New Electric Grid Technologies for Renewable Generation Deployment

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By *Merwin Brown, PhD*

Program Director, Electric Grid Research

University of California

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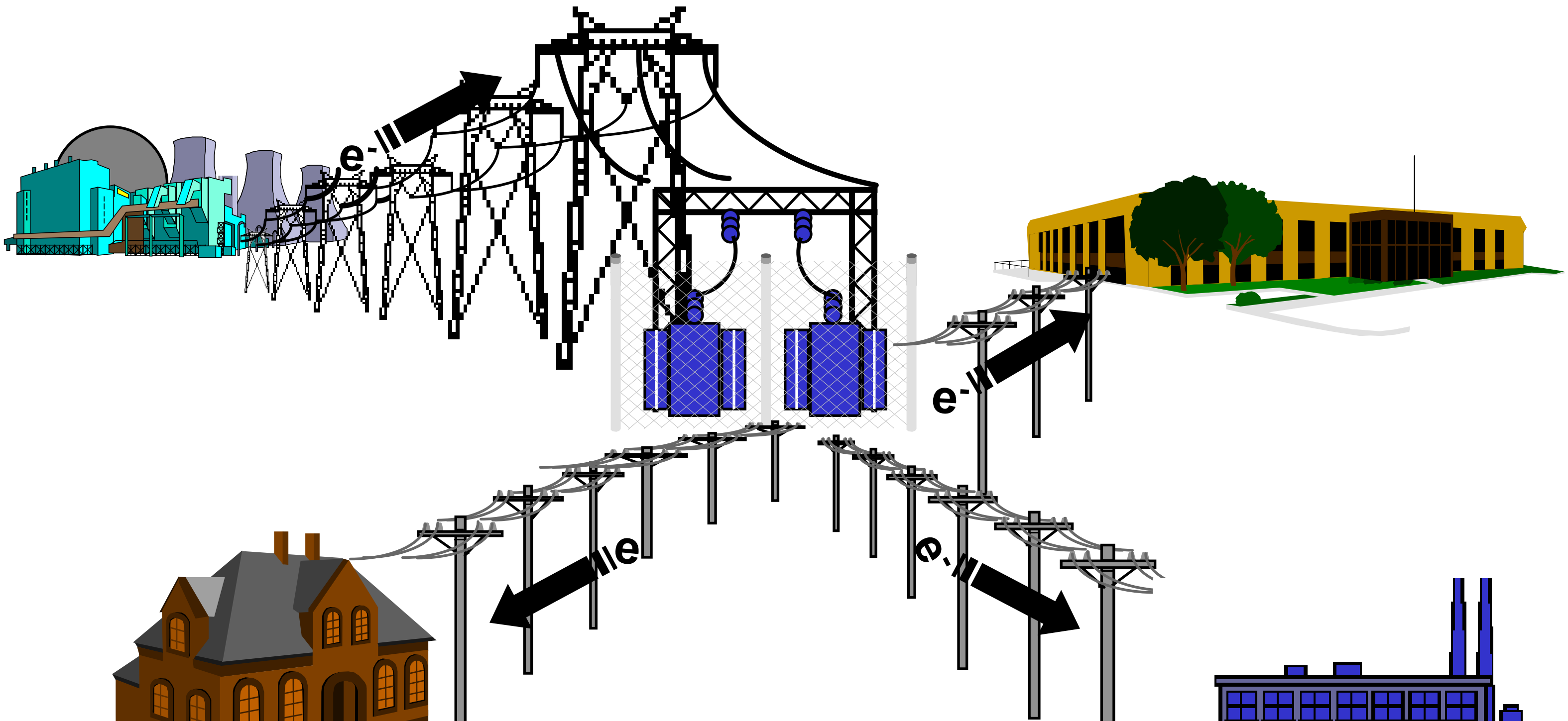
For most of the 20th Century, transmission had a relatively simple role moving electricity from central power plants to the consumers.



Transmission system behavior was predictable, and under the close control of an operator - much like conducting an orchestra. ♬ ♬ ♬

But conducting the 21st century electric grid is becoming a more hair raising experience:

- Being connected to the world's largest machines, i.e., a multi-state, multi-country, brittle power grid
- Accommodating competitive wholesale power markets
- Serving growing and changing electric loads that are becoming part of the "orchestra"
- Dealing with economic and public policy pressures

Being instrumental for meeting aggressive renewable energy goals

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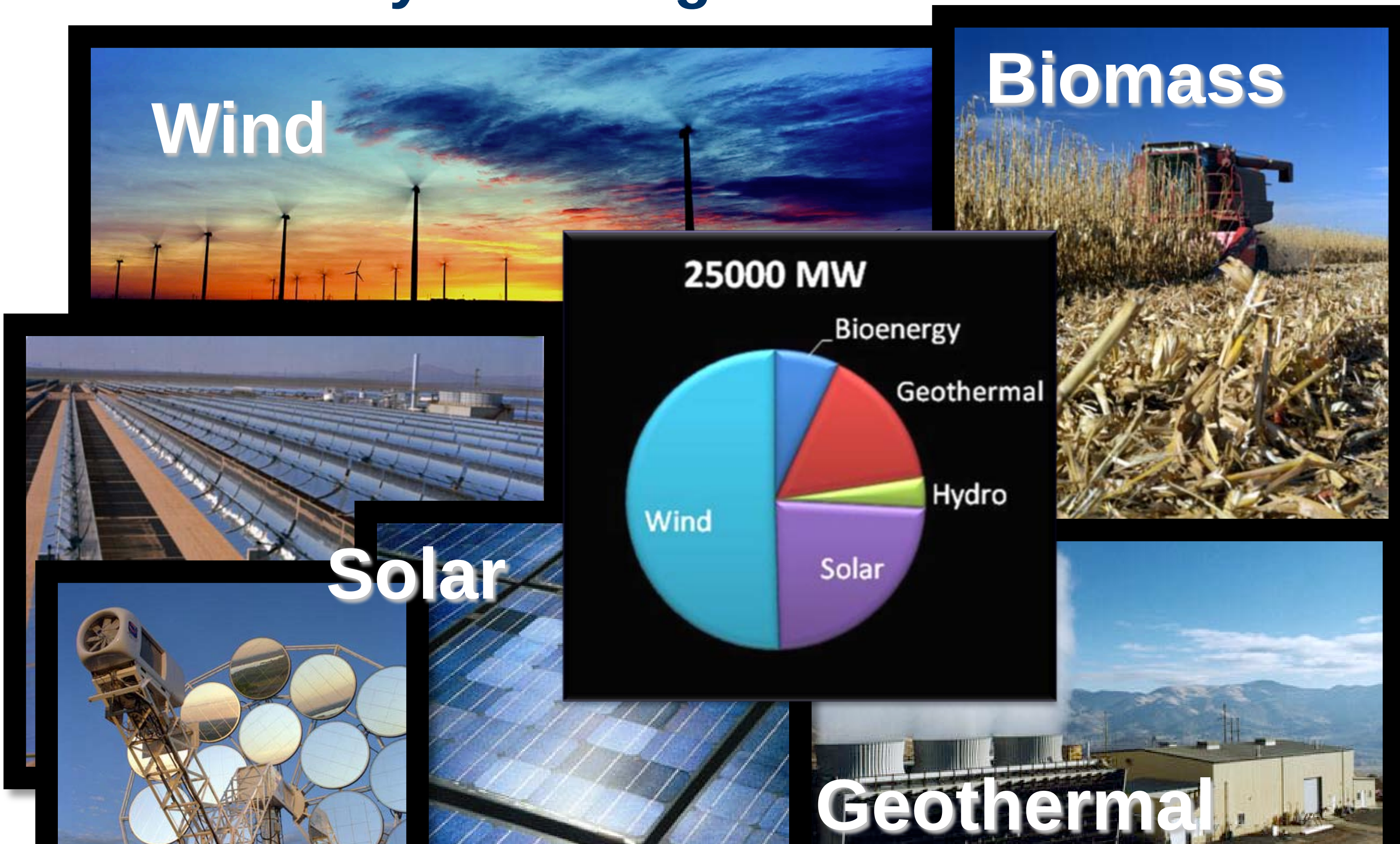
Renewable resources portfolio mix for 33% by 2020 might look like this…



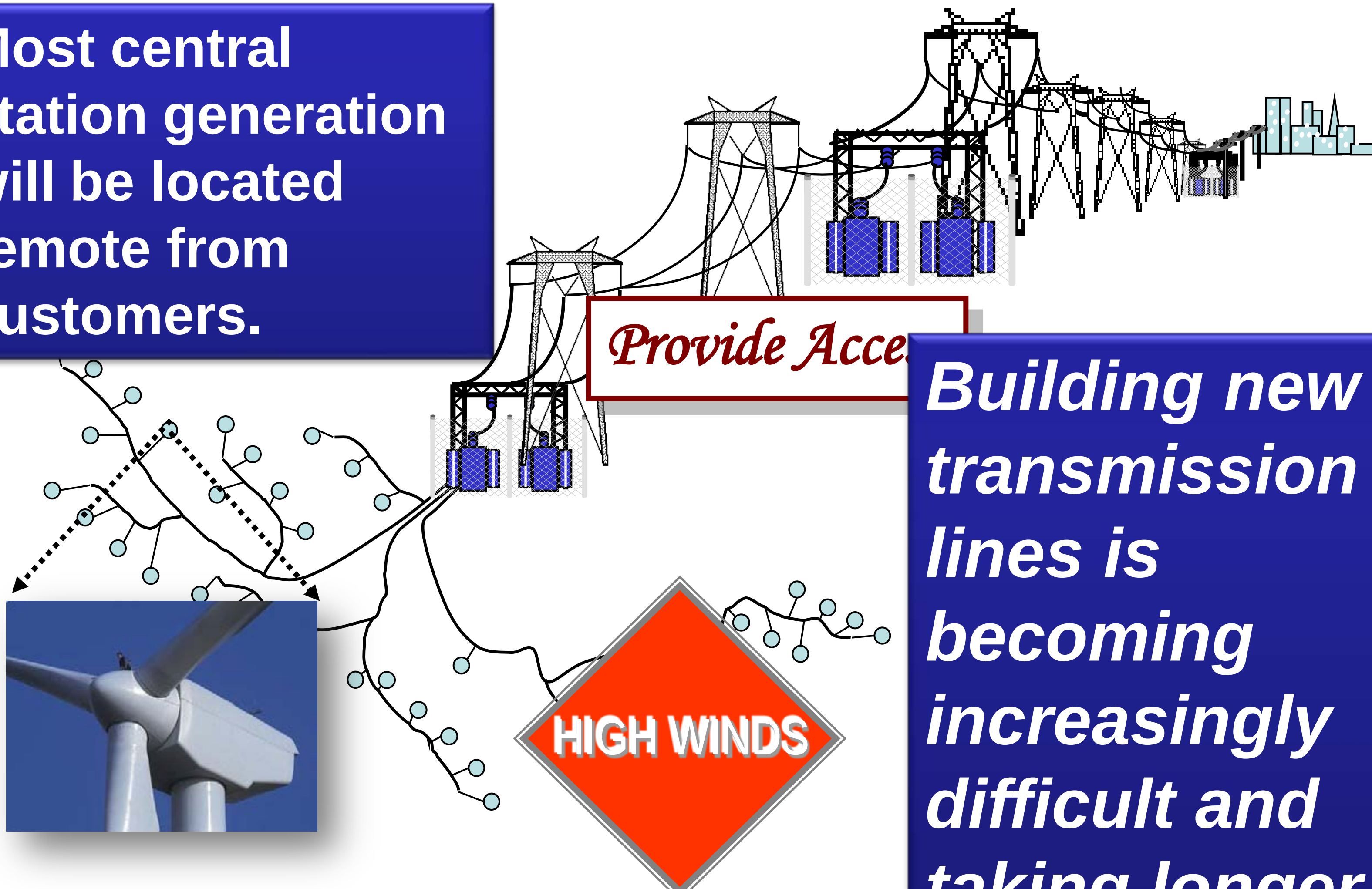
…And variable wind and solar resources will be a large part of the mix.

But to grid operators, 33% renewables looks more like this…

The Saga of Renewable Generation and Grid Integration reveals many challenges.

The Saga of Renewable Generation and Grid Integration

Most central station generation will be located remote from customers.



Building new transmission lines is becoming increasingly difficult and taking longer.

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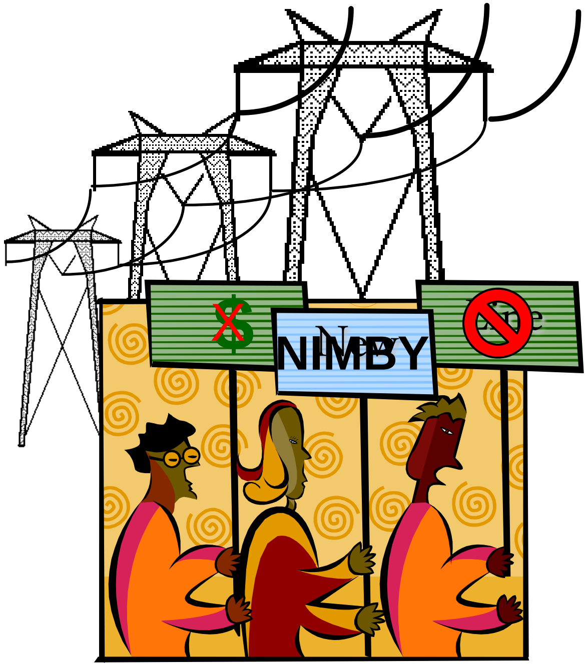


- **Proving need and value**
- **Distributing benefits & allocating costs**
- **Assessing and mitigating environmental, land use & aesthetic impacts**
- **Getting approval from multiple agencies and jurisdictions**

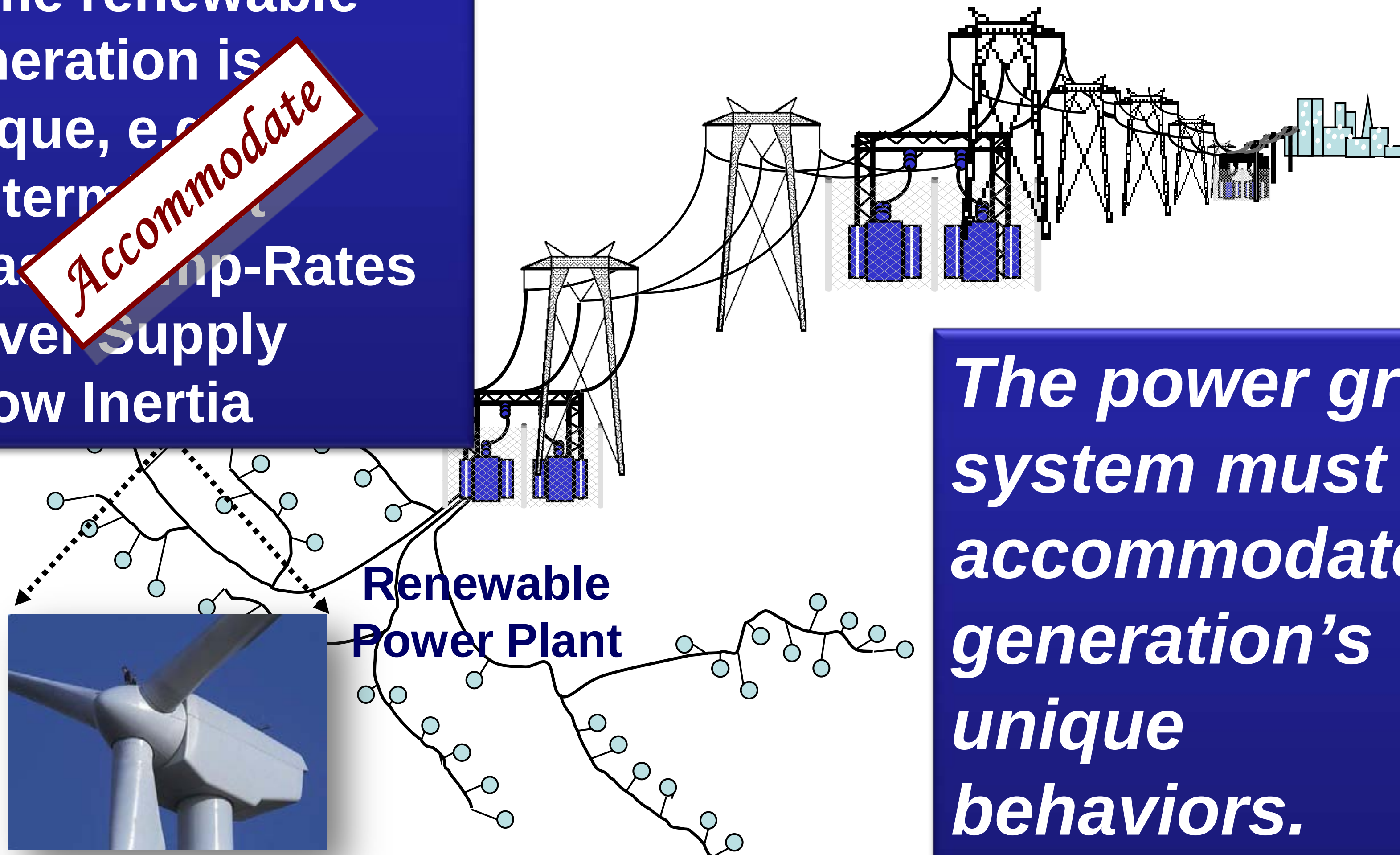
Delay in siting & building new transmission is often cited as major barrier to meeting renewable generation policy goals.

The Continuing Saga of Renewable Generation and Grid Integration

Some renewable generation is unique, e.g

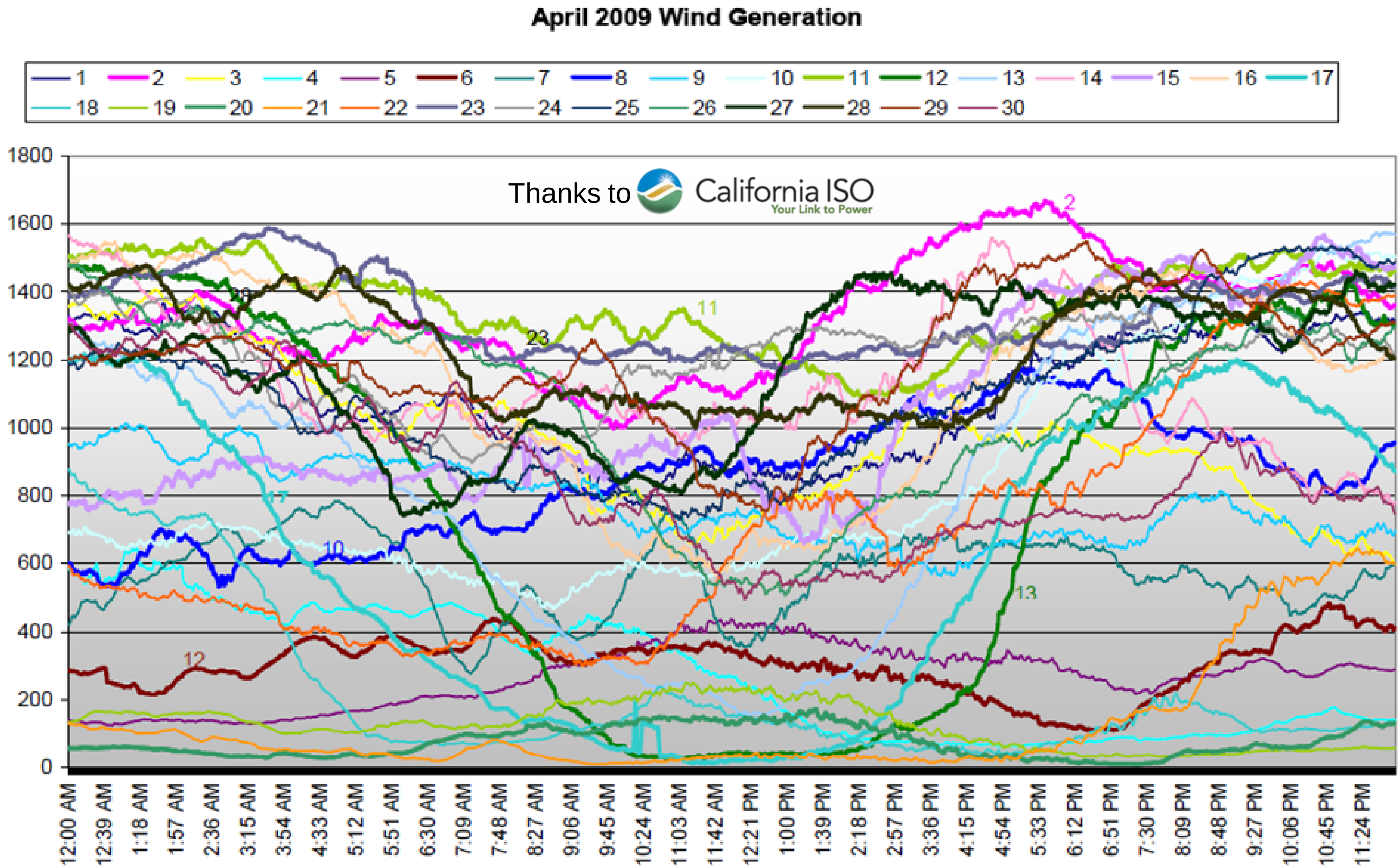
- **Interm t**
- **Fa mp-Rates**
- **Ove Supply**
- **Low Inertia**

Accommodate



The power grid system must accommodate generation's unique behaviors.

Wind generation can vary widely from day to day and hour to hour.



Wind generation is a challenge to forecast.

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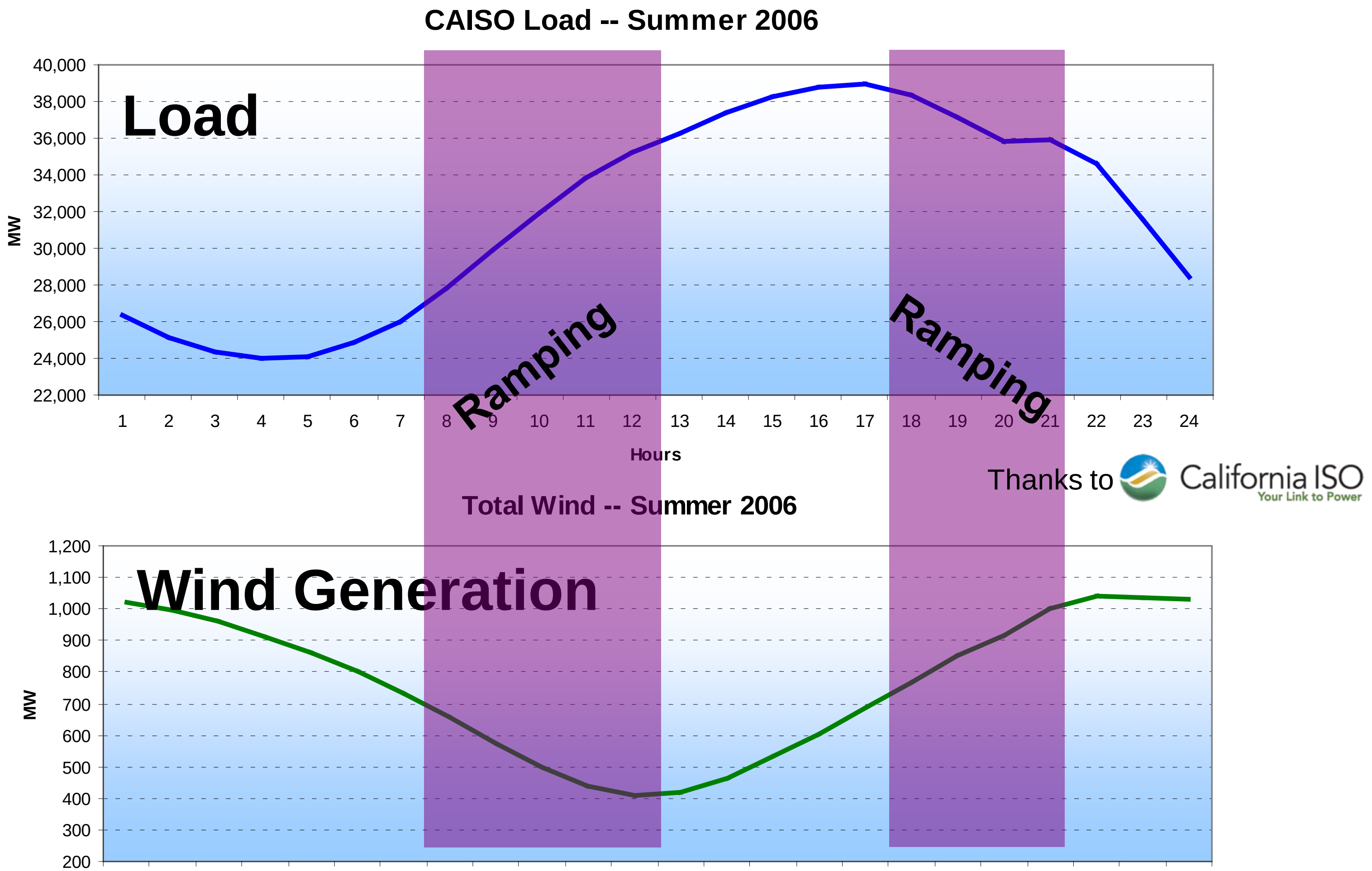
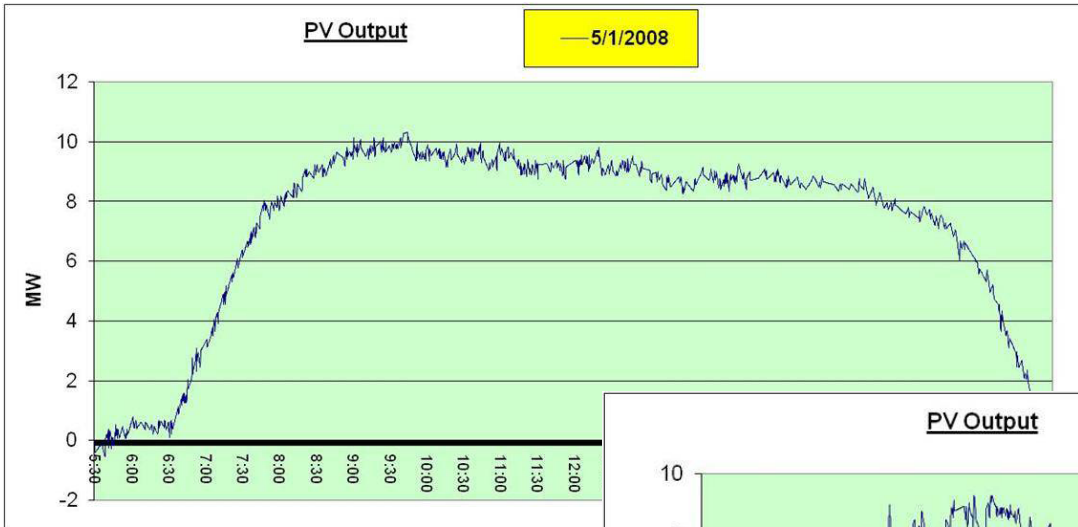
Typical load & wind profiles are almost inverse images.

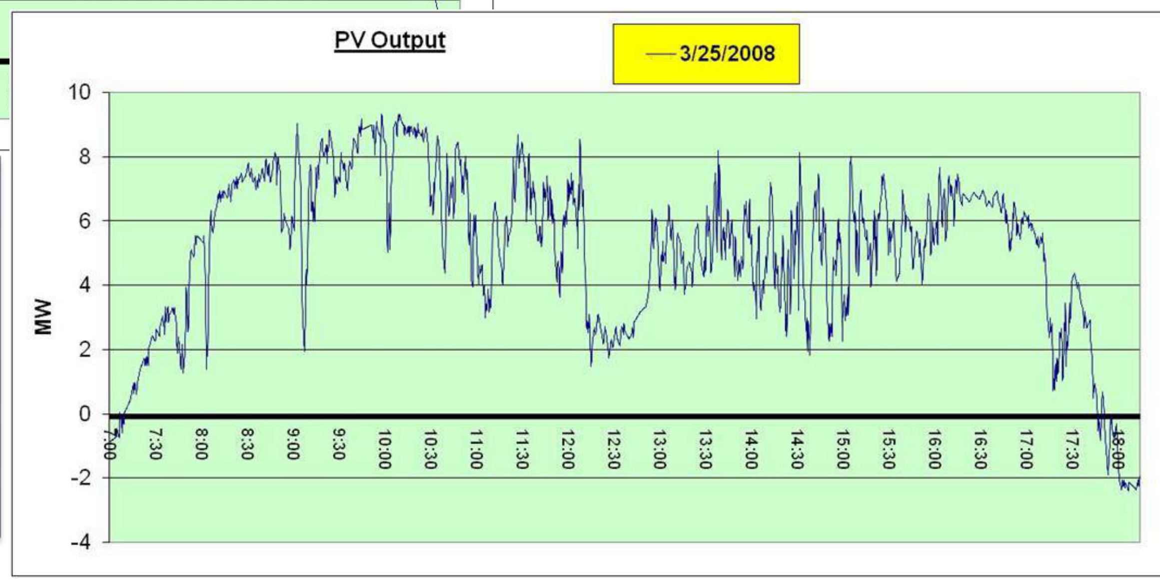


Creates issues with oversupply and load-following ramping.

Solar generation can vary widely from day to day and hour to hour.



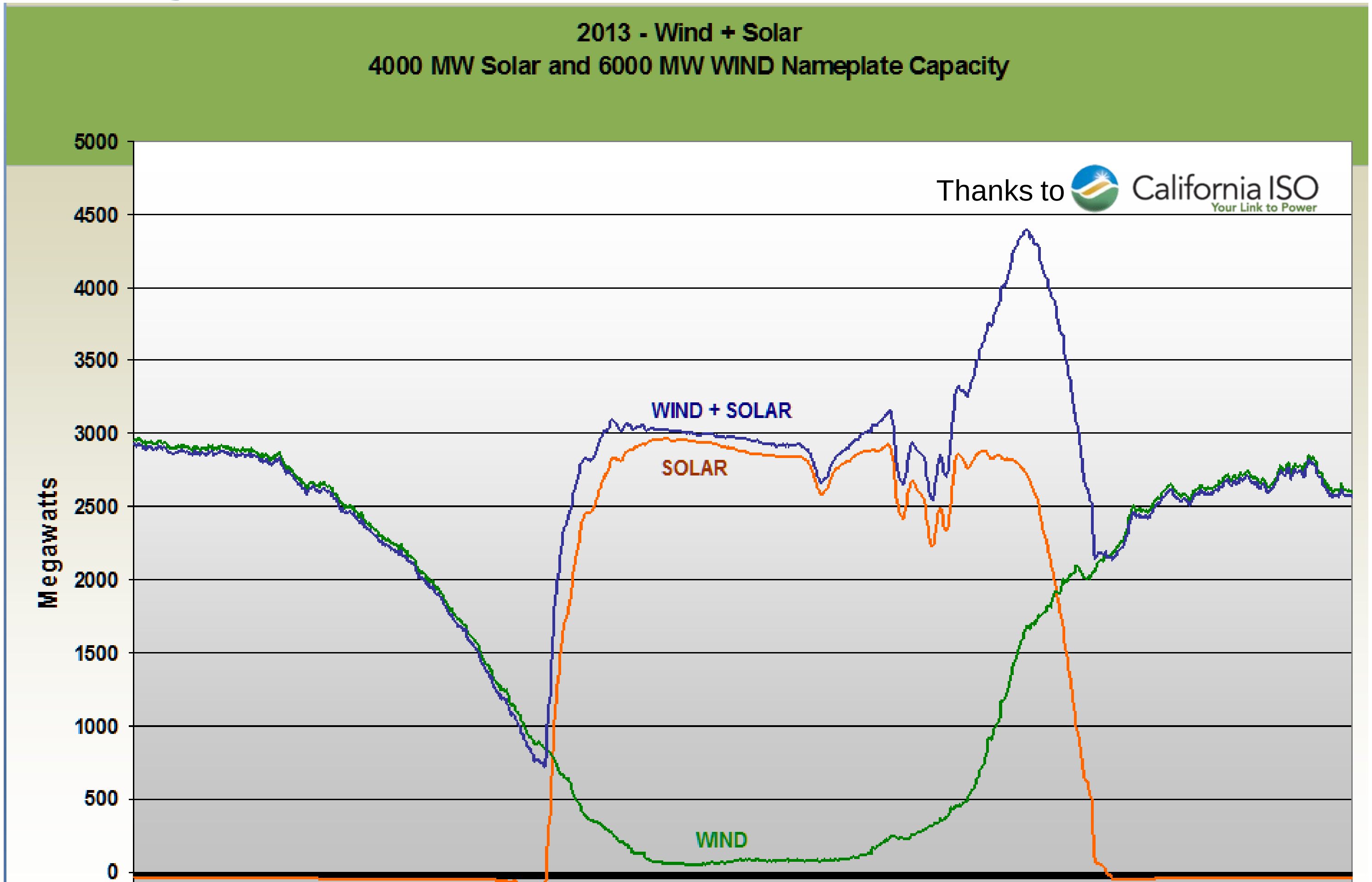
PV output on sunny day in NV (10 sec sampling)



PV output on partly cloudy day in NV (10 sec sampling)

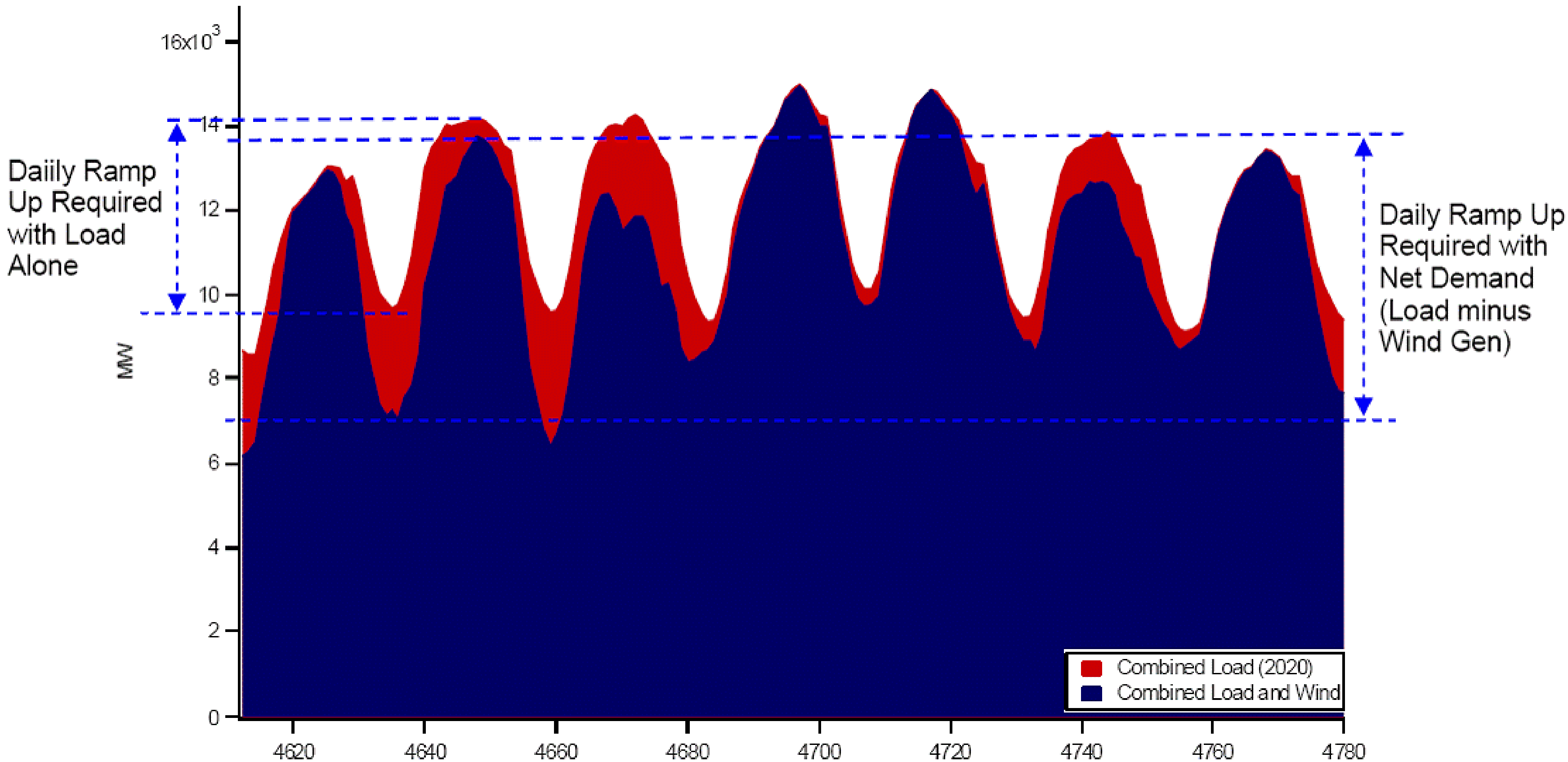
Source: NERC Report - Accommodating High Levels of Variable Generation – March 2009

Projected Profiles of Wind +Solar



Wind and solar generation combined appear to make ramping worse.

Variable generation can increase the need for system flexibility.

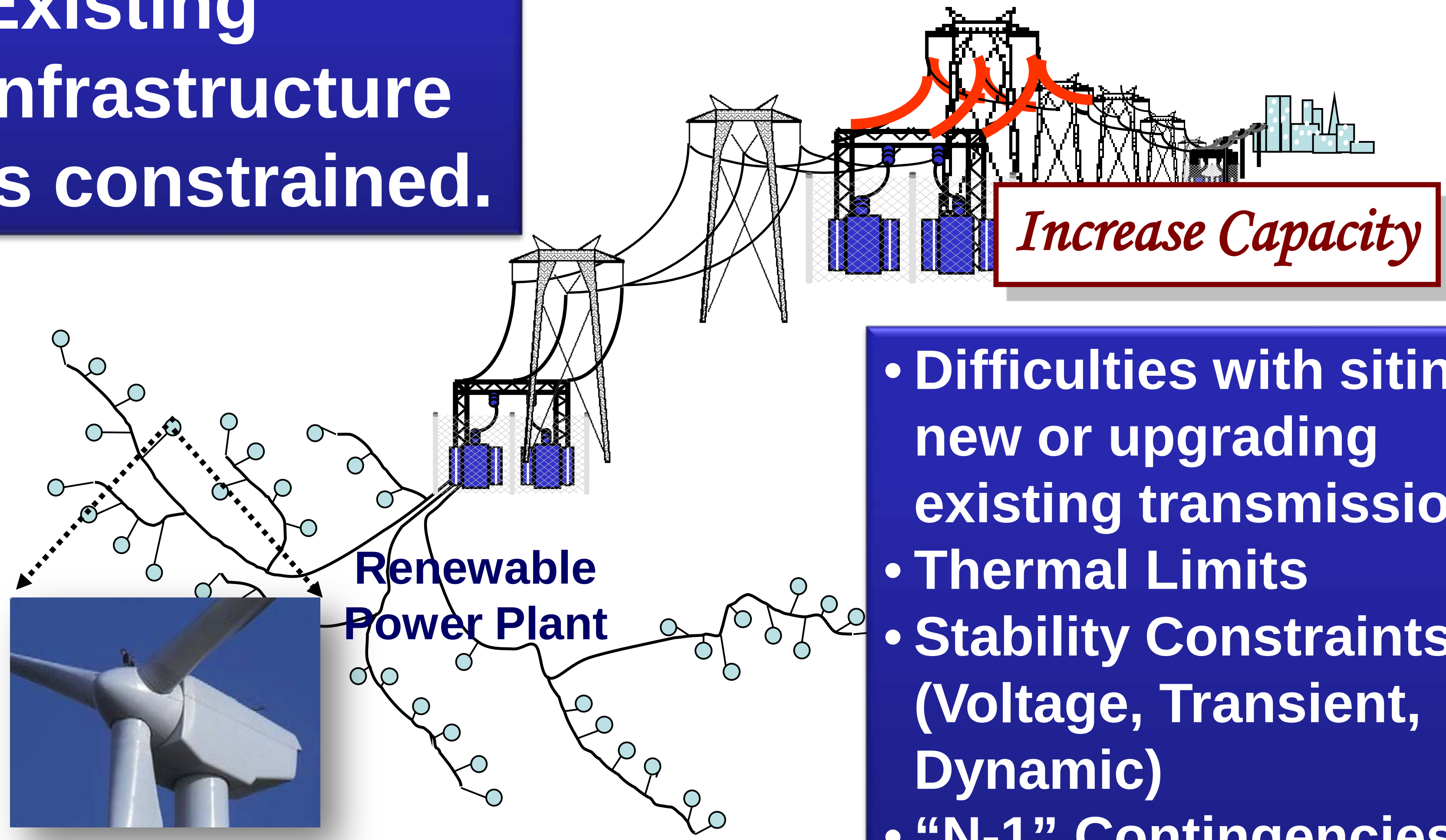


Thousands of MW of new rapidly dispatchable generation required for ramping.

Source: NERC Report - Accommodating High Levels of Variable Generation – March 2009

The Continuing Saga of Renewable Generation and Grid Integration

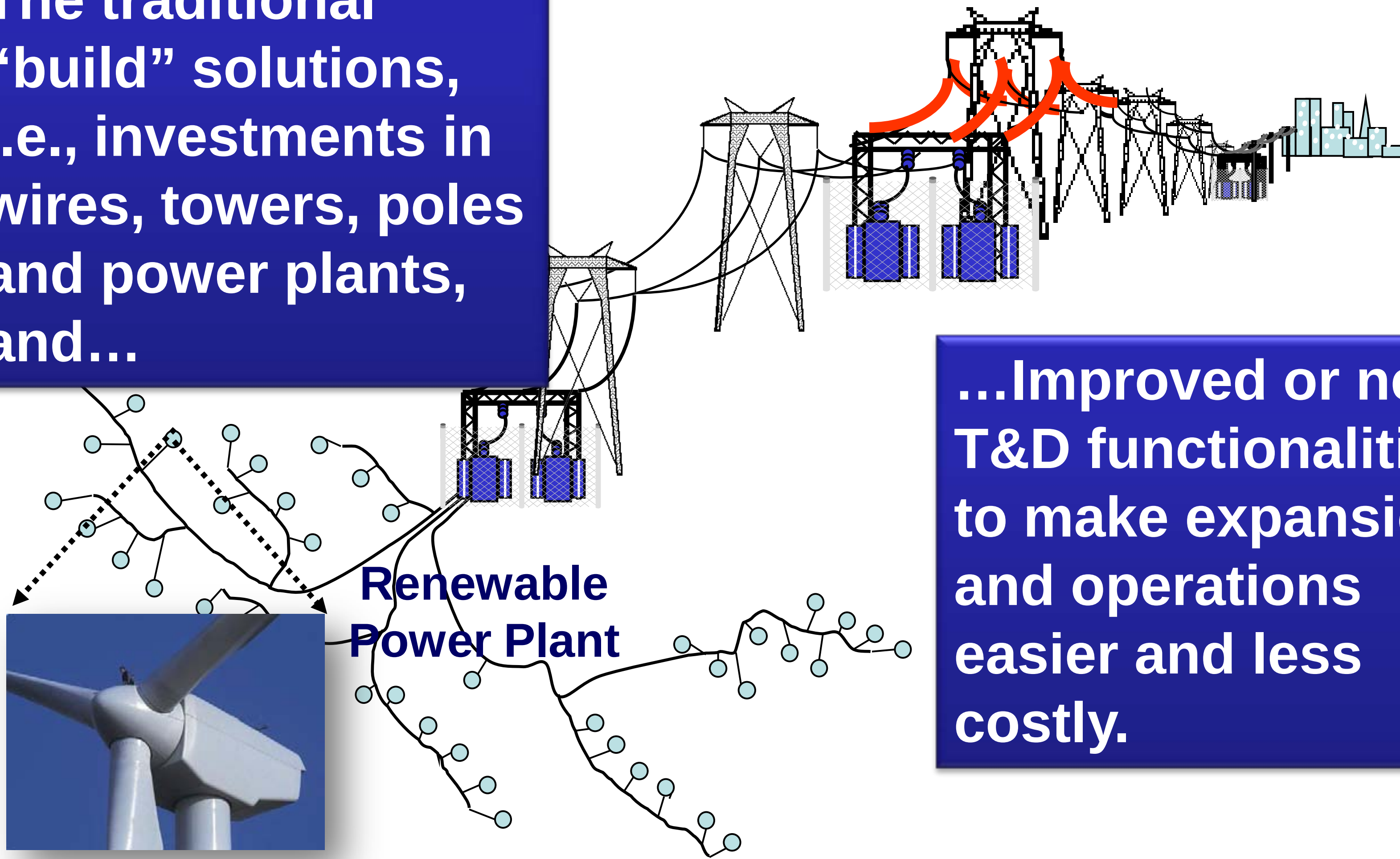
Existing infrastructure is constrained.



- **Difficulties with siting new or upgrading existing transmission**
- **Thermal Limits**
- **Stability Constraints (Voltage, Transient, Dynamic)**
- **"N-1" Contingencies**

There are essentially two options for successful expansion and operations of T&D:

The traditional "build" solutions, i.e., investments in wires, towers, poles and power plants, and…



…Improved or new T&D functionalities to make expansion and operations easier and less costly.

For now we can “build” our way out of these problems, but at higher renewable penetrations…

- …traditional “build” solutions, i.e., investments in wires, towers and power plants, can’t do it alone.
- New technologies will be needed to make renewable integration easier and less costly…

…especially technologies that make the grid smarter

New Technologies to Provide Faster *Access* for New Renewable Plants…

… by putting new power lines in a better light.

- **Underground Transmission**
- **High Voltage Direct Current**
- **Engineered Compact Designs**
- **Advanced Transmission Line Conductors**
- **Distributed Renewables & Demand Response**

- **Web-based Interactive Stakeholder Siting Tools**
- **Cost Allocation & Strategic Benefit Analysis Tools**

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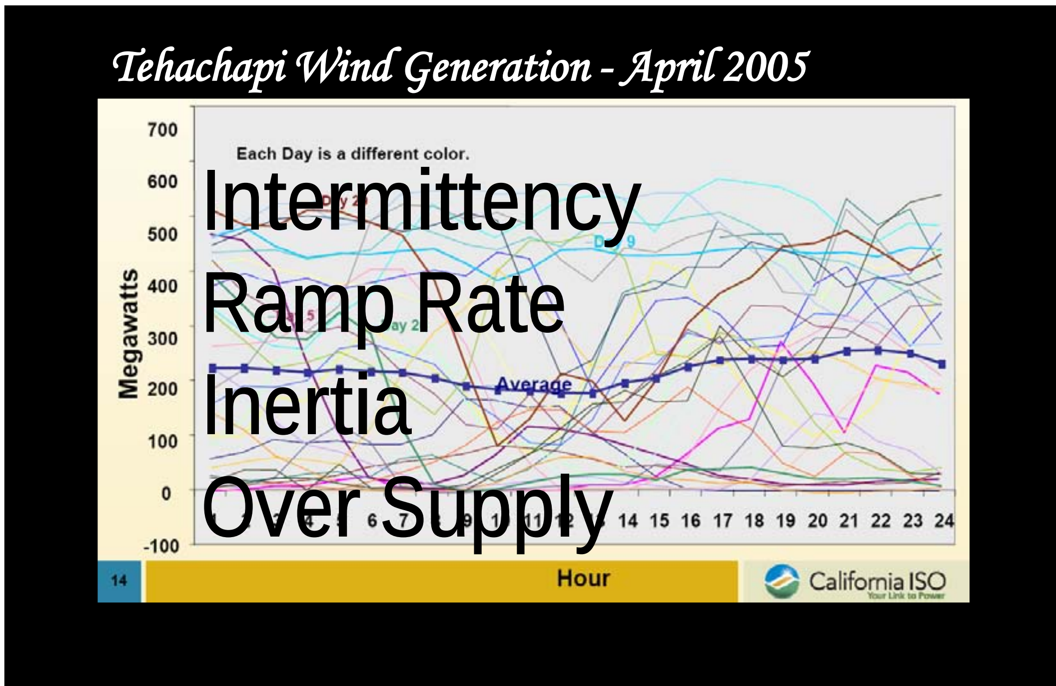
New Technologies to *Accommodate* Unique Renewable Generator Behaviors…

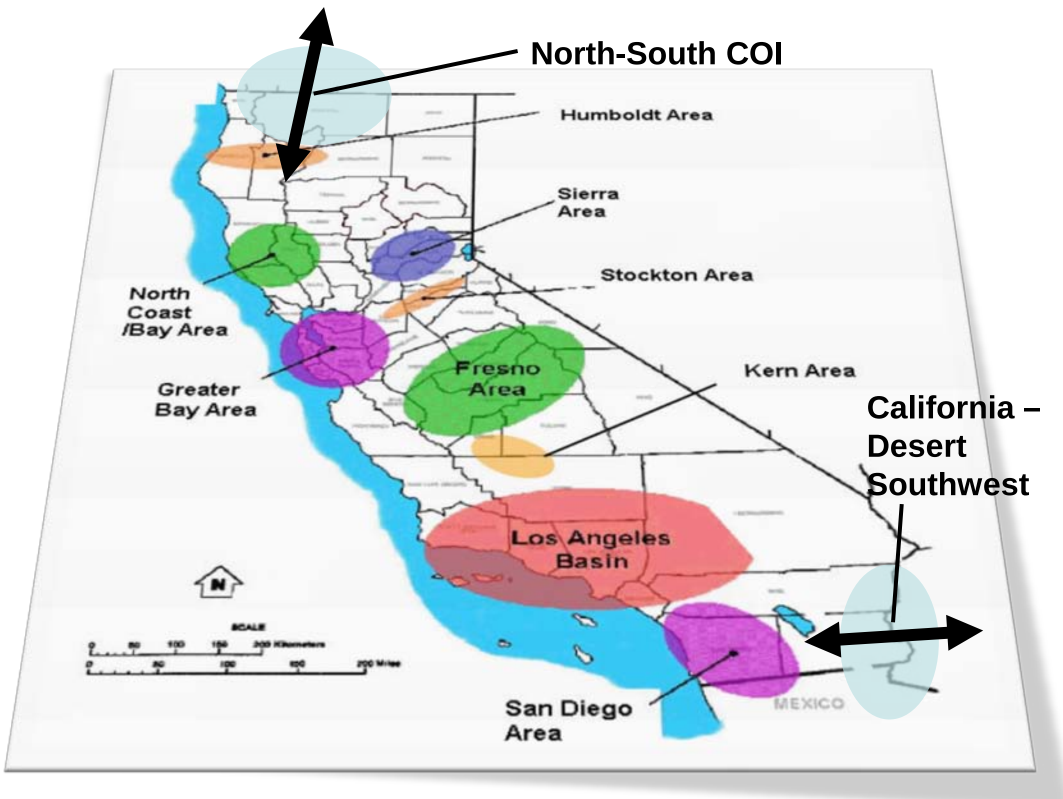
…through a smarter and more flexible grid.



- **Energy Storage & Intelligent Agent (temporal power flow control)**
- **Solar and Wind Forecasting Tools**
- **Generator and Load Modeling**
- **Demand Response**
- **Synchrophasor Monitoring**
- **Power Flow Control (spatial)**
- **Distributed Generation**
- **Advanced Intelligent Protection Systems**
- **Statistical and Probabilistic Forecasting Tools**

New Technologies for Increased Grid Power *Capacity*…

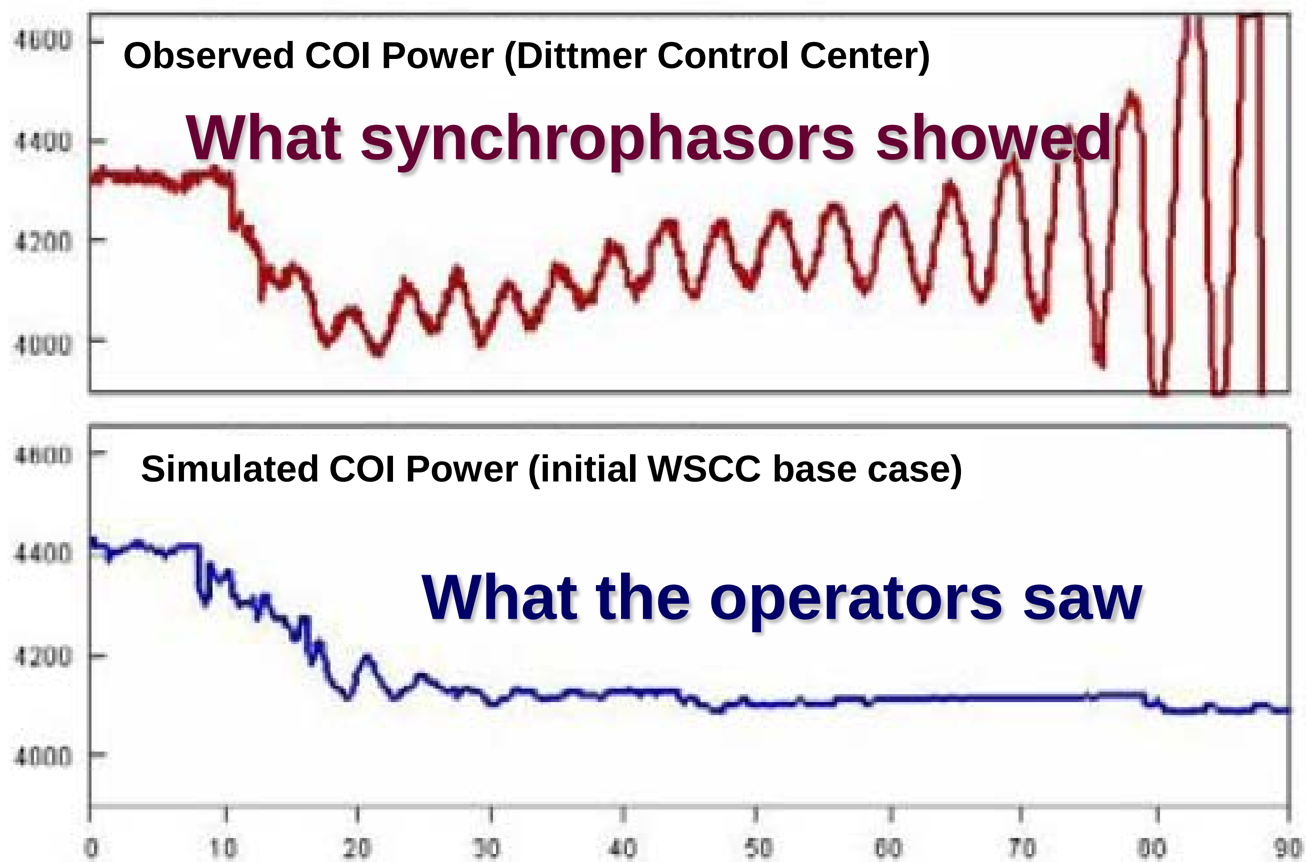
… by optimizing the grid for greater power flow.



- Dynamic Thermal Ratings
- Real-Time System Ops (synchrophasors)
- Power Flow Control (spatial)
- Energy Storage (temporal power flow control)
- High Voltage Direct Current
- Distributed Generation & Demand Response
- Advanced Intelligent Protection Systems
- Statistical & Probabilistic Analysis & Planning Tools
- Advanced Transmission Line Conductors

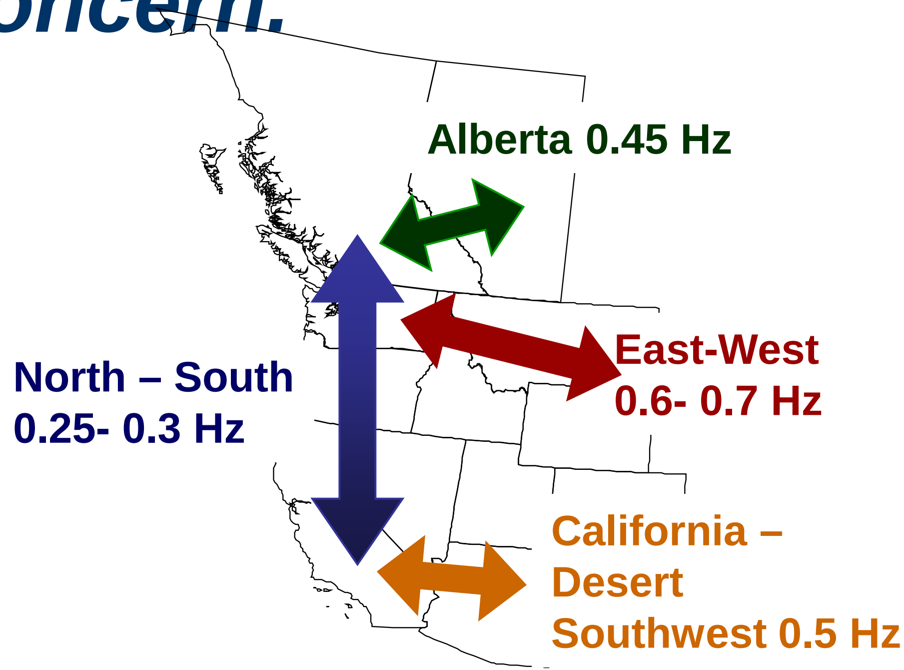
Example: Increase Capacity: Two Views: California-Oregon Intertie

August 10th, 1996, Power Flow During Generator Trip



This event triggered an inter-area power oscillation and ended in a wide-area power outage in western US.

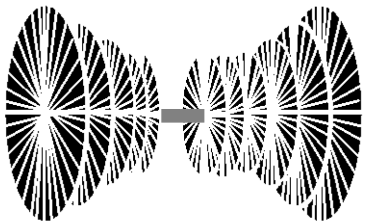
A number of these oscillations are showing up annually, and are a cause of growing concern.



Oscillations have caused western transmission capacity to be derated by thousands of MW, restricting the export/import of renewable power. System inertia is thought to be a factor.

Some renewable generators have low or no inertia.

- Traditional (thermal) power plants have inertia in the rotational mass of their turbine-generators.

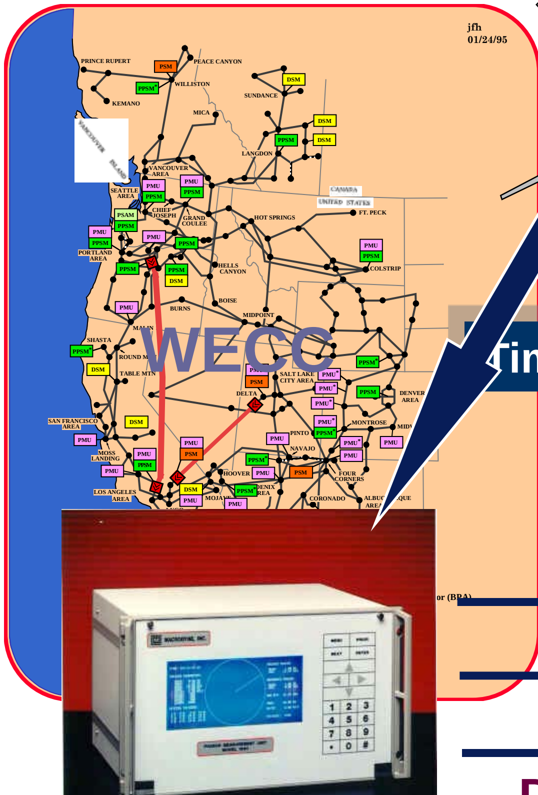


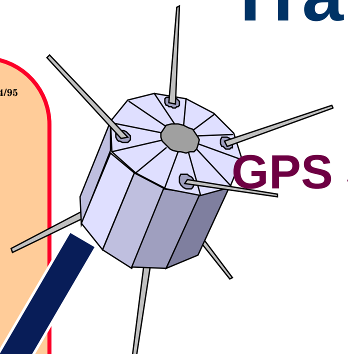
- Some renewables exhibit traditional inertia

- Wind and some solar exhibit low or no inertia.

If large amounts of renewables worsen the oscillation threat, how will the grid operator be able to respond?

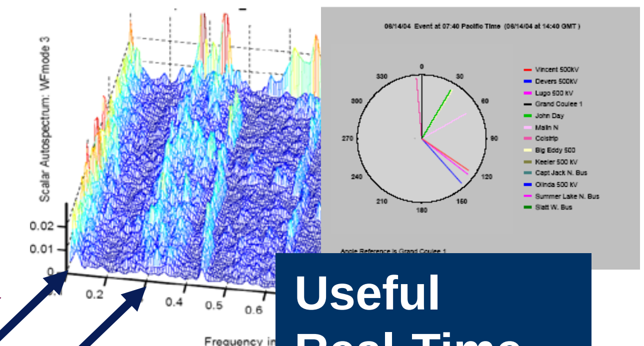
Synchrophasor Measurements – The Basis of the "Smart Grid" Transmission





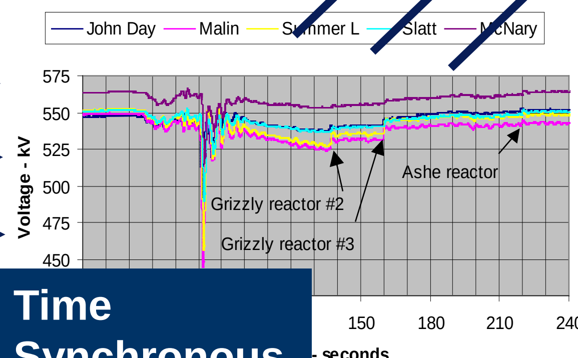
GPS Satellite

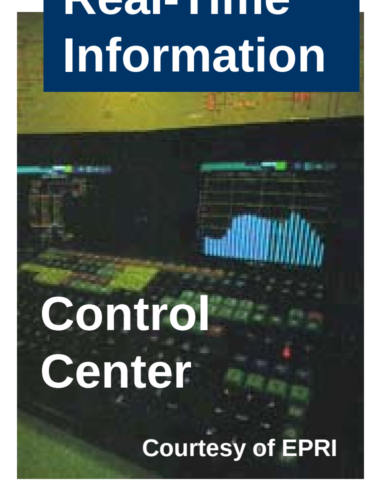
Time-Stamp



Data

Useful Real-Time Information





Control Center

Data

PMUs (Phasor Measurement Units)

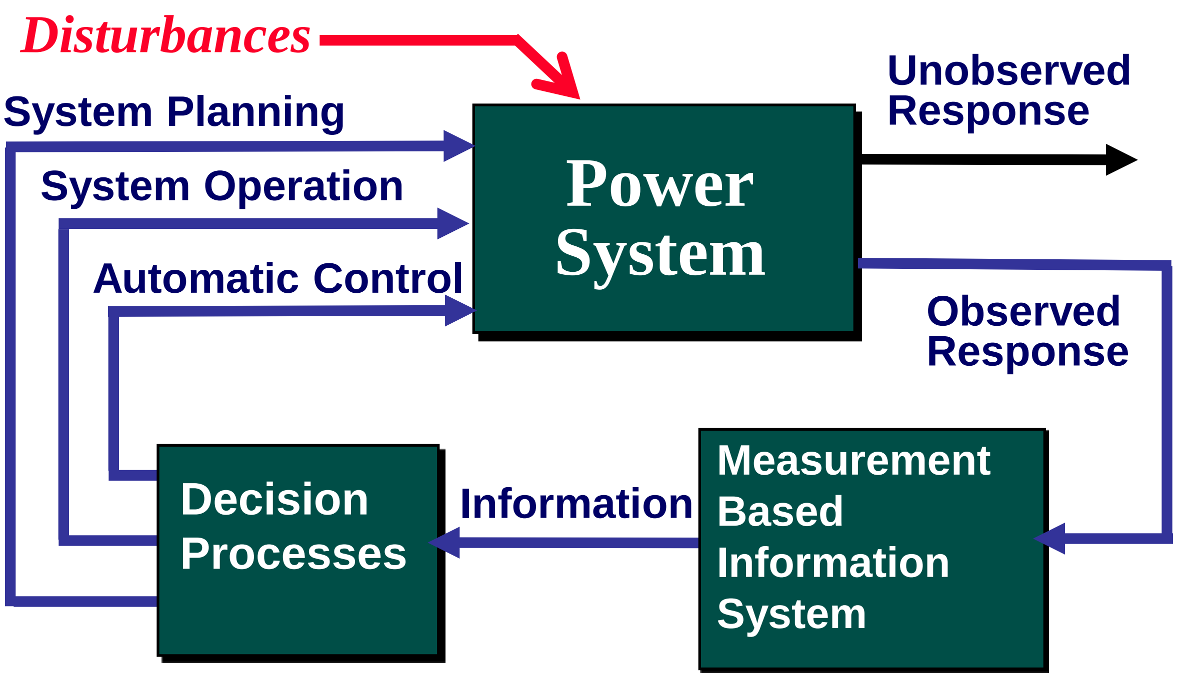
Time Synchronous Data

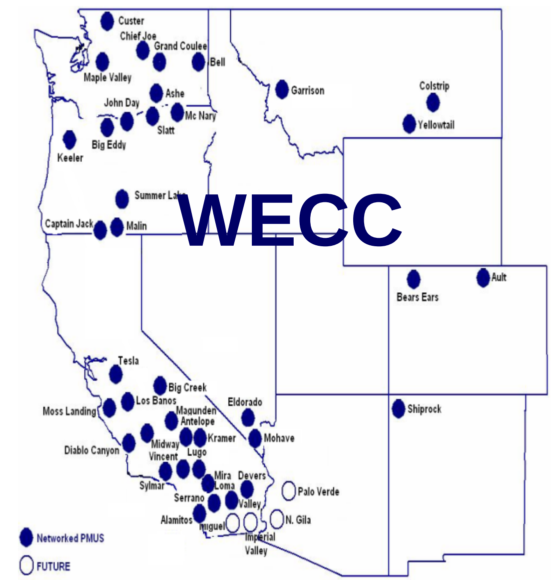
Are like "X-ray" to "MRI" improvements in diagnostics capability.

The Before and After of Synchrophasor Measurements

Synchrophasors ^ 30/second ^

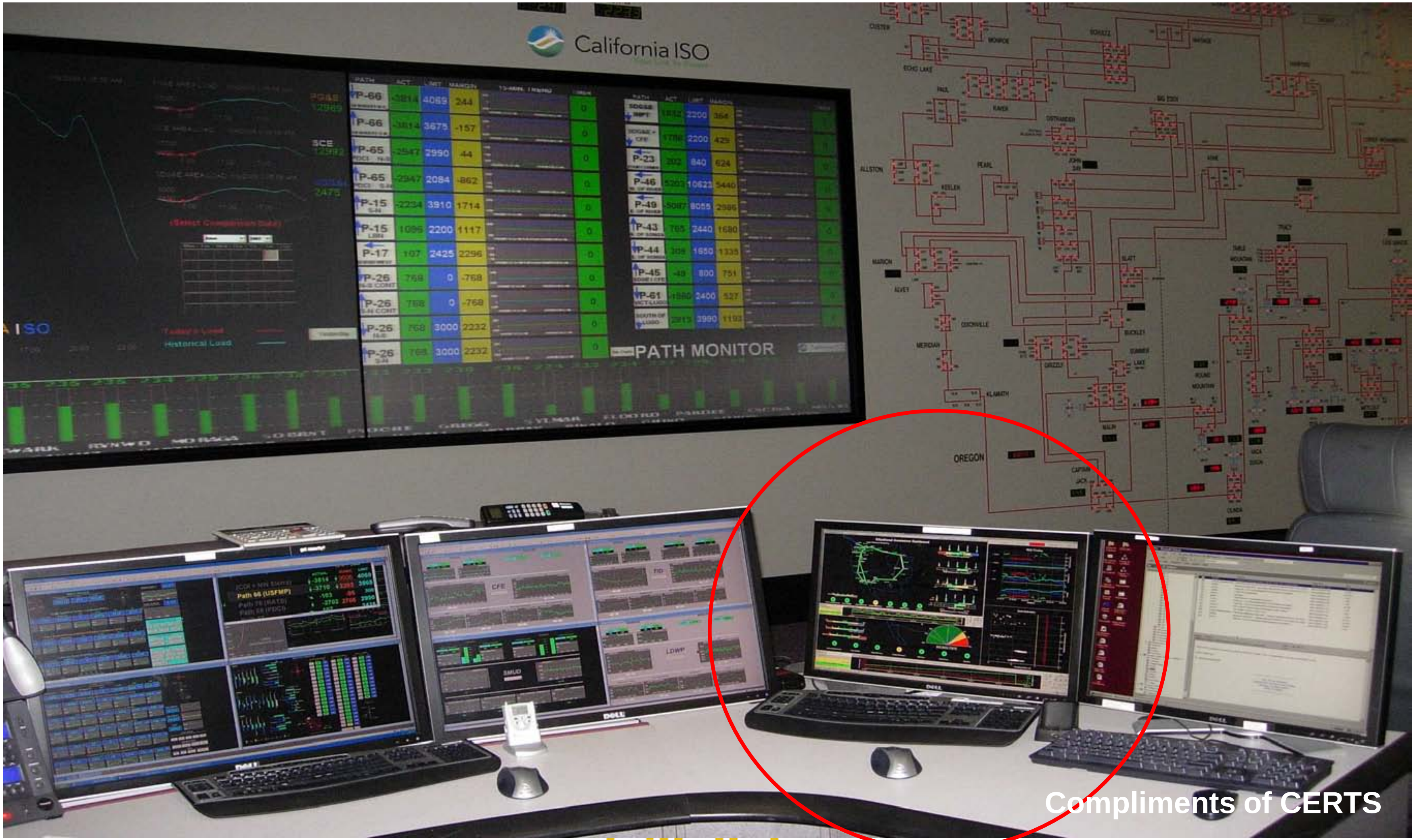
~~Traditional~~ Real-Time Data Rate = Every ~~4-5 seconds~~



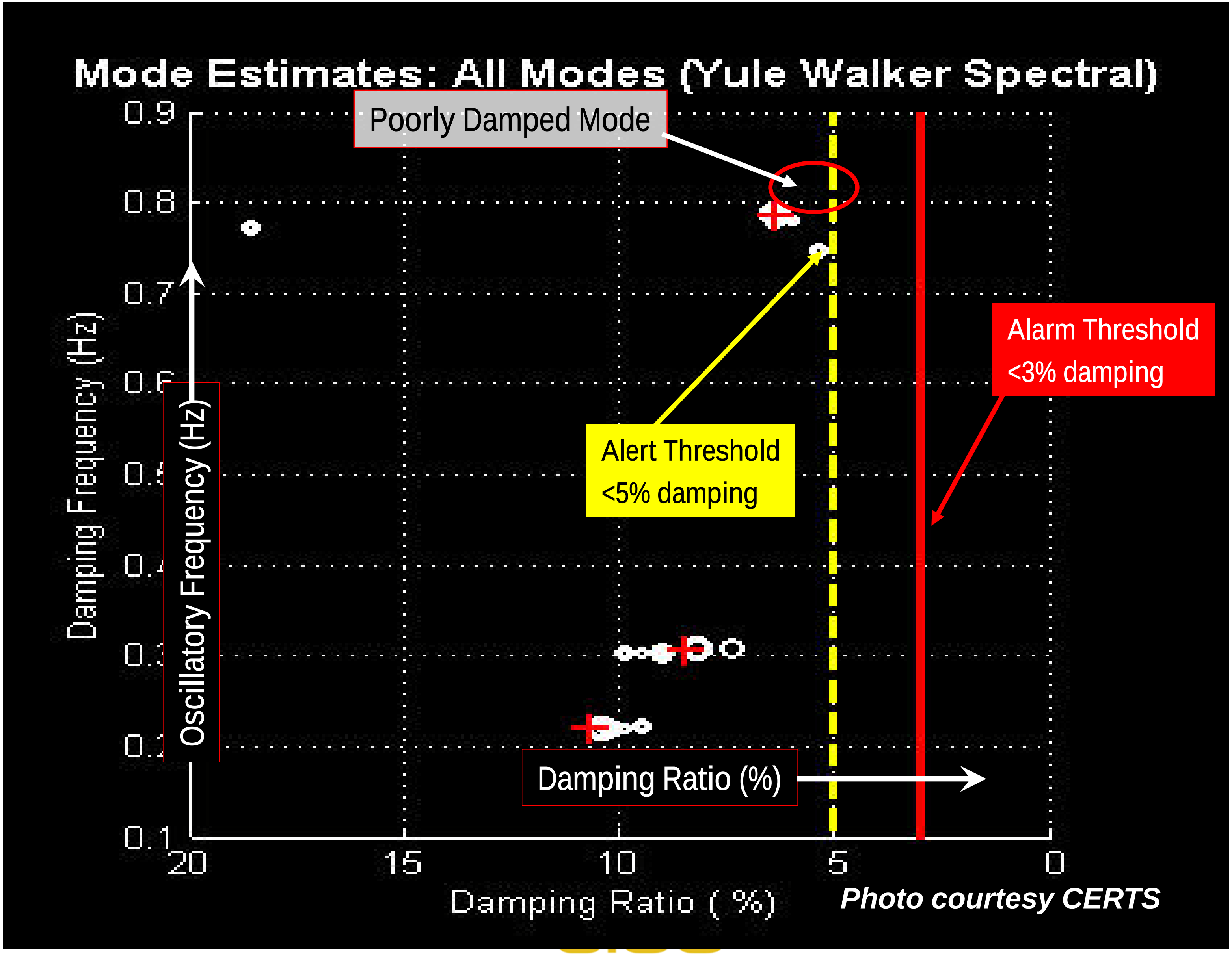


An unprecedented ability to see, know, plan and control.

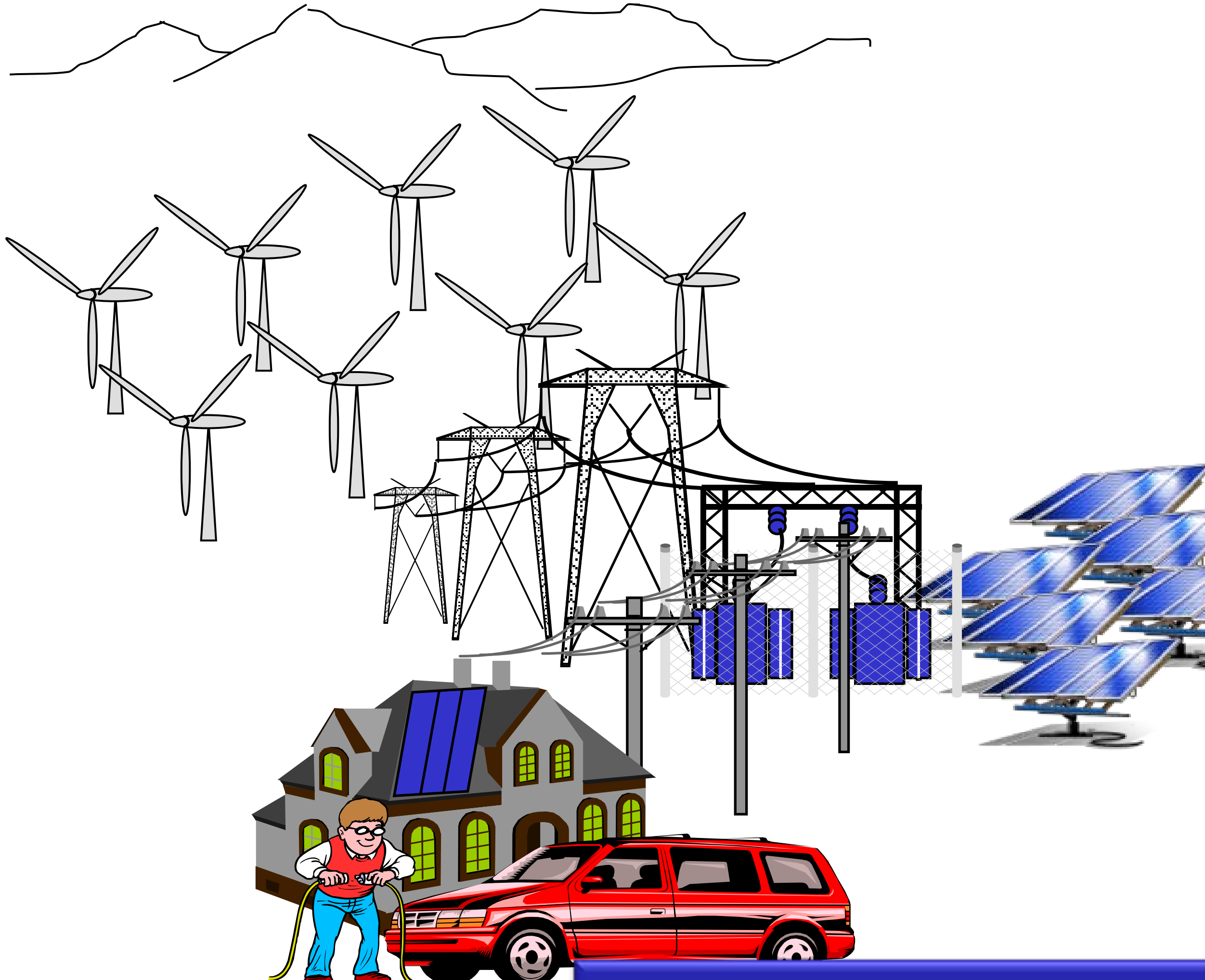
CAISO, SCE, PG&E, and SDG&E Are Pioneering the Use of Phasor Technologies in California



Mode Estimate: Example



At the other end of the grid, DG renewables offer their challenges

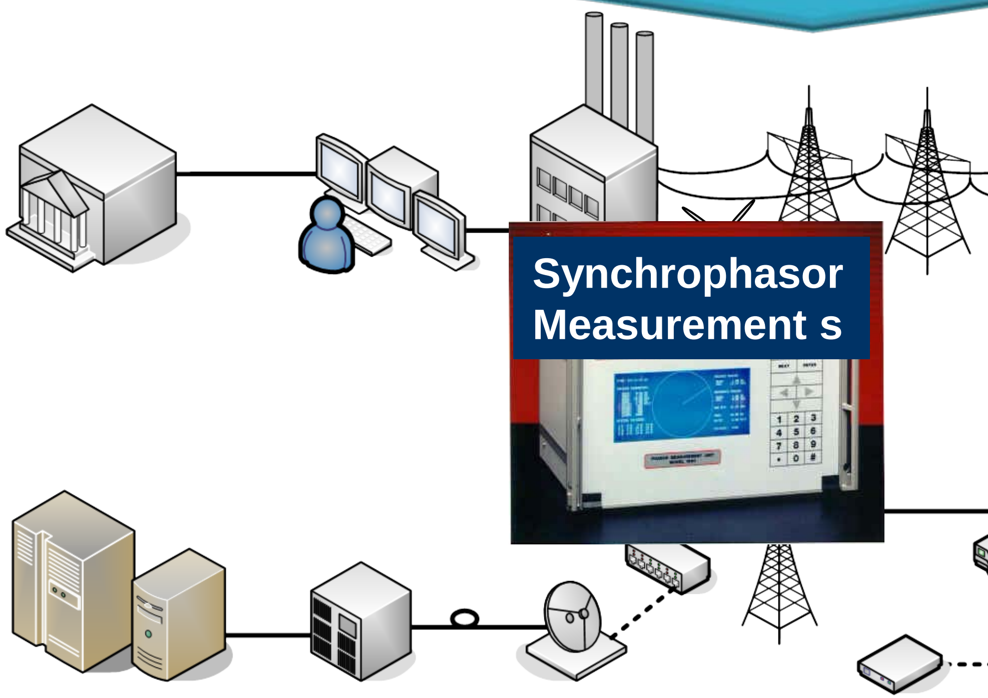


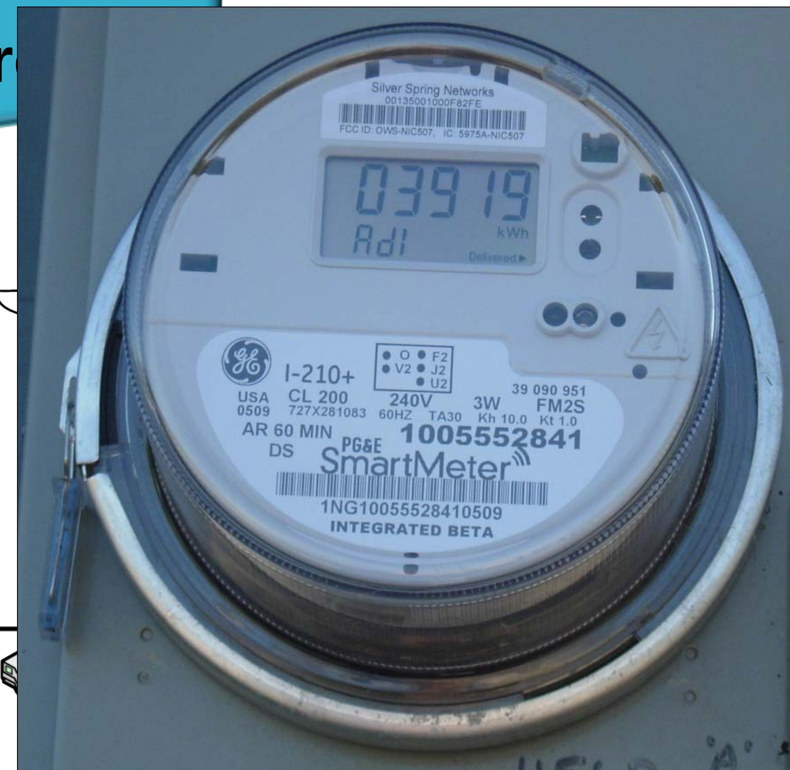
- Safety
- Reverse power flow
- Voltage highs and lows
- VARs
- Power quality
- Equipment accelerated fatigue and thermal damage

"Smart" grid is part of the answer.

“Smart Grid” formed by joining 2 infrastructures

Electrical Infrastructure

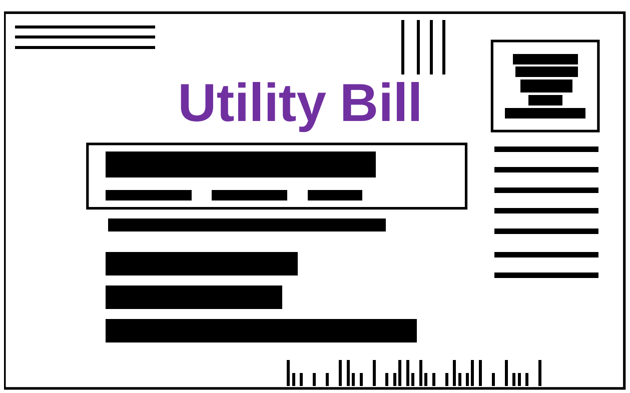




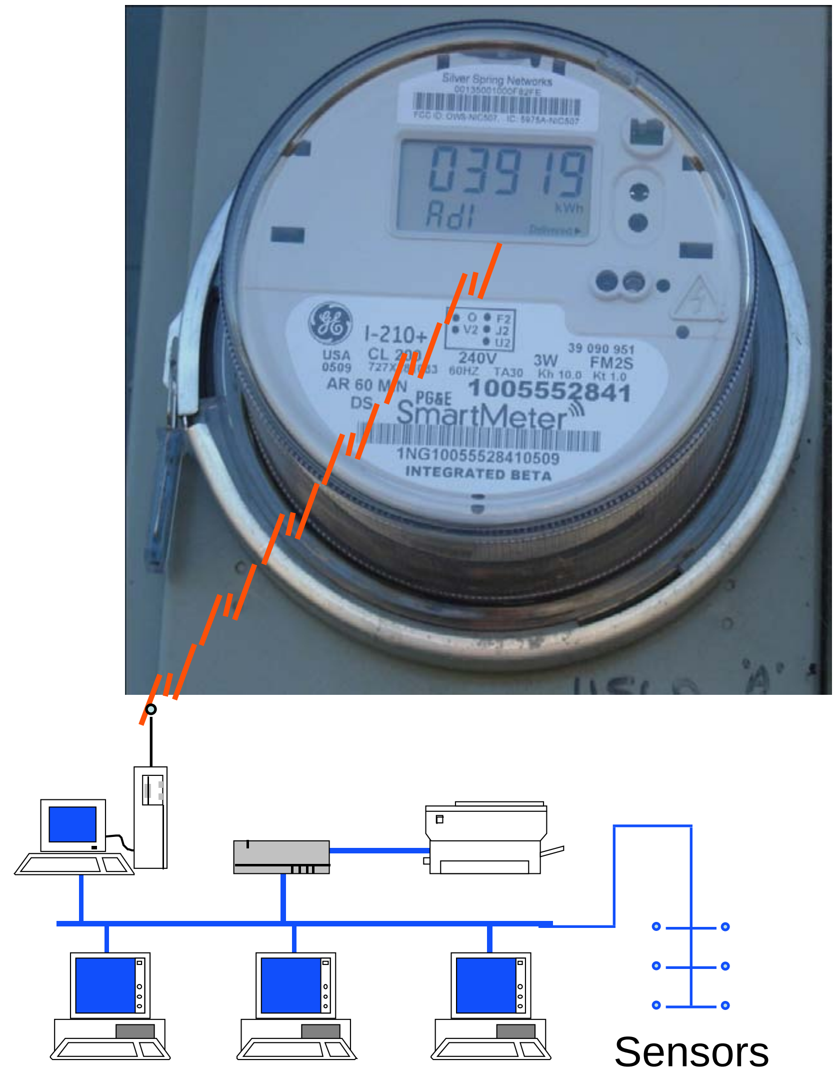
The digital “smart meter” makes the customer an integral part of the electric grid.

The Smart Meter

Past...



Future...



For additional information or discussion, contact :

Merwin Brown
Director, Electric Grid Research
Voice: 916-551-1871
Merwin.Brown@uc-ciee.org
www.uc-ciee.org

And he'll find someone to help you.

"People tend to overestimate what can be accomplished in the short run but to underestimate what can be accomplished in the long run." **Arthur C. Clarke**