

ACHIEVING 100% RENEWABLE GRID- TECHNOLOGY VIEW

PENINSULA CLEAN ENERGY

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PRADEEP GUPTA

VARIABLE RENEWABLE ENERGY (VRE)

- Annual VRE penetration level = Fraction of annual energy (kWh) met by VRE
- Instantaneous VRE penetration level = Fraction of instantaneous power (kW) met by VRE at any point in time.

DEALING WITH VARIABILITY AND UNCERTAINTY

- Electric load is highly variable.
- Conventional generators can easily change power output to meet load.
- Wind and solar have uncertain power output determined by local weather.
- Greater grid flexibility required as VRE increases.
- VRE generators (solar and wind) are highly correlated geographically so larger net load ramps in the evenings

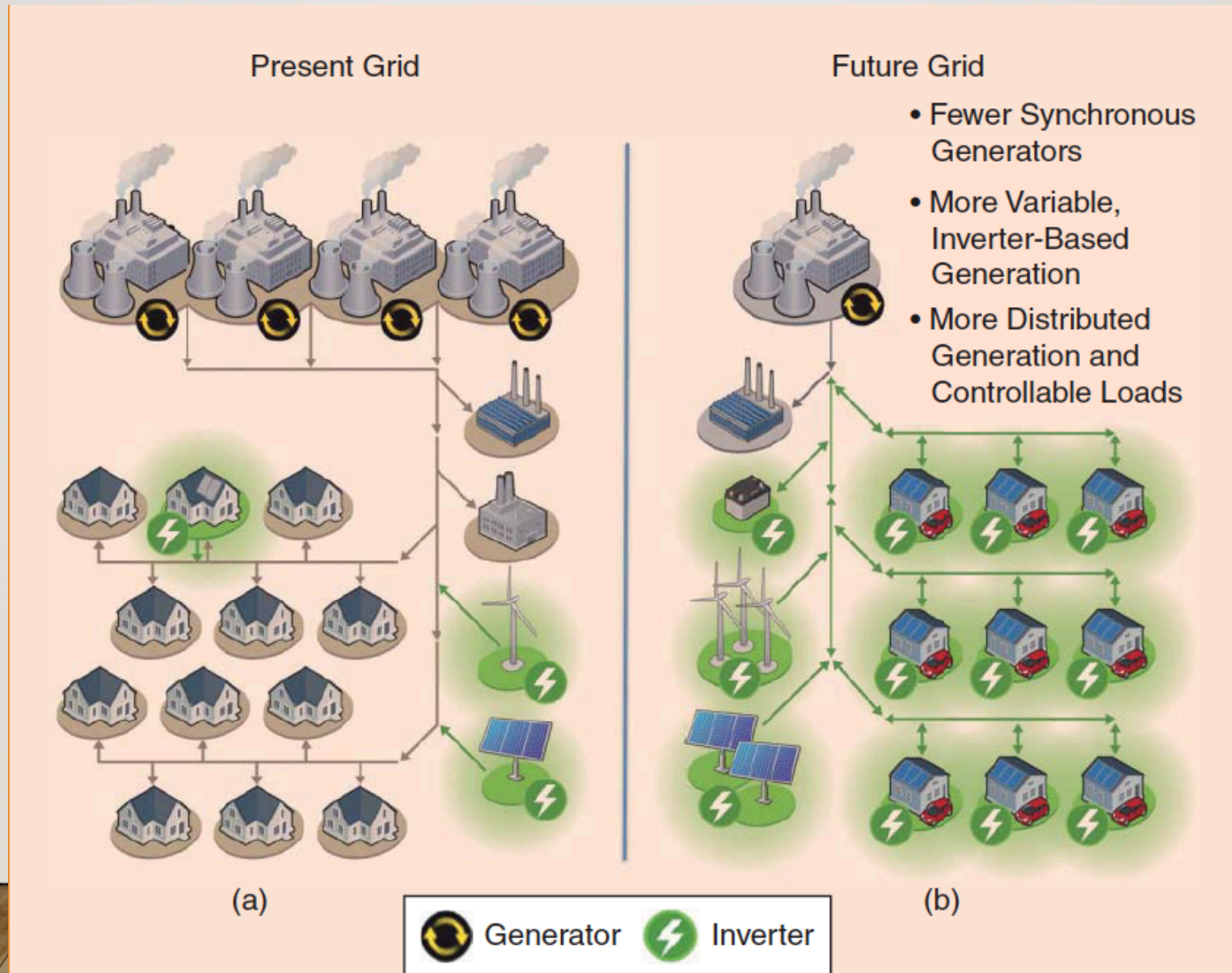
POSSIBLE SOLUTIONS

- Sufficient geographic diversity of VRE sites.
- Expansion of transmission system to move VRE power to areas needing power.
- Greater coordination among balancing authority areas.
- Energy storage from times of excess VRE energy to times of need.
- Several storage technologies- pumped hydropower fleet, compressed air energy storage, batteries. Demand response technologies to shift load demand.
- New loads that have flexibility in use pattern- EV charging.

HIGHER VRE IMPACTS GRID RELIABILITY

- Current grid is dominated by central station conventional synchronous generators
- Higher VRE penetration results in higher instantaneous VRE.
- Higher than 50% instantaneous VRE will change to inverter based grid.

What is Inverter Dominated Grid ?




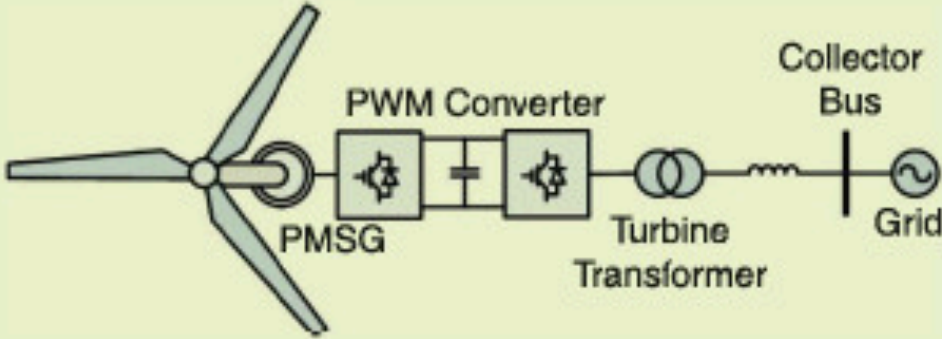
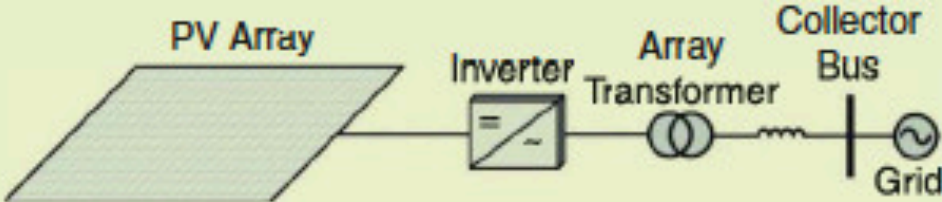
SYNCHRONOUS GENERATORS CHARACTERISTICS

- Synchronous generators create ac electricity at fixed frequency 60 Hz.
- Once synchronized to the grid, the output is controlled easily:
 - Real power (frequency) output by controlling shaft torque.
 - Reactive power (voltage) by controlling so called field current.
- Reliable grid operation (freq and voltage) obtained by automatic generator controls (AGC).
- Synchronous generators have built in synchronizing torque which stabilizes the system after a system disturbance.

SYNCHRONOUS GENERATORS CHARACTERISTICS

- Physics- huge mechanical inertia of rotors and turbines store significant kinetic energy.
 - Interconnected system of generators are able to withstand fluctuations in net load and generations with small changes in sytem frequency.
- Frequency deviation is inversely proportional to net inertia.
- Net inertia, AGC and synchronizing torque allows mitigation of large real and reactive power imbalances in the grid.
- This fundamentally important characteristic will change with inverter based generation.

VRE TECHNOLOGIES GRID INTERFACE

Generation Type	Inertia	Active Power Control	Reactive Power, Voltage Control	Fault Ride-Through
Conventional synchronous generation 	√	√	√	
Wind turbine generator with full-size power conversion 	√*	√	√	√
	√**	√	√	√

VRE TECHNOLOGIES GRID INTERFACE

- Power electronics interface called inverters.
- Converts DC to AC
- Manages flow of energy by controlling switching semiconductor devices very rapidly.
- Strictly electronics- no rotating masses or mechanical components.
- Battery storage is not VRE but is needed for energy balance in high VRE systems and uses inverters.

CONTROLLERS FOR VRE TECHNOLOGIES

- Closed loop controllers
 - Digital controllers
 - Processing real time measurements
 - Chosen control strategy dictates electrical dynamics during disturbances not the physical properties.
- Two classes of inverters:
 - Grid following
 - Grid forming

GRID FOLLOWING INVERTERS

- Manipulated electronics to inject current in to the grid that tracks the sinusoidal grid voltage, or “follows” the voltage at its terminals.
- Pre assumption: “stiff” ac voltage with minimal voltage and frequency deviations is maintained.
- Historically this assumption held well with low VRE.
- But with high VRE with grid following inverter dominated grid, it is not true.

NEXT GENERATION GRID FORMING INVERTERS

- Challenges to be addressed
 - Will be realized gradually over years as synchronous generators are replaced
 - Smaller in power rating so large population- millions
- Characteristics:
 - Compatible with existing systems
 - Decentralized to reduce fast communications requirements
 - Able to operate without synchronous generators
 - Advanced control methods for active power, reactive power and power quality

NEXT GENERATION GRID FORMING INVERTERS

- Approaches
 - Droop control
 - Virtual synchronous machines with inertia
 - Emerging synchronization of coupled oscillators with digital control.

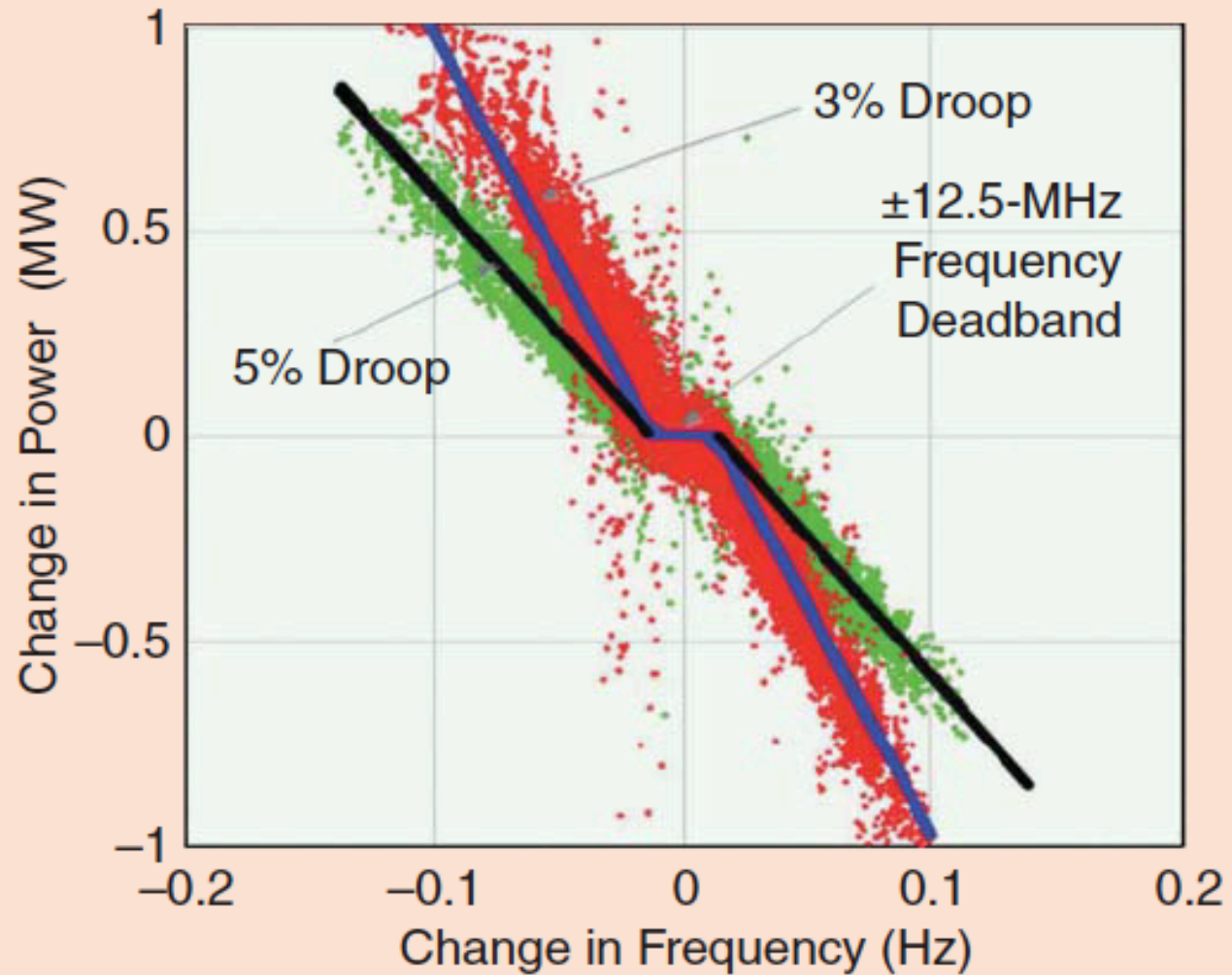
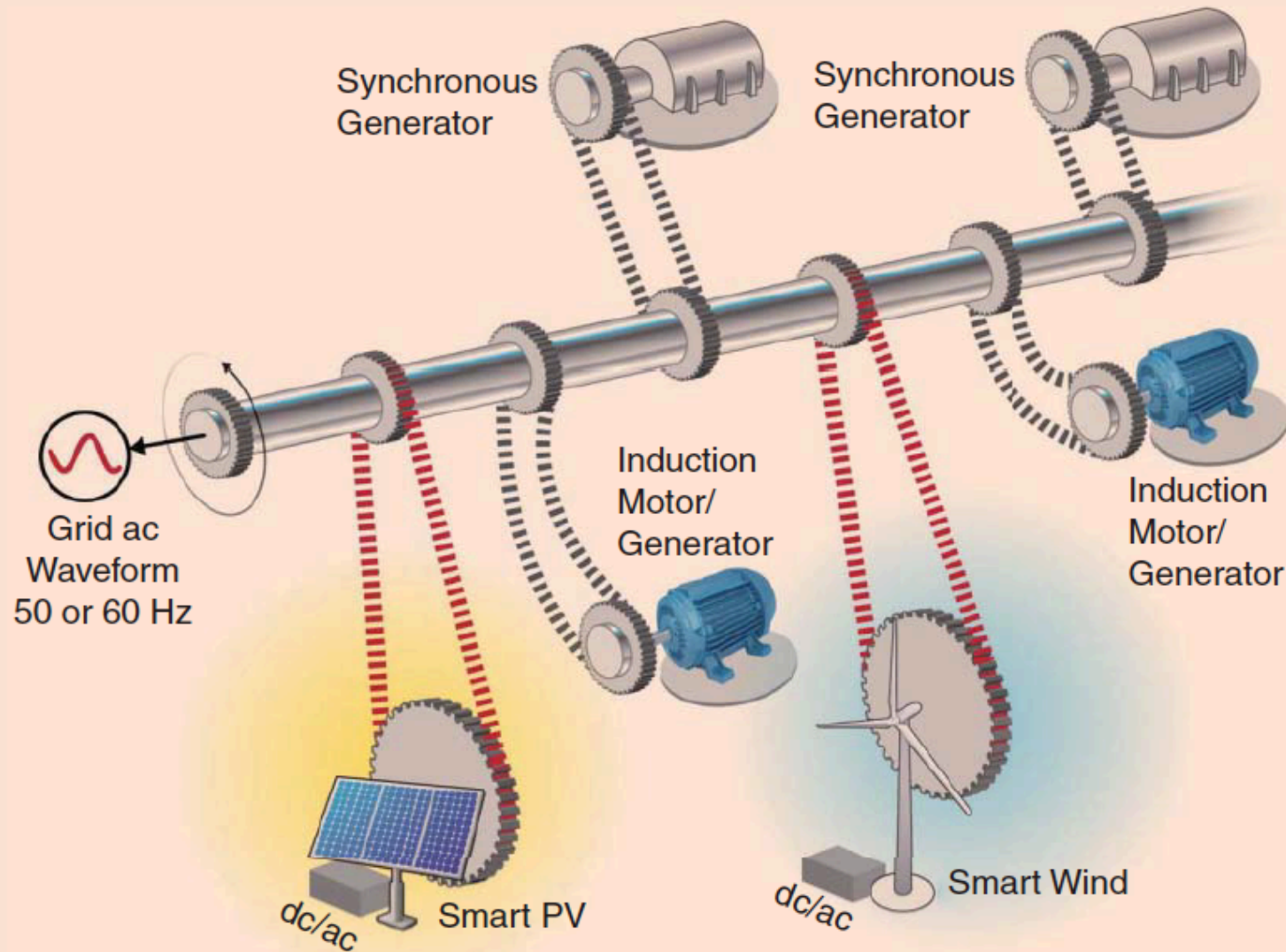


figure 10. A PV plant providing primary frequency response (3% and 5% droop).

POWER SYSTEM STABILITY



NEW PILOT PROJECTS AT SCE

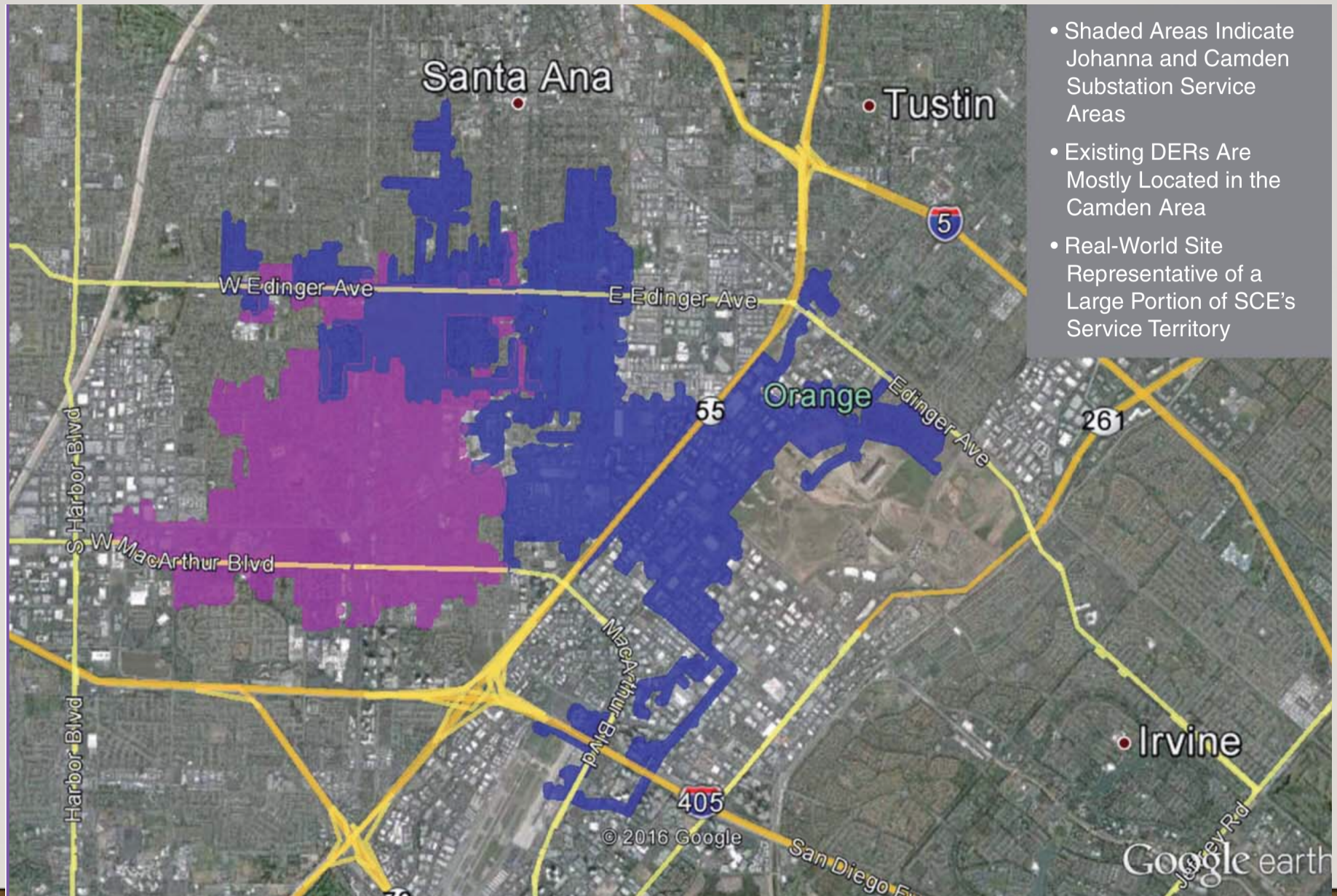
- The Advanced Research Projects Agency-Energy (ARPA-E) Network Optimized Distributed Energy Systems (NODES)
 - **GE** Global Research's **Synthetic Reserves** from Aggregated Distributed Flexible Resources project
 - **National Renewable Energy Laboratory's** project, Real-Time Optimization and Control of Next-Generation Distribution Infrastructure, that unifies real-time **voltage and frequency control at the home/DER controllers' level** with network-wide energy management at the utility/aggregator level.
 - **Pacific Northwest National Laboratory's** Multi-Scale **Incentive-Based Control of Distributed Assets** project will develop and test a hierarchical control framework for coordinating the flexibility of a full range of DERs, including flexible building loads, to supply reserves to the electric power grid.

CALIFORNIA ENERGY COMMISSION SMART INVERTER FIELD DEMONSTRATION PROJECT

- EPRI/ SCE field testing of a standard modular interface of inverters with any communications protocols.
- SUNSPEC/ SCE project to demonstrate the ability of residential DER assets to provide ancillary grid services while being managed through an aggregator.

CPUC/DOE/CEC/SCE- INTEGRATED GRID PROJECT

1. SP1: Substation and Distribution- better state estimation by data, monitoring sensors
2. SP2: Distributed Volt/VAR Control (DVVC)- CEC Smart Inverter Project- controlling VAR at DERs.
3. SP3: Distributed Energy Management- controlling DER and storage to avoid overloads.
4. SP4: Virtual Microgrid- control power flow on single point connection to the grid.
5. SP5: Incentive Mechanisms for customers to offer DER for aggregation.
6. SP6: Field Area Network- faster communications network to collect process data
7. SP7: Cybersecurity
8. SP8: Integration- integration of applications from various vendors
9. SP9: Distributed Optimized Storage- make storage visible to grid operator, available to wholesale market when not needed.
10. SP10: Beyond the Meter- aggregation of DER behind the meter through web based network.



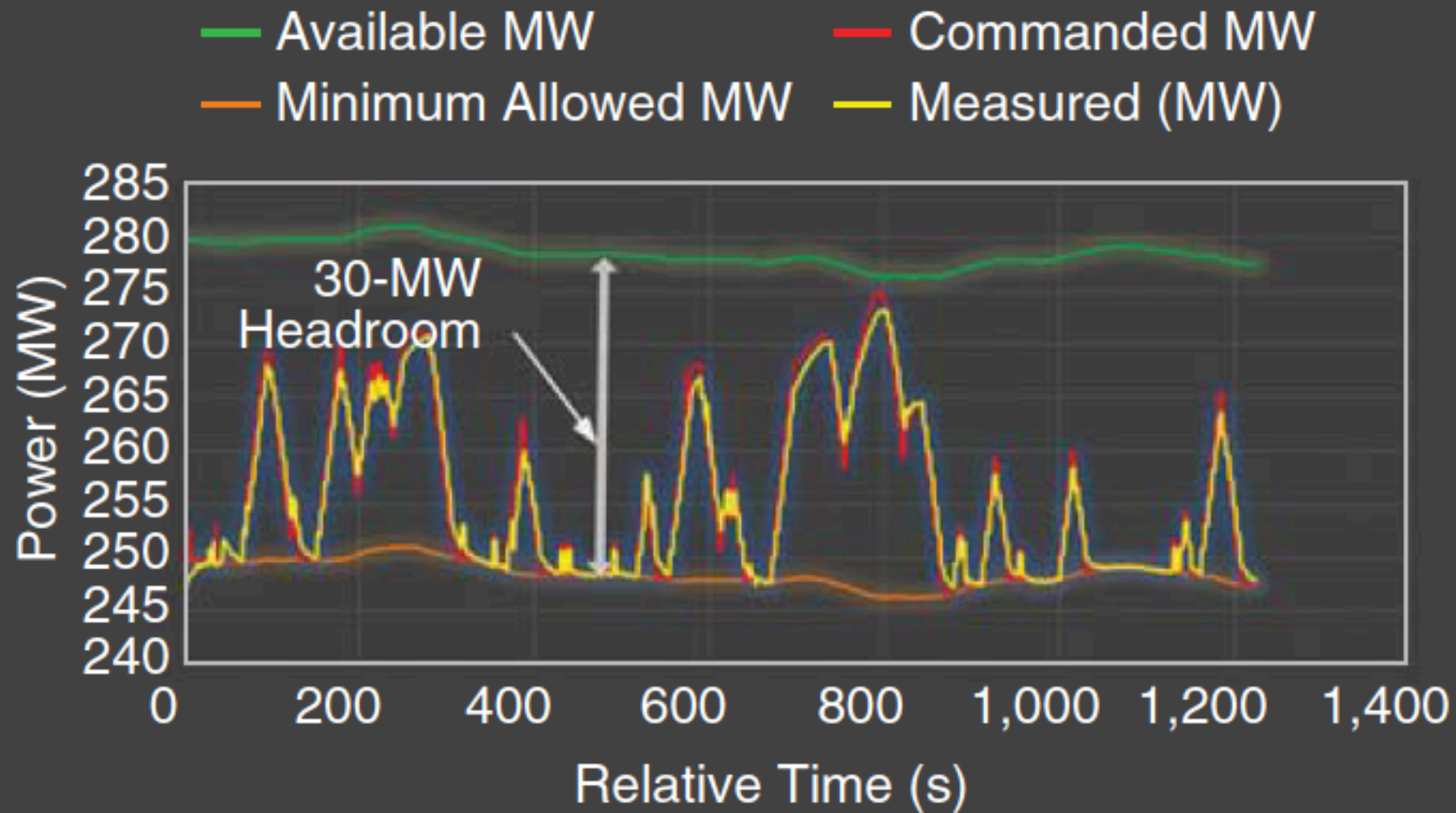


figure 4. The results of a midday AGC test using a First Solar 300-MW PV plant in the CAISO service area.

CONCLUSIONS

- 100% VRE poses technology challenges.
- 100% VRE grids will require
 - Better ways to match supply demand
 - New systems with high VRE compatible with existing systems
 - Design of inverter based systems to provide grid services for system stability
 - Design to acknowledge large number of inverters.
- With proper controls. Inverter based systems can maintain and improve system stability.
- Improved coordination- law makers, utilities, resource providers, customers, vendors of hardware and software.
- CEC/ PUC/ DOE/ SCE field projects testing new technologies.