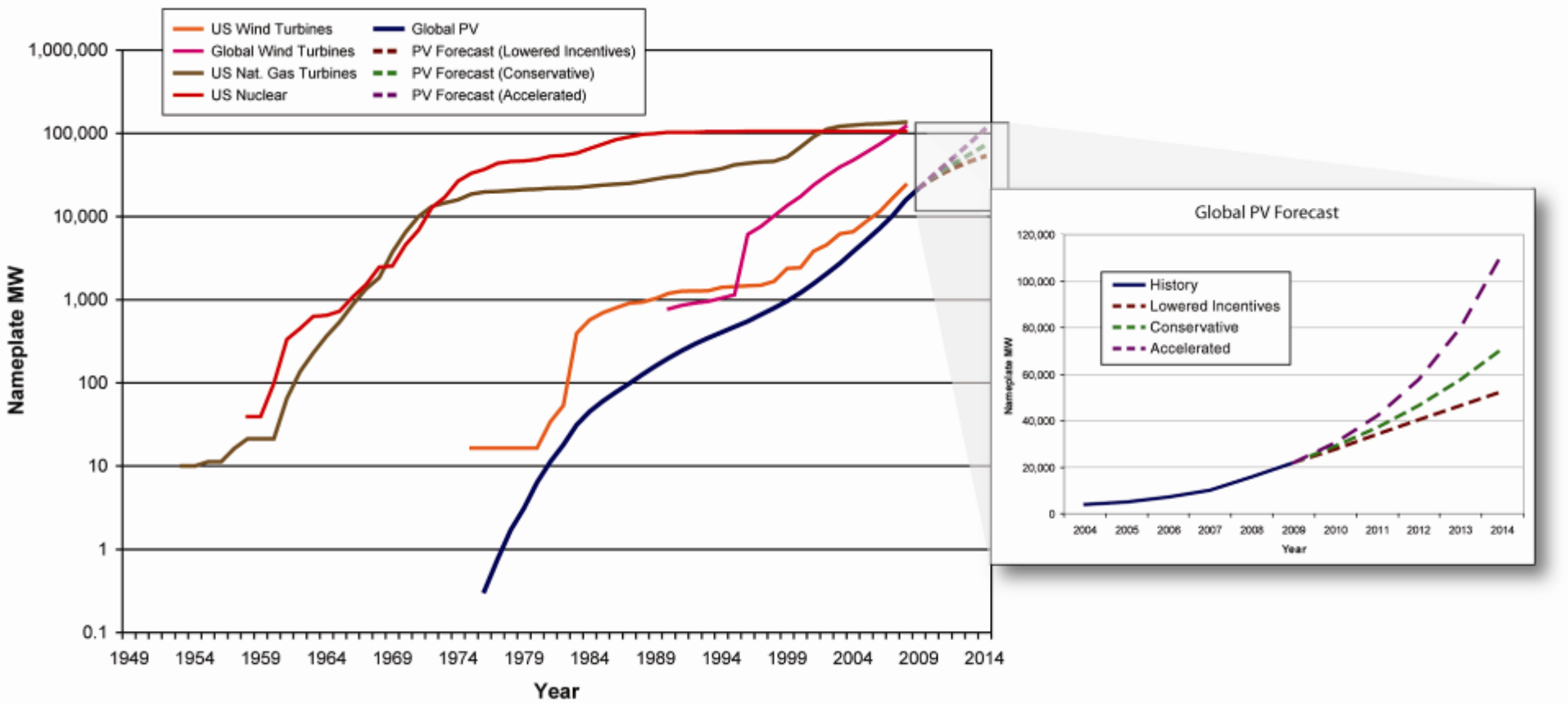
- Connection Point
  - Relative Size
  - Feeder Loading
- Aggregate Total kVA
  - Penetration Levels



$$\text{Contribtution Ratio} = \frac{\text{Aggregate kVA}_{sc} \text{ of DR on Feeder}}{\text{System kVA}_{sc}}$$

$$\text{Penetration Factor}_{\textit{Total feeder load}} = \frac{\text{Aggregate DR rating on Feeder in kVA}}{\text{Peak Load on Feeder in kVA}}$$

Adoption Rates for Select Generation Technologies with Global PV Forecast



Sources: EIA (U.S. Nuclear, Nat. Gas, and Wind), European Wind Energy Association (Global Wind), and Navigant Consulting PV Service (Global PV, Historic and Forecasted).

Issues to be considered for High Penetration DG

- Role DG in voltage regulation, both steady state and dynamic?
- Best response to abnormal grid voltage, setting trip limits?
- Responsibility to prevent unintended islanding?
- Coordination with existing protection systems?
- Is DG negative load or a grid asset…adapting to changing conditions?
- Knowing weather to use central or distributed control and communication

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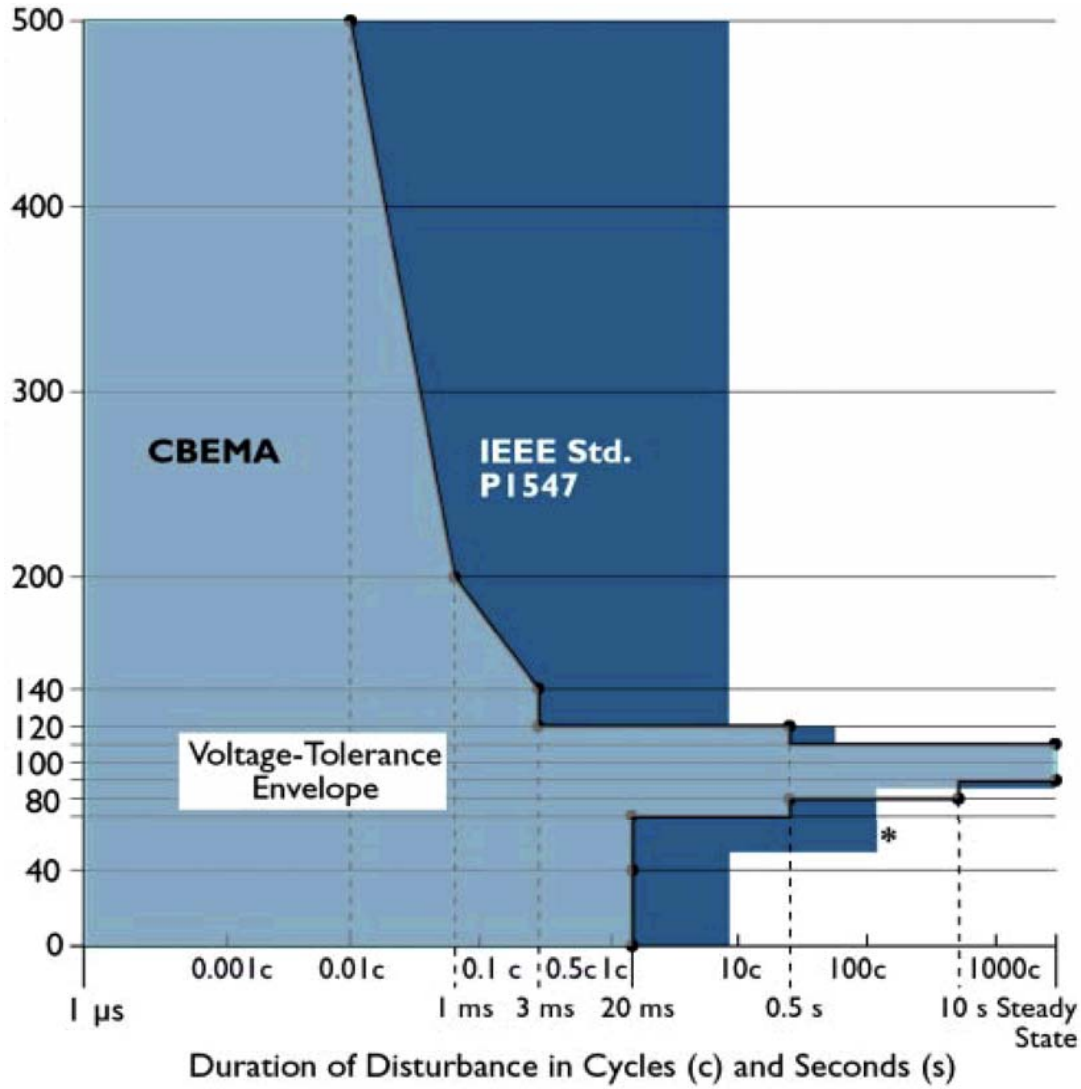
Under and Overvoltage Ride-Thru



Limits in IEEE 1547 compared the ANSI C47 voltage limits and to ride-thru expectations for typical computer loads (CEBMA Curve)

Anti-Islanding works well for individual DG

KEY: GRID-CONNECTED INVERTER POWER SYSTEMS

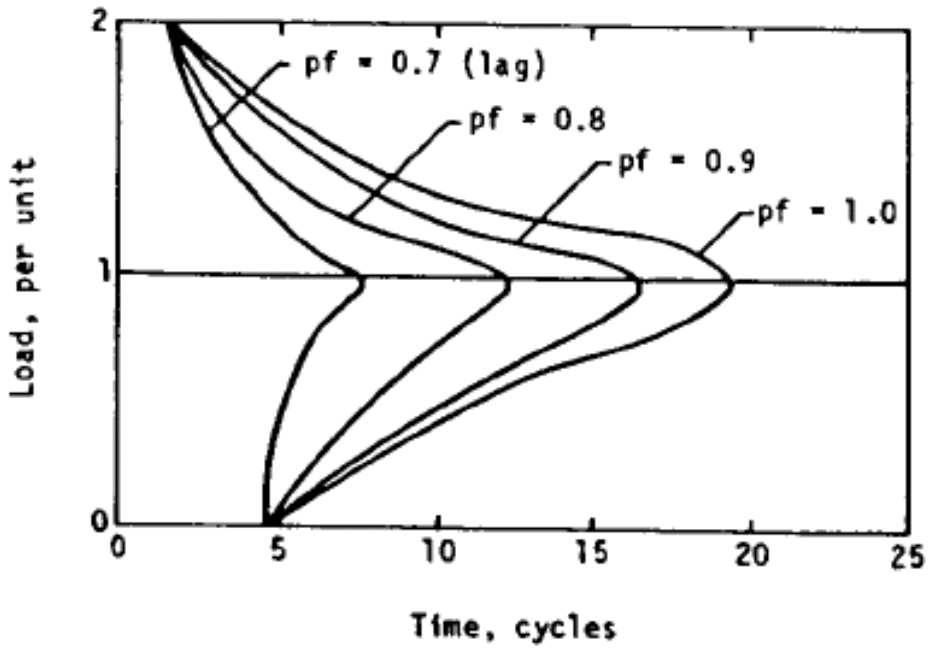
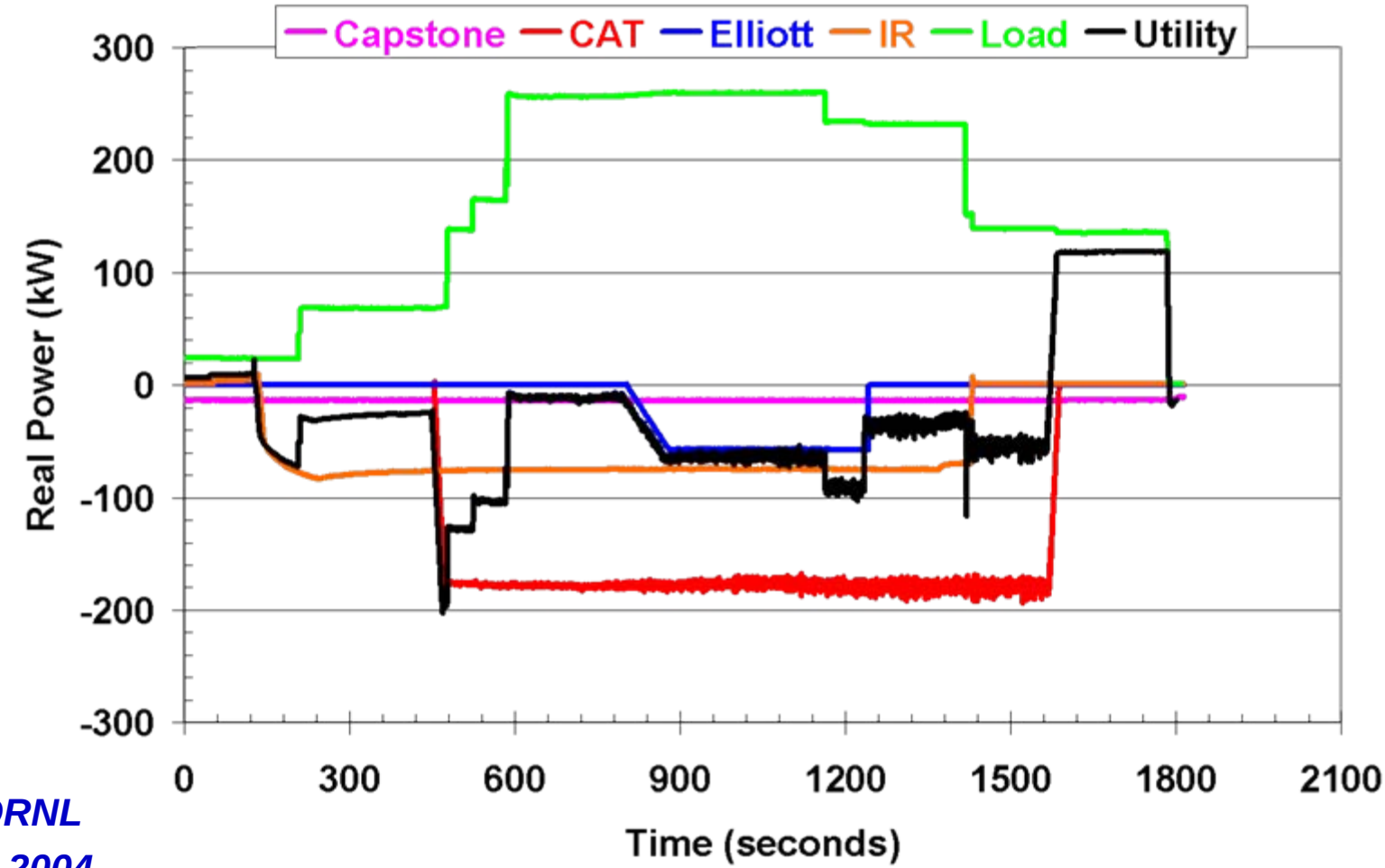


Fig. 15. Time to inverter shutdown versus local load conditions in per unit (inverter deisgned for unity power factor).

Early Inverter Test Results Sandia Lab 1982-83

Dynamic interactions of multiple DGs complicates quickly (anti-islanding???)



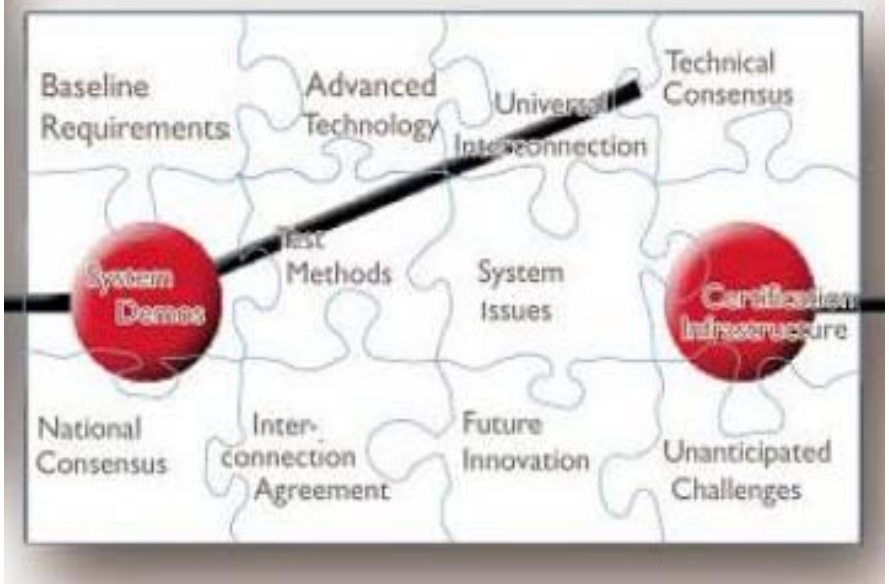
EPRI-ORNL Testing 2004

Need to Change the Rules for High Penetration

% of Generation	≤ 2%	≤ 10%	≤ 30%	100%
Grid Penetration Scenarios	I. Low-numbers and level of PV with relatively stiff grid connection	II. Moderate-level of PV with relatively soft grid connection	III. High-level of PV with capacity of grid less than the load demand	IV. PV operates part time as an island or micro-grid
PV Impact and its Role in the Grid	Very low, not significant to grid operation	Non critical, can affect distribution voltage near PV	Critical to power delivery and meeting demand	Primary power source for stand alone operation
Interconnection and Integration Objectives	Non interference, good citizen and compatible	Manage any local distribution impacts	Engage PV for system operations and control	Rely on PV for stability and regulation
Rules/Standard Operating Procedures	IEEE 1547-2003 current practice radial feeders	Modified 1547, add network and penetration limits	New rules include operation and grid support requirement	Standalone rules that are system dependent
Main Concerns with-respect-to system dynamic grid impacts	- Voltage and current trip limits, - Response to faults - Synchronization	- Interfere with regulation, - Recovery times, - Islanding - Coordination.	- Availability - Regulation provided - Ramping response - Interactions of machine controls	- Availability - Load following - Voltage control - Normal and reserve capacity

.....Transitions On- and Off-Grid.....

Questions



Tom Key

865-218-8082

tkey@epri.com