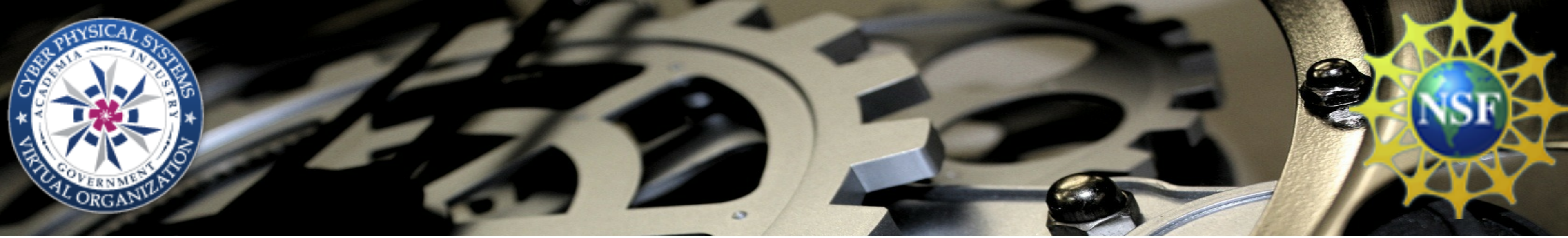

National Workshop on
The New Clockwork for Time-Critical Systems

Synchronization Issues in Prosumer Start Grids

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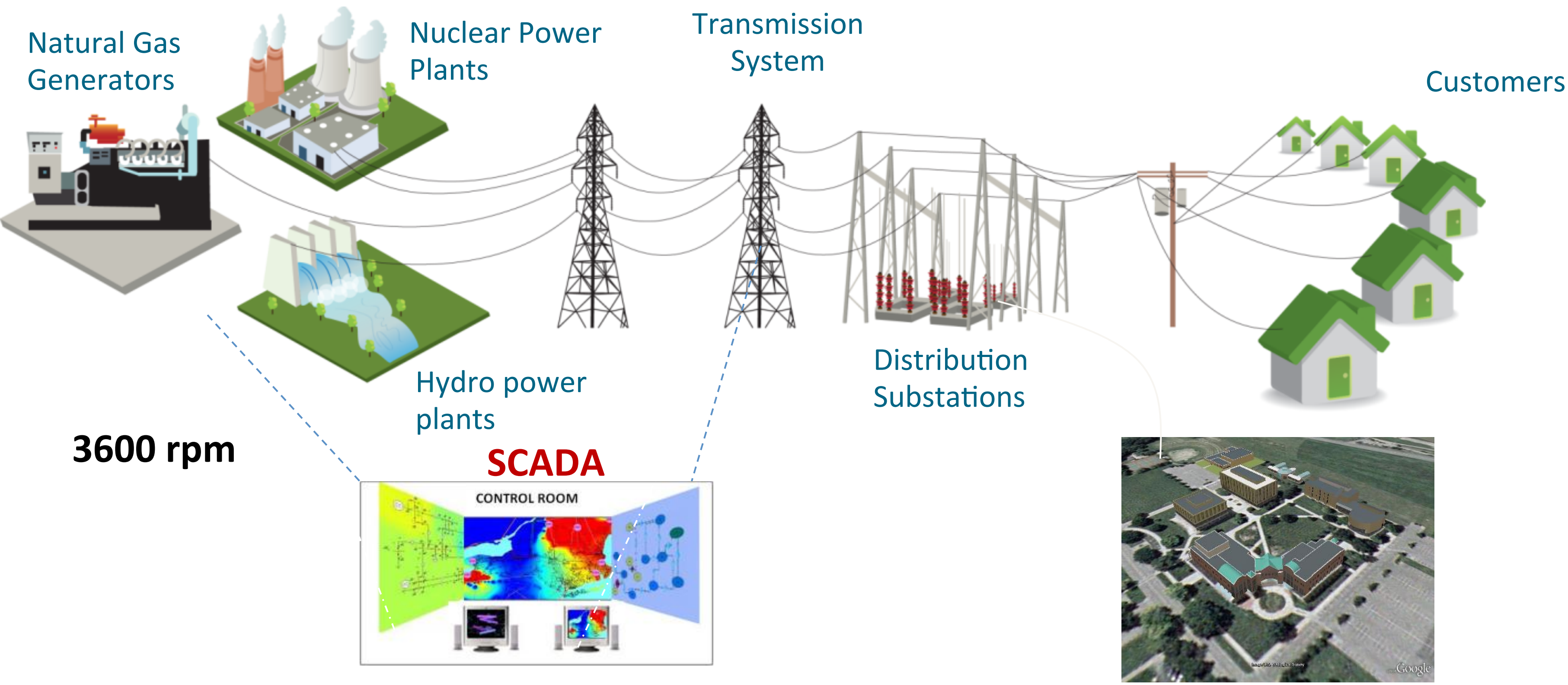
Outline

- Control requirements in AC Electricity Grids
  - Power synchronization and time synchronization.
- Synchronized phasor measurements for bulk electricity monitoring and (eventually) control.
- Research needs in emerging distributed cyber-control paradigms.

The Traditional Grid

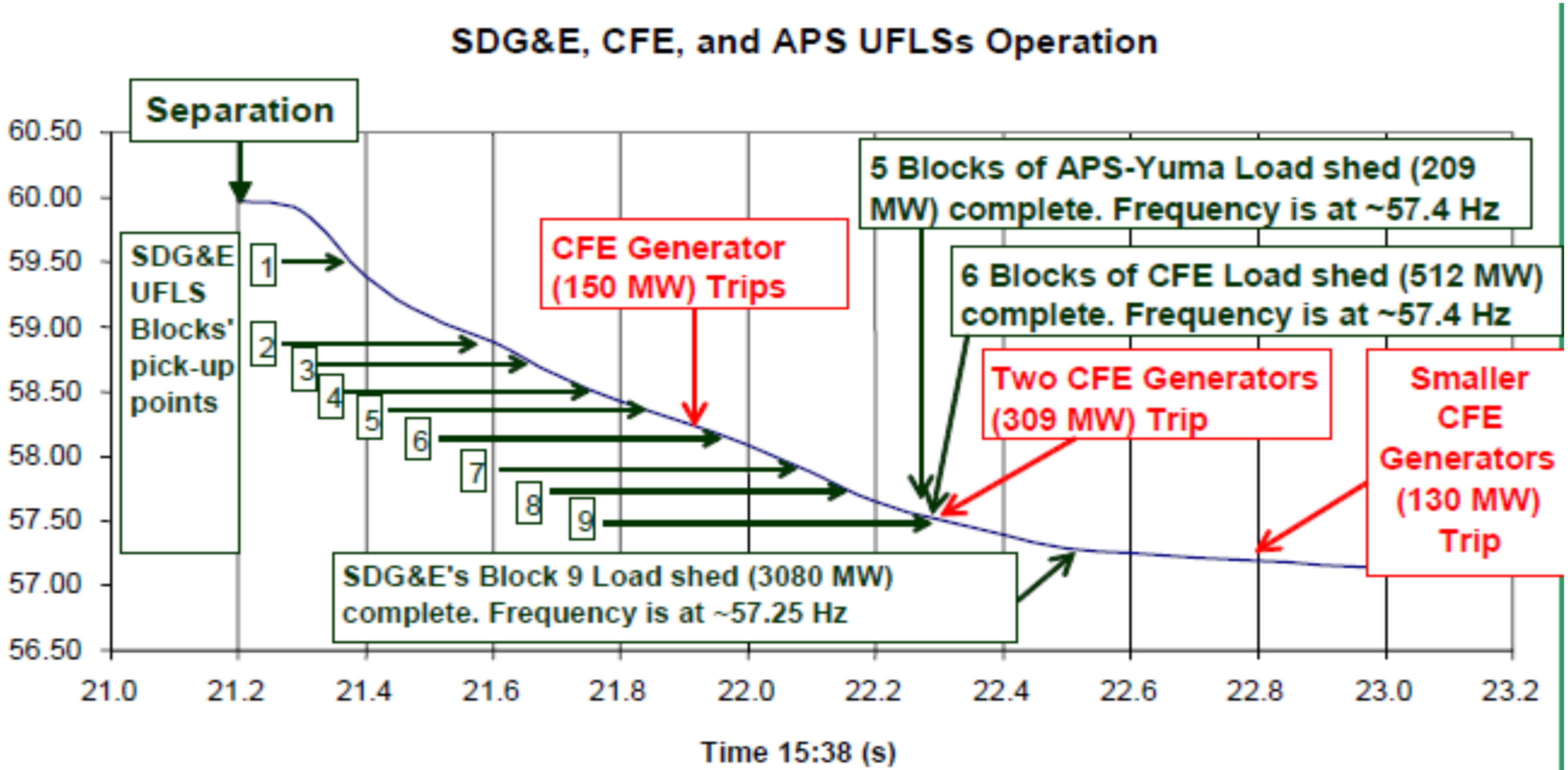
GENERATION	AC TRANSMISSION	LOAD



- Generation must be ***synchronized*** and must balance (follow) the load at all times.

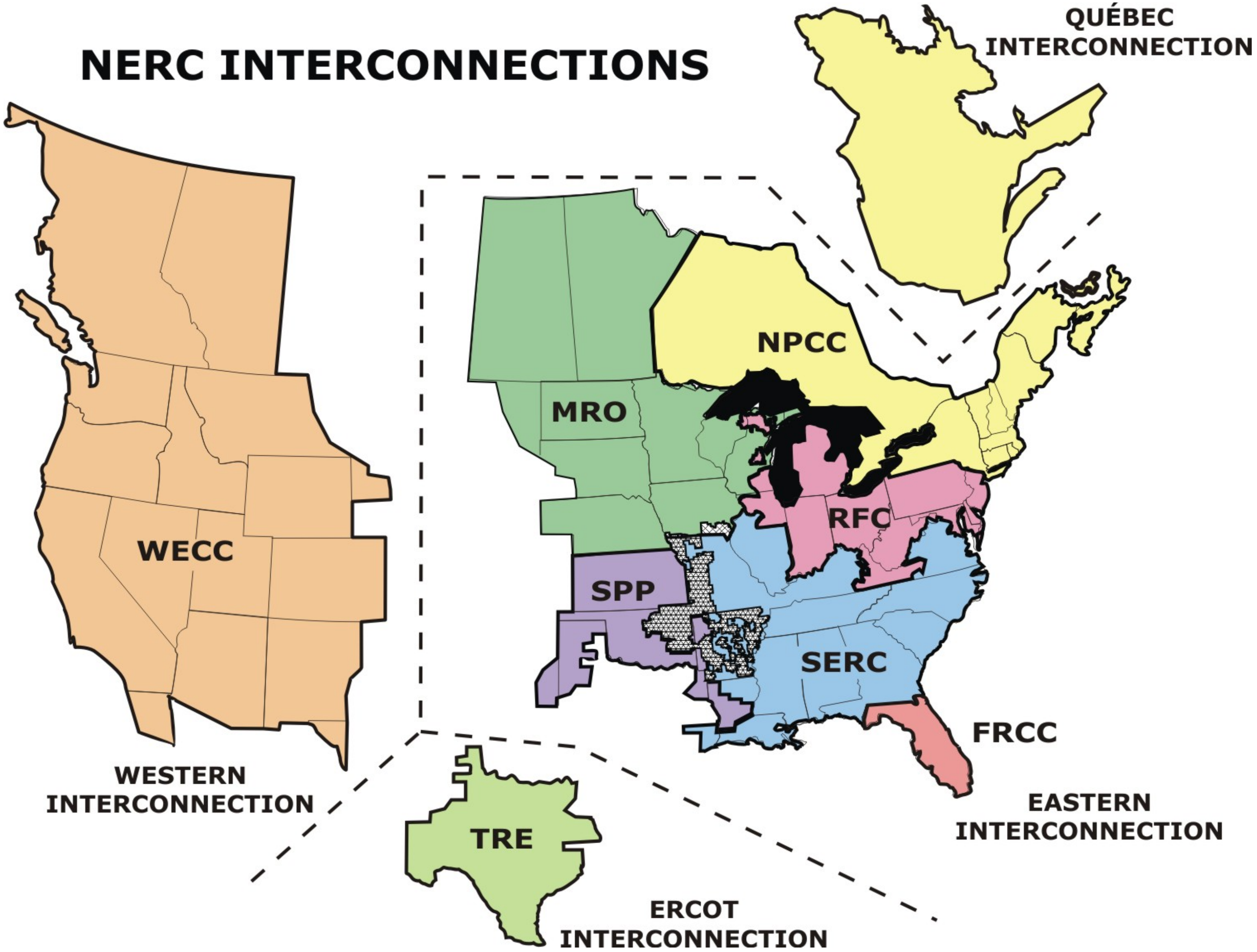
Frequency Control

- Frequency must be maintained very close to nominal 60Hz.
  - 59.5 Hz is a problem. Example: 2011 San Diego Blackout



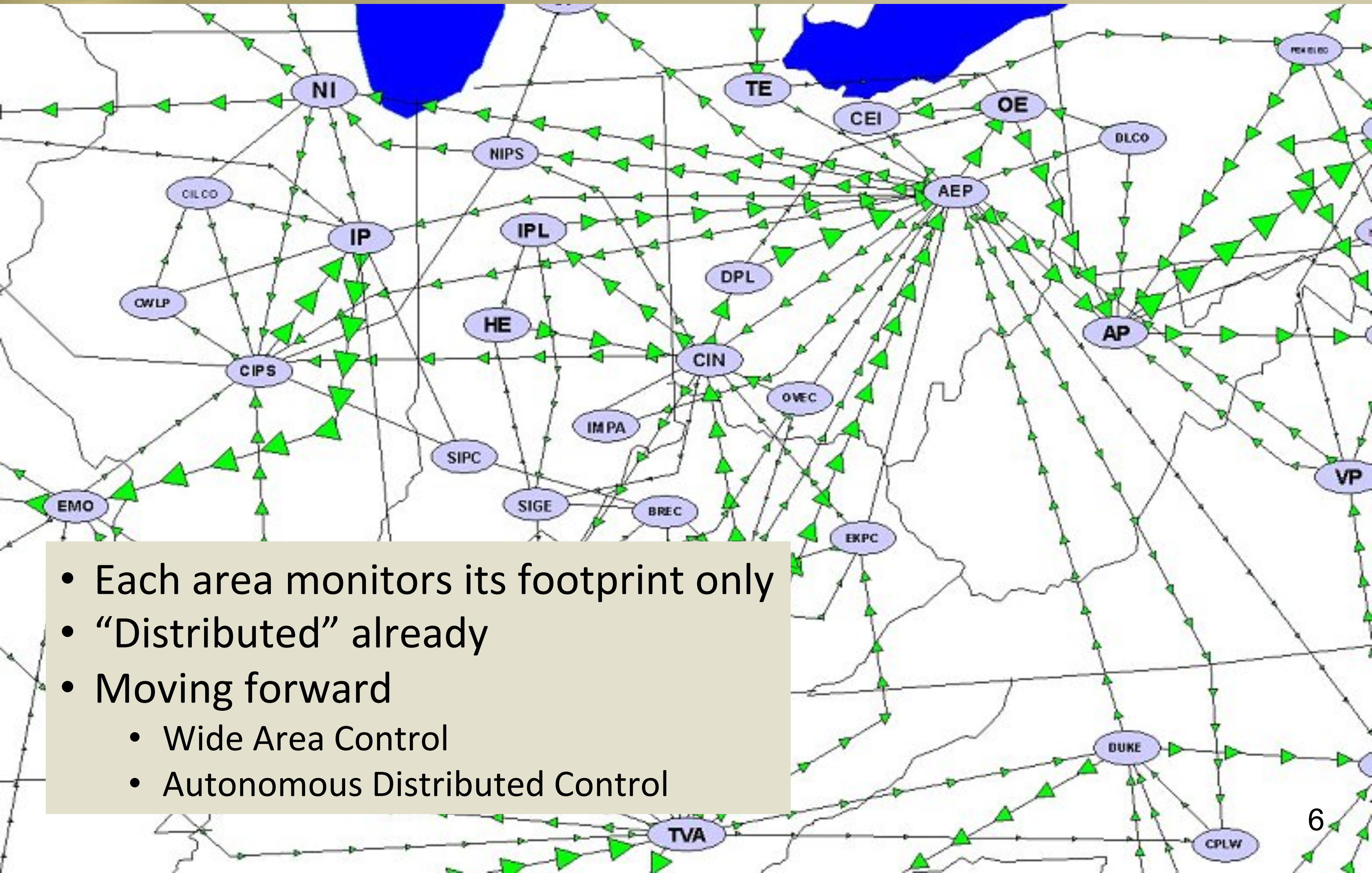
- Note, first protection step at 59.5 at 0.2 sec.
- However, we can know that the breaker tripped in <1ms.

Frequency Control



Control Areas

Gen = Load + Losses + Interchange



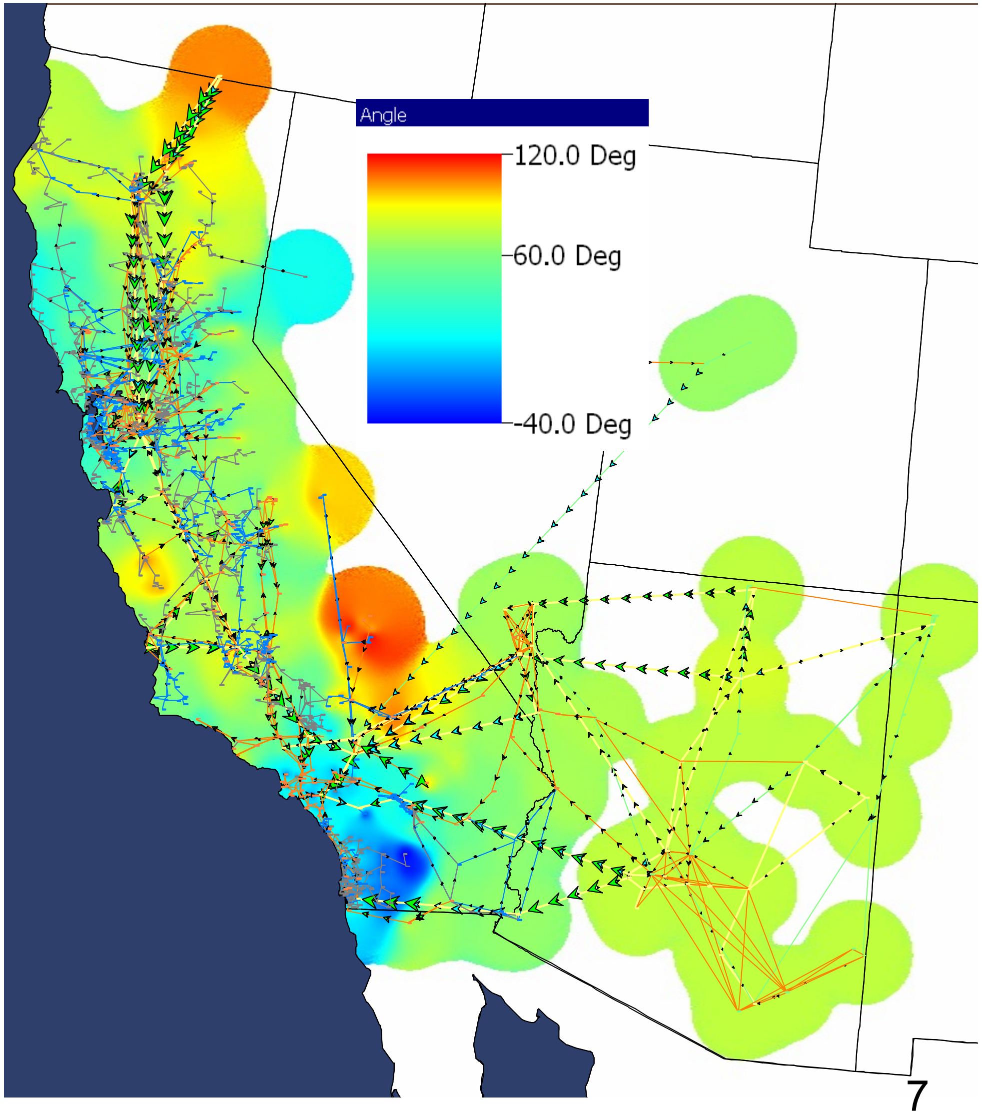
- Each area monitors its footprint only
- “Distributed” already
- Moving forward
  - Wide Area Control
  - Autonomous Distributed Control

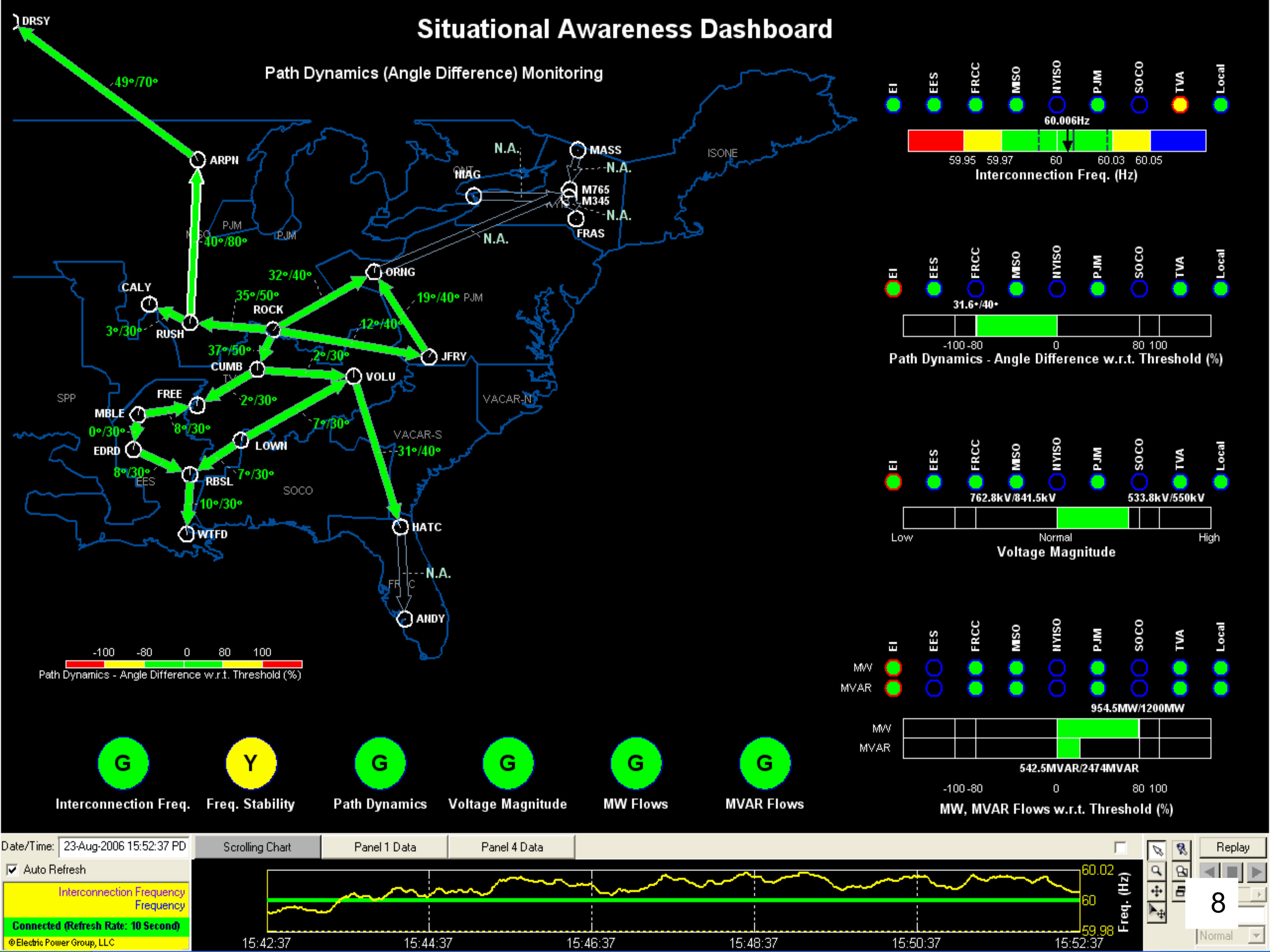
2. Phasor Measurement Units

- Power flows are a function of node voltage angle separation.

$$P_{jk} = \frac{V_j V_k}{X_{jk}} \sin(\theta_j - \theta_k)$$

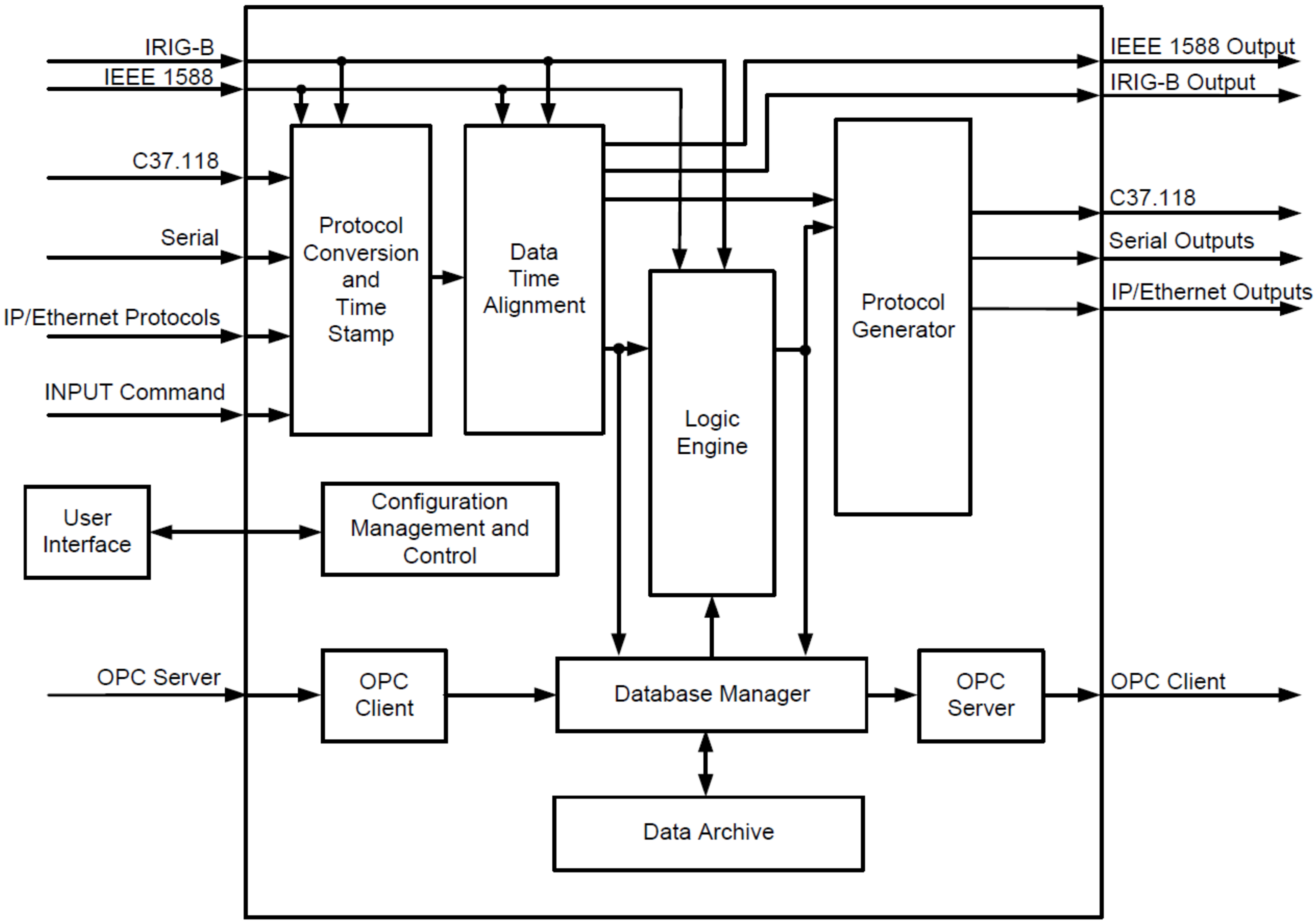
- 1 deg = 46.3 μs.
- Synchronized Phasor Measurement Units sample at 30 times per cycle of 60Hz. -> 0.5 ms.
- Over 850 more networked PMUs and data concentrators will be added to the North American grid through 2013.





Situational Awareness Dashboard
Path Dynamics (Angle Difference) Monitoring
DRSY
49°/70°
ARPN
40°/80°
CALY
RUSH
ROCK
ORNG
JFRY
CUMB
VOLU
FREE
MBLE
EDRD
LOWN
RBSL
WTFD
HATC
ANDY
MASS
NIAG
M765
M345
FRAS
N.A.
32°/40°
35°/50°
19°/40°
12°/40°
3°/30°
37°/50°
2°/30°
2°/30°
8°/30°
0°/30°
7°/30°
7°/30°
8°/30°
10°/30°
31°/40°
SPP
PJM
EES
SOCO
VACAR-N
VACAR-S
ISONE
-100 -80 0 80 100
Path Dynamics - Angle Difference w.r.t. Threshold (%)
EI
EES
FRCC
MISO
NYISO
PJM
SOCO
TVA
Local
60.006Hz
59.95 59.97 60 60.03 60.05
Interconnection Freq. (Hz)
31.6°/40°
Path Dynamics - Angle Difference w.r.t. Threshold (%)
762.8kV/841.5kV
533.8kV/550kV
Low
Normal
High
Voltage Magnitude
MW
MVAR
954.5MW/1200MW
542.5MVAR/2474MVAR
MW, MVAR Flows w.r.t. Threshold (%)
G
Interconnection Freq.
Y
Freq. Stability
G
Path Dynamics
G
Voltage Magnitude
G
MW Flows
G
MVAR Flows
Date/Time: 23-Aug-2006 15:52:37 PD
Scrolling Chart
Panel 1 Data
Panel 4 Data
Replay
Auto Refresh
Interconnection Frequency
Frequency
Connected (Refresh Rate: 10 Second)
©Electric Power Group, LLC
60.02
60
59.98
Freq. (Hz)
15:42:37
15:44:37
15:46:37
15:48:37
15:50:37
15:52:37
Normal

PMU Functional Diagram



Bulk Power Control Apps.

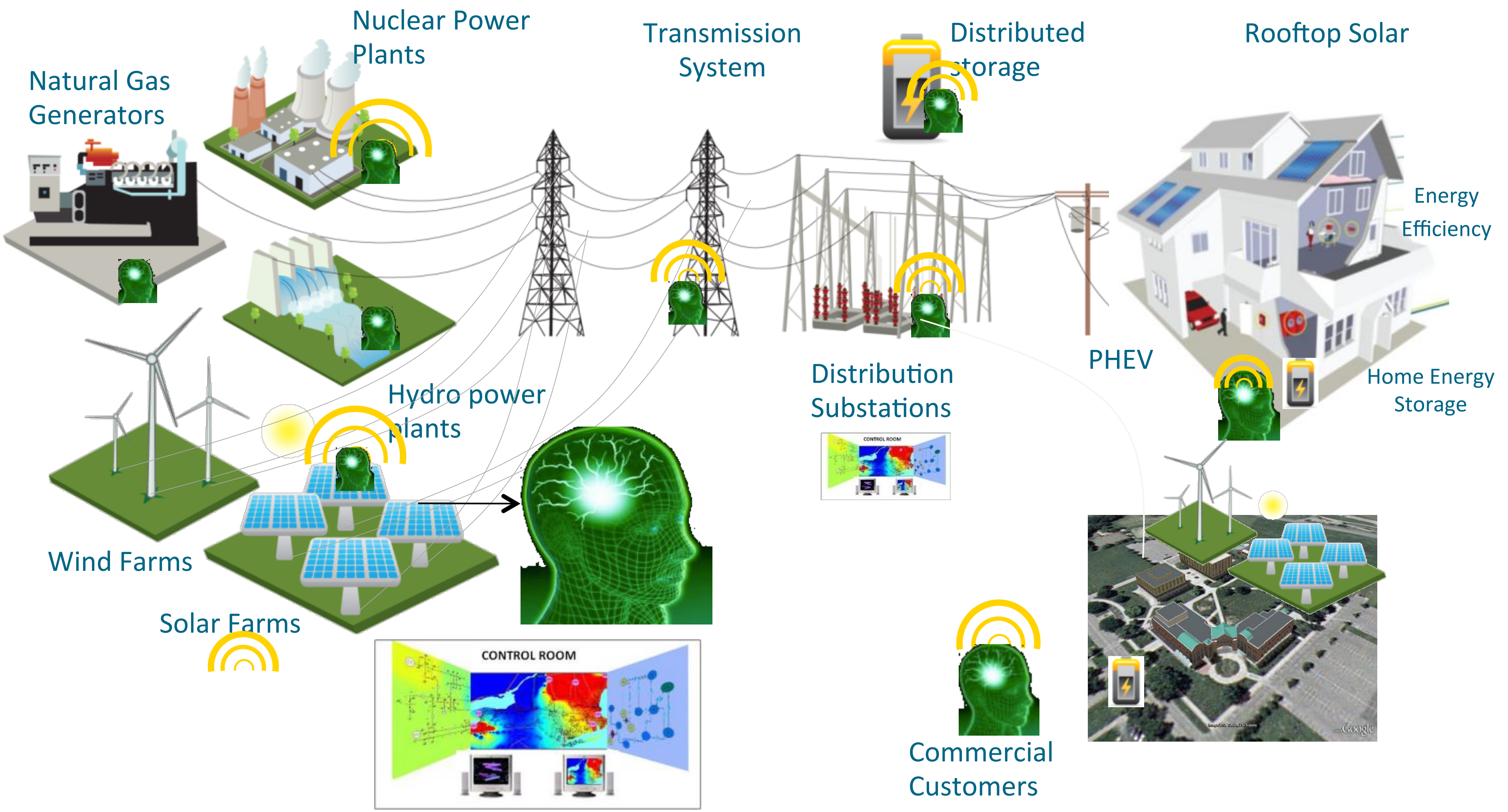
Domain	Application	Description	Need
Monitoring	Wide Area Visualization	Able to share wide area angle views	50 μs
	State Estimation	Dynamic Estimation Distributed State Estimation	50 μs
	Outage Identification	What elements were disconnected	100 μs
Protection	Adaptive Relaying	Dynamically change relay settings	100 μs
	Wide Area Protection	i.e. under-frequency load shedding	1 ms
	Fault Location	Location of fault: from 1 mile to 100 ft	1 μs
Control	Instability Prediction	Early detection of unstable modes	0.1 μs
	Wide-area control	Damping of inter-area oscillations	100 μs
	Disturbance Recording	Forensics: Precise sequence of events	10 μs
Modeling	Model Verification	i.e. error in device parameters	20 μs
	Model Identification	i.e. internal parameters of generation	20 μs

3. Future Grid

- Distributed sources, storage and loads

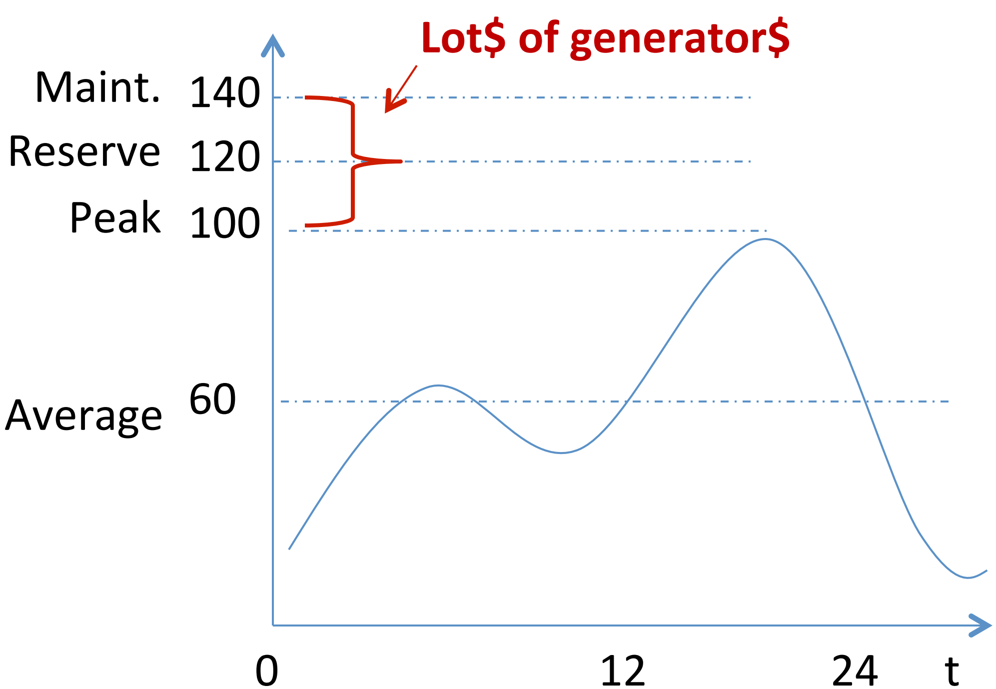
- Increased sensing and two-way communication all the way to residential premises.
- 10^4 more data.
- Possible to control the entire infrastructure from bulk to residential appliances through software.
- -> Distributed decision-making

Future Grid: Prosumers



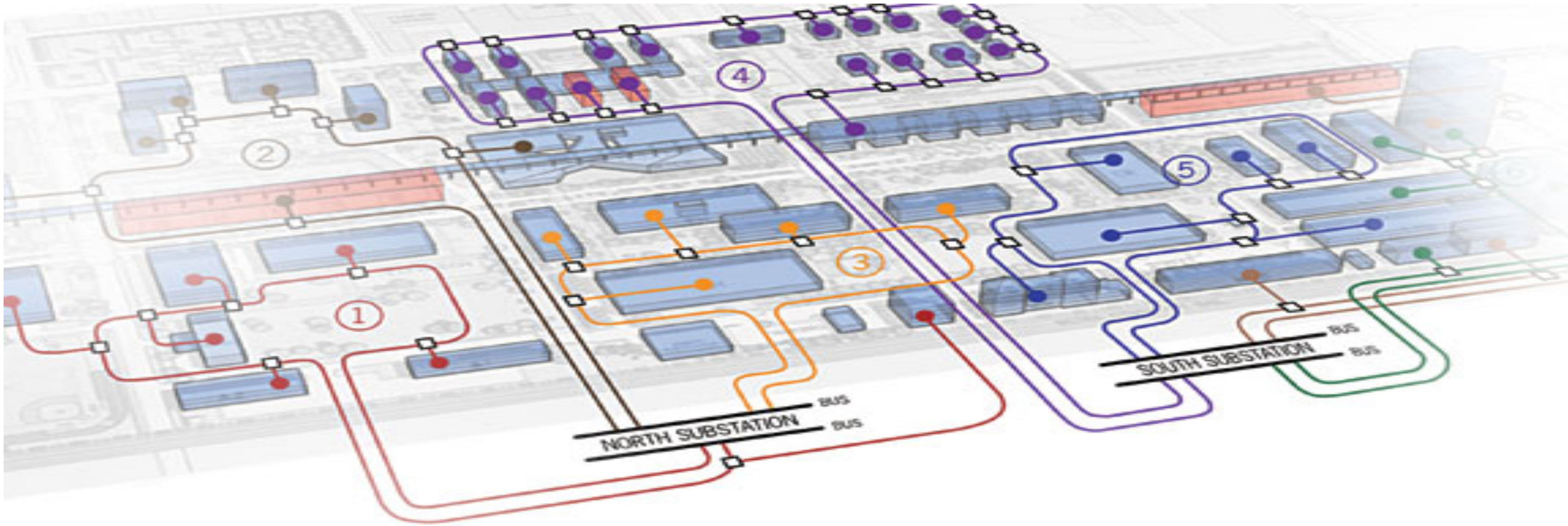
Example: Load-Assisted Freq. Reg.

- Critical to balance generation and load
- Large generators can fail. (Large generator = $1 billion).
- Must have reserve -> build another generator.



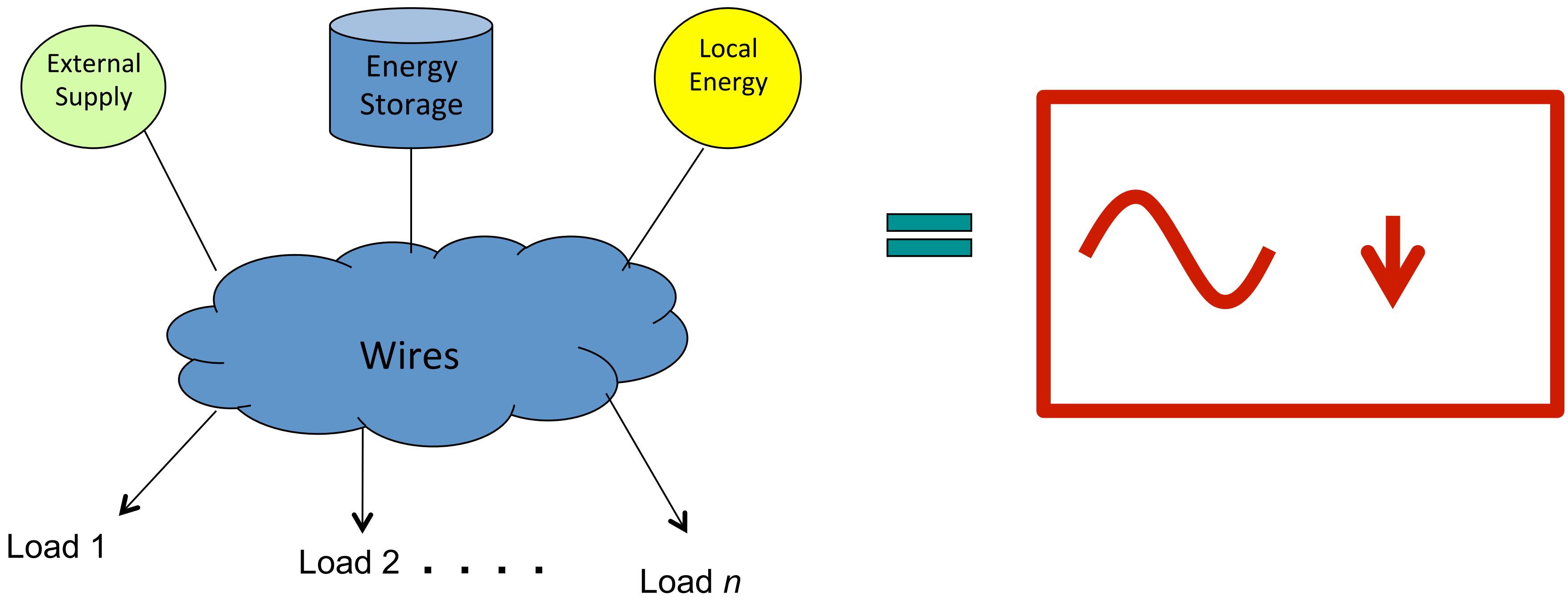
- Instead, can wait or stop air-conditioners, EV charging, refrigerator cycling, storage, water pumps, and other ***deferrable loads***.
- Need precise information, control and services infrastructure.

Example: Islanded Microgrid



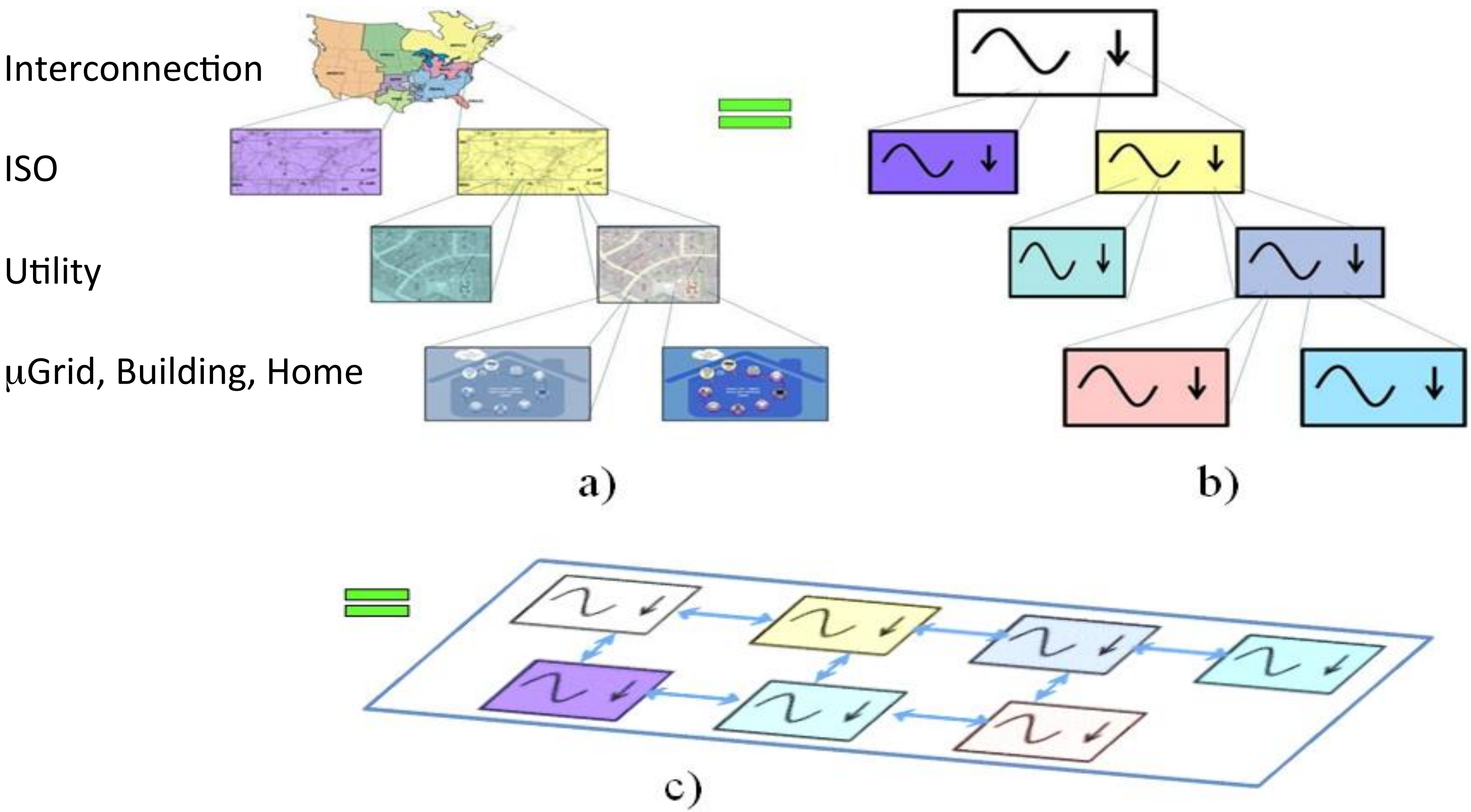
- Angle separation in a microgrid < 1 degree
- Islanded synchronization, islanded angle matching, and connection at zero closing. -> 100 µs
- Storage, solar, and some wind are inverter interfaced.
  - Paralleling these requires tight synchronization -> 1 ms
  - Synchronizing the firing angle reduces noise -> 20 µs

Prosumer Abstraction



- A generic model that captures basic functions (produce, consume, store, etc.) can be applied to power systems at any scale.

Flat Electricity Industry



Future Grid Summary

- Emergence of Prosumers
- Cyber-control of the entire infrastructure.
- All actors can participate and help out. Examples:
  - EV-assisted frequency regulation
  - Deferrable loads and storage systems
  - Self-restoration and self-healing
  - Autonomous, stand alone microgrids.
- Use real-time middleware
  - Platform for real-time prosumer services
  - Electricity operating system
  - Internet for Energy

Research Needs

1. Distributed Control Architecture
    1. Information Architecture
    2. Computation Architecture
    3. Communications Architecture
    4. Security Architecture
2. Scope and Protocol harmonization:
    1. Inside the electricity industry
    2. With other industries.
    3. Multi-scale model unification
3. Who needs what quality (reliability, speed, precision) of information.
    1. Strictly Autonomous versus Networked Control

Research Needs

4. Understand the combined CPS dynamics:
    1. **Modeling:** what layers and components are relevant
    2. **Theory and Analysis**: i.e. can we proof a time bound for guaranteed grid stabilization?
    3. **Simulation:** Physics of Electric Power, Sensing and Actuation, Distributed Controllers, Communication, Information, Computation -> Giant co-simulator.
    4. **Programming:** Can a generic AF be developed?
5. Can core distributed power control protocols be embedded in the middleware?

Thanks!