INFORMATION AND COMPUTATION HIERARCHY FOR SMART GRIDS

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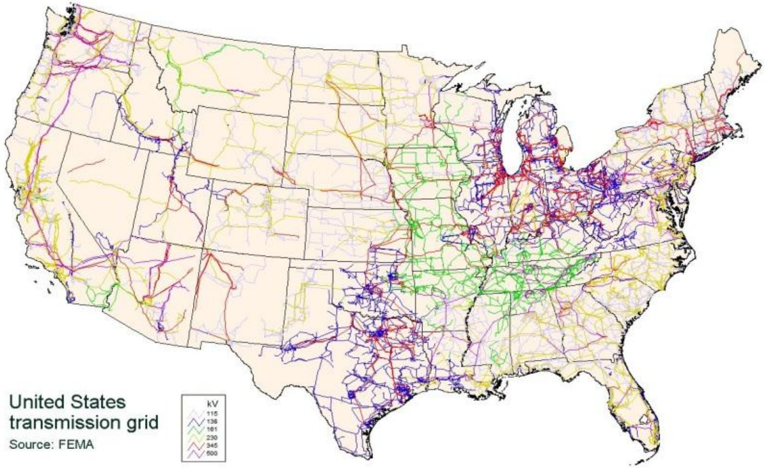
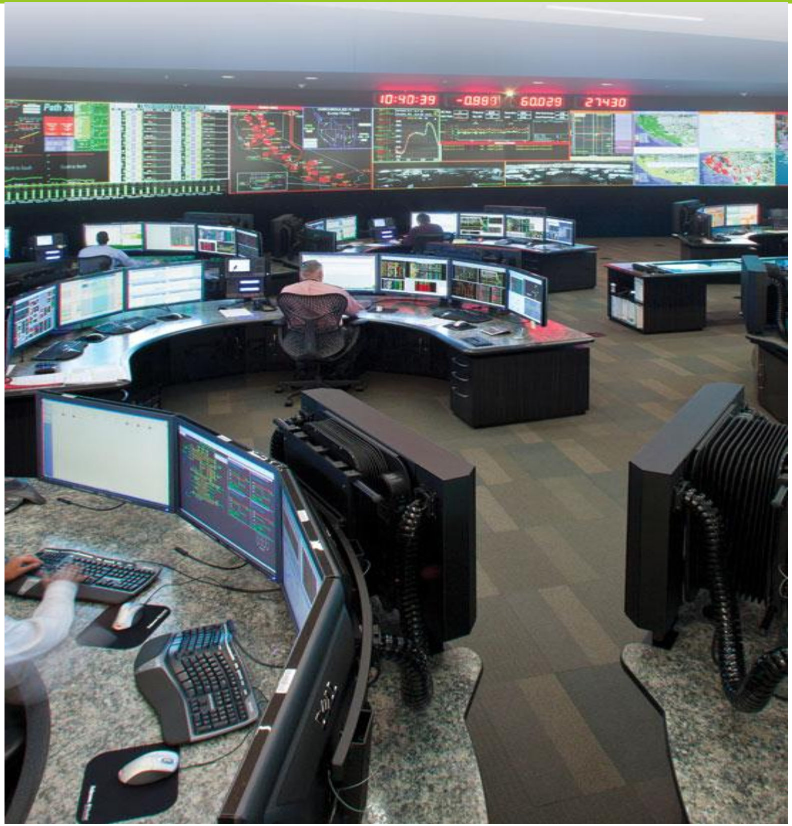
The oldest, largest, & most complex CPS

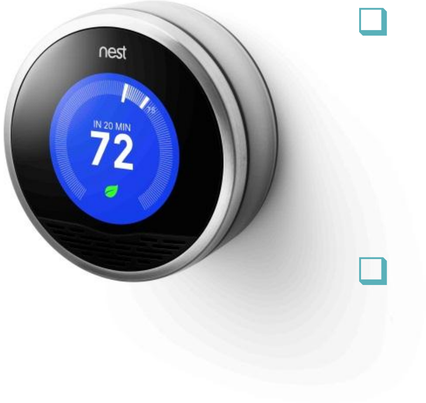




Possibly the oldest, the largest and one of the most complex CPS

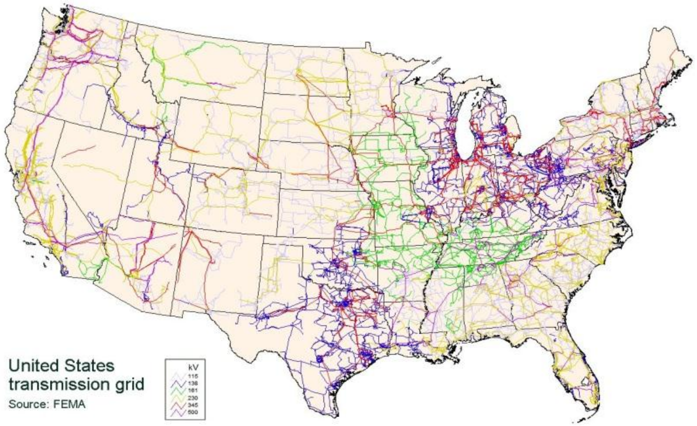
- ~10,000 plants, ~15,000 generators
- Miles of lines and costly equipment

Emerging operating regimes



- Greater renewable (stochastic and varying) and distributed generation
- Large scale consumer participation through demand response
- Increasing reliance on cyber infrastructure transmission and distribution. Security and privacy!
- Disruptive technologies in storage and electric vehicles

Technology drivers



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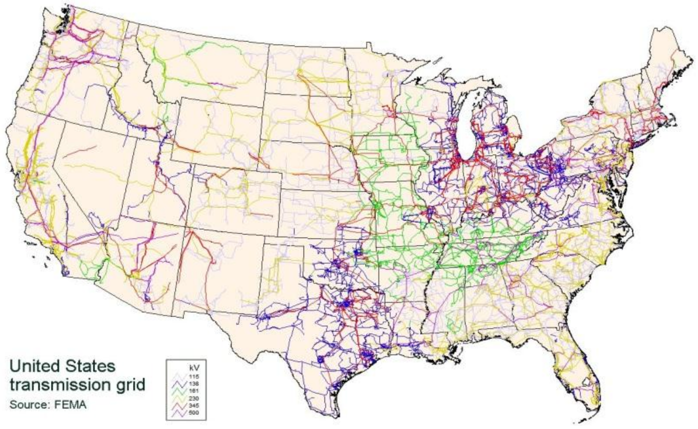
- PMUs: high resolution measurements for enhanced observability in time and space.
- Smart meters: enhanced observability in the distribution network
- Smart wireless devices and apps: empower user participation.
- Cloud computing: unprecedented computation power and storage capability

What makes the future grid different….



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Stochasticity:

- Non-Gaussian, long range dependencies and heavy tail phenomenon
- Rare events with enormous cost
- Contingencies with uncountable # scenarios.

Big data over cyber infrastructure:

- Cross-network, multi-scale, multi-modality, locational, bad, and malicious
- Impractical to communicate, no place to store, overwhelming in size and complexity, difficult to learn, and possibly dangerous to use

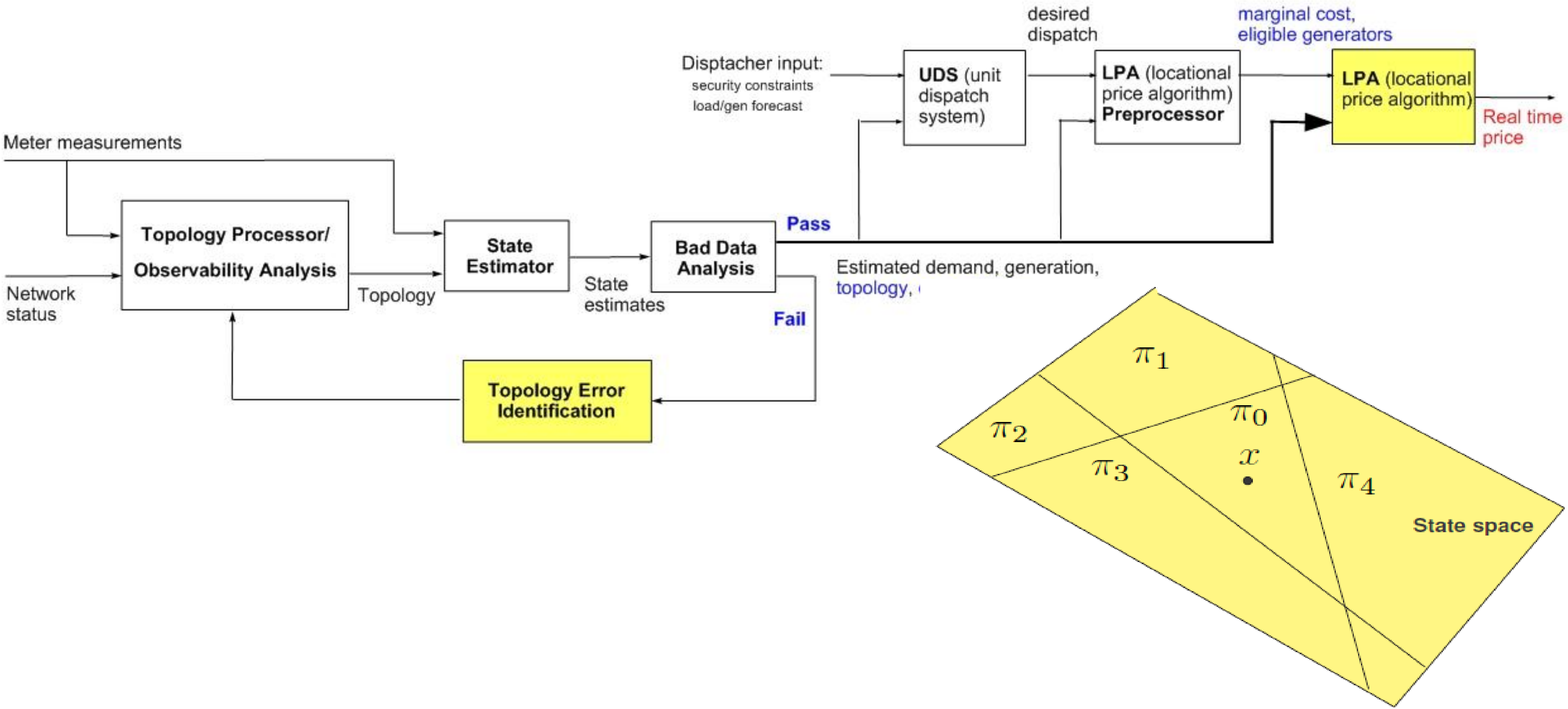
Information and computation hierarchy

- **Networking architecture**
  Public and private infrastructure
- **Computation architecture**
  HPC, cloud
- **Quality of service:**
  Speed, delay, reliability, risk (not just in average)
- **Robustness, tolerance, resilience**
  missing packets, inconsistency, bad and malicious data…
- **Complexity, costs, security, privacy, etc.**

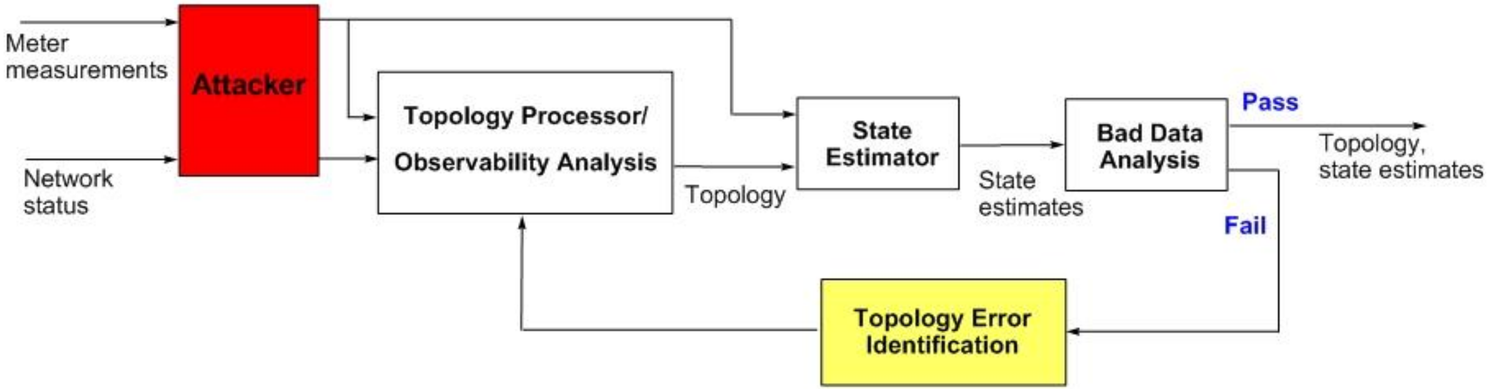
Information hierarchy in space

- Information hierarchy in space addresses the problem of collecting and disseminating information to a large geographical area.
- CAP: a fundamental limit on distributed reliable processing.
  - Consistency: see the same data at the same time
  - Availability: all response upon request
  - Partition tolerance: fault tolerant (e.g. N-1contingencies)
- Locality: information generated at different locations may be inconsistent, out of date, erroneous, even malicious.

Example: cybersecurity of smart grid



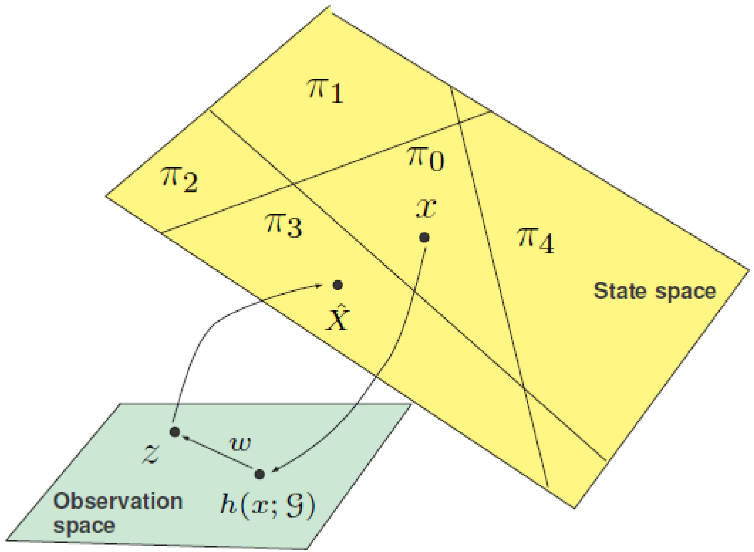
Man-in-the-middle attack

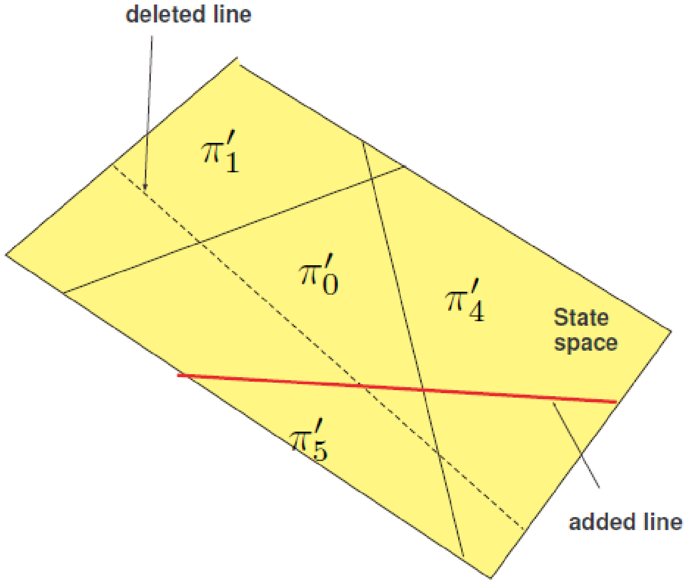


Attack objectives:

- **mislead** the control about the topology and the state of the network;
- make the attack **undetectable**

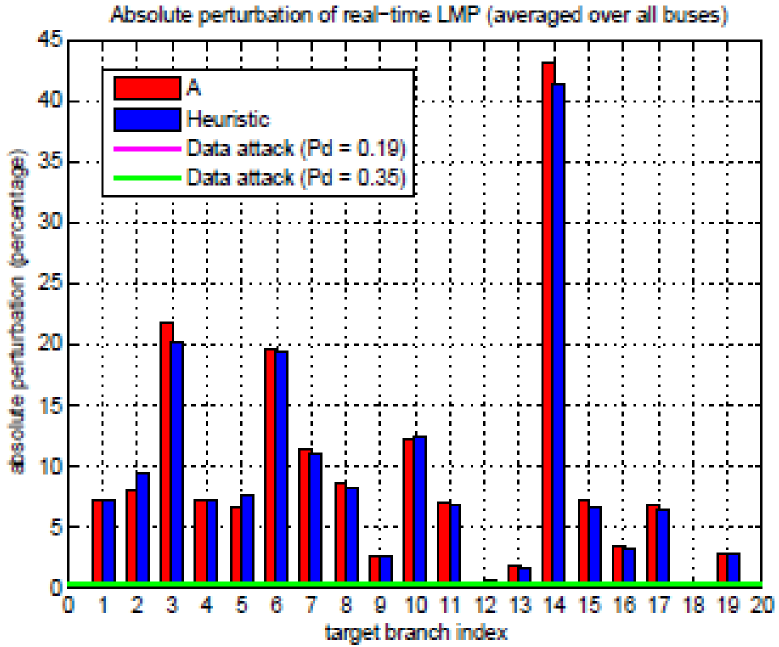
Impacts of data and topology attacks

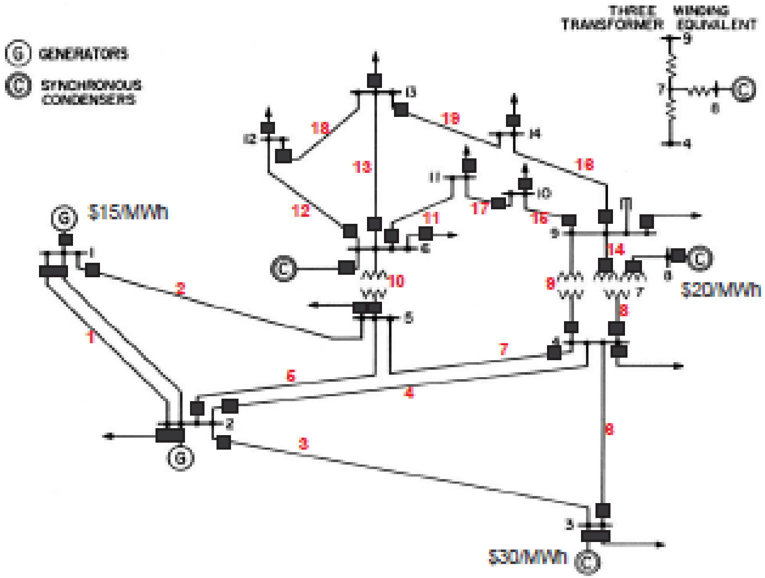




- ❑ Data attack changes LMP via state estimates.
- ❑ Topology attack changes LMP directly.

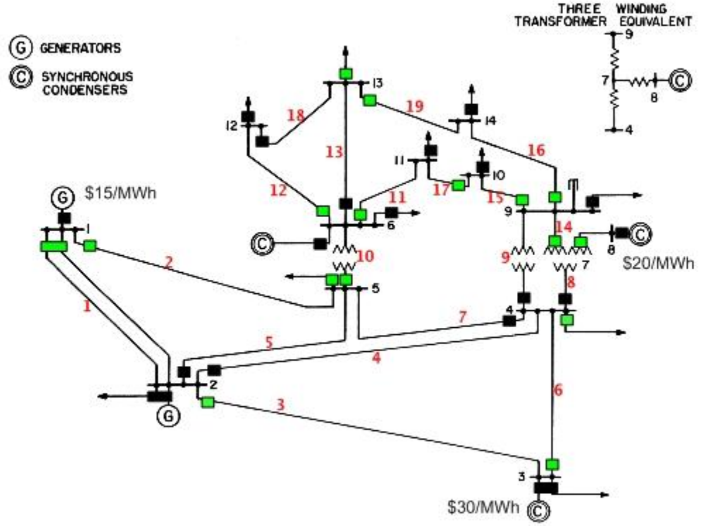
Topology attacks are more powerful

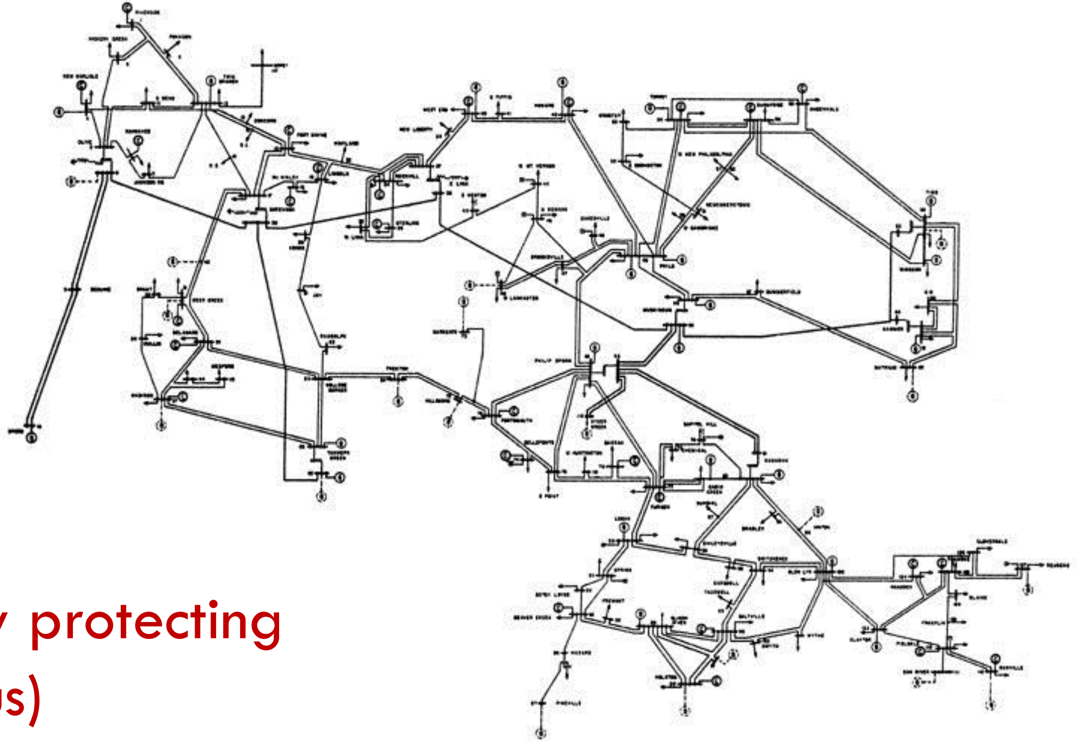




- Change a few (<5) meter data and use only local information!

Against joint topology & data attacks





Making attack detectable by protecting

- ~30% meters (IEEE 14 bus)
- ~25% meters (IEEE 118 bus)

Information hierarchy in time

- Information hierarchy in time addresses the problem of what kind of information is required and by what time decisions have to be made.
- Time sensitive decisions are essential for the integration of stochastic generations and demand response.
- The value of information diminishes if it is not delivered in time. Is TCP/IP framework good enough?

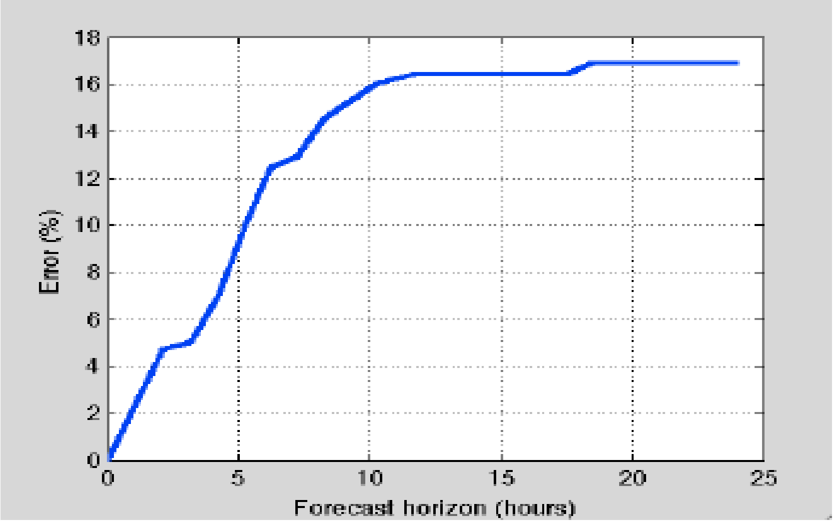
Example: Risk Limiting Dispatch

Existing modus operandi

(day ahead + real time)

- ❑ Decoupled dispatch
- ❑ Static reliability criteria
- ❑ Limited recourse opportunities
- ❑ Demand treated as inelastic

Forecast error vs. horizon

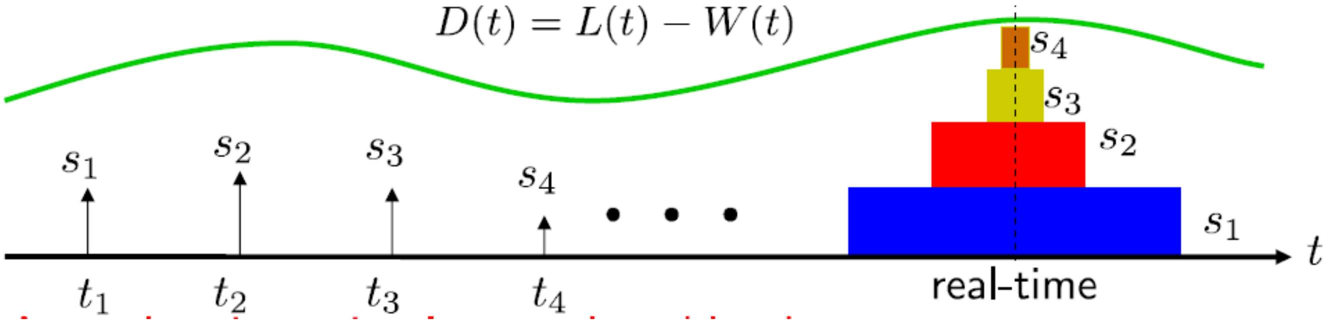


CAISO study: with 33% renewable

- ❑ Regulation capacity: 227MW → 1,135MW.
- ❑ Load following capacity: 2,292MW → 4,423MW

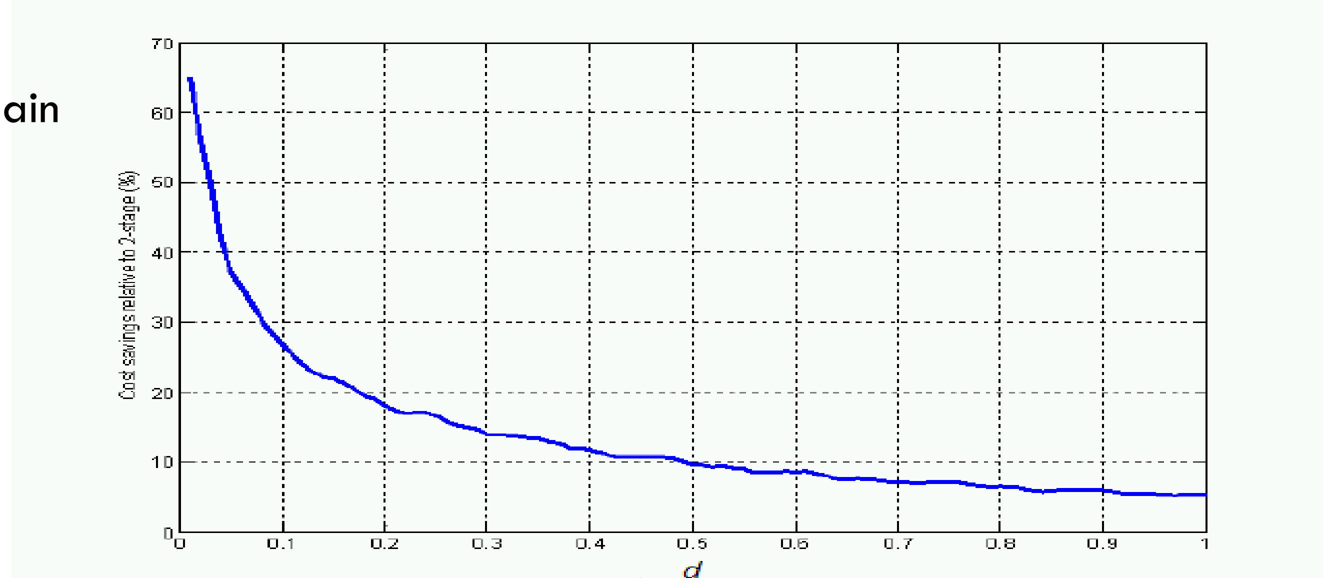
Example: risk limiting dispatch

- Structure: intra-day multi stage energy purchase and sales
- Information structure: all observation prior to decision time
- Criteria: dynamic reliability and risk limits
- Optimal policy: Dual threshold: “buy-hold-sell”



Example: Risk Limiting Dispatch

% gain

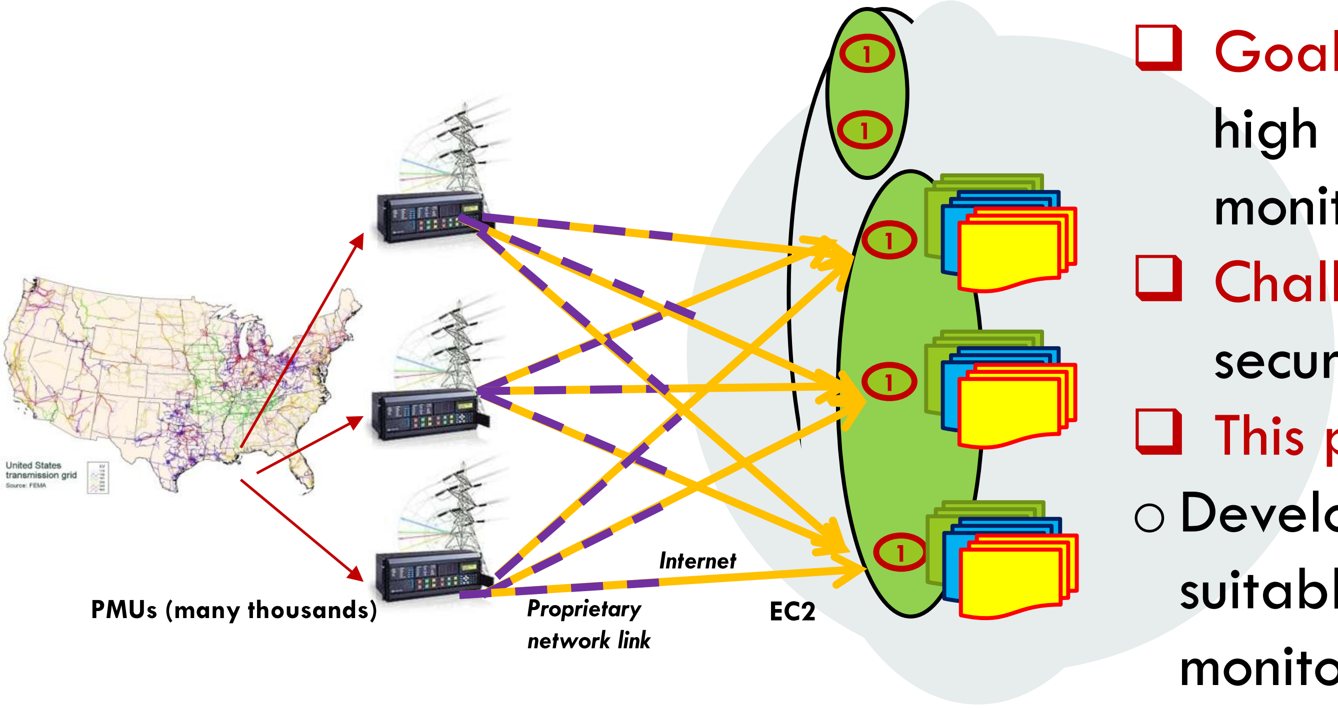


Wind shortfall

Related references

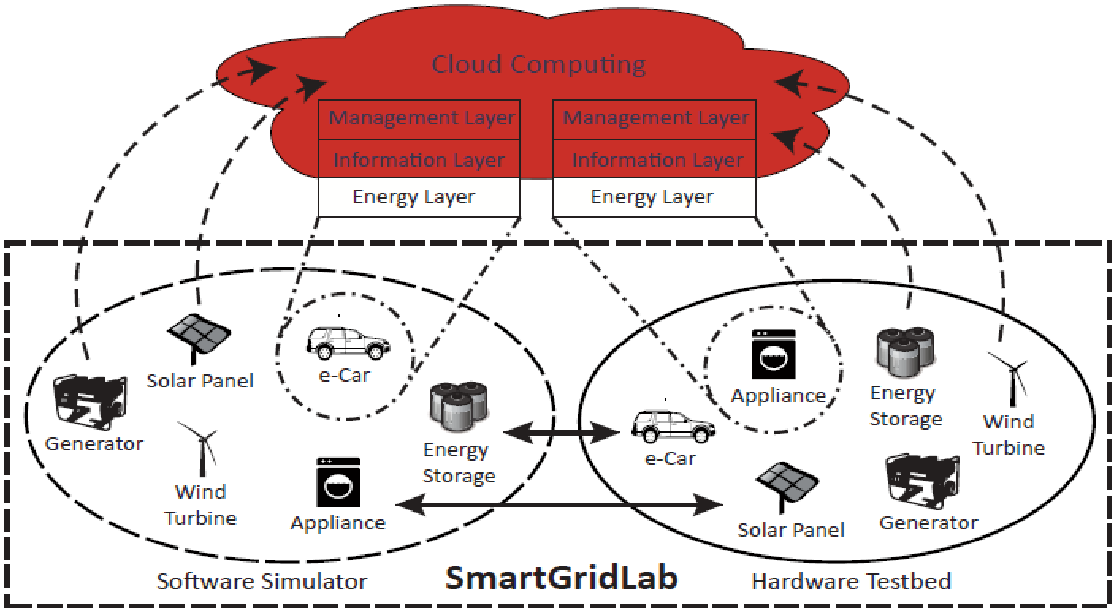
- E. Bitar et. al., Bringing wind energy to market, IEEE TPS, to appear.
- R. Rajagopal, E. Bitar, P. Varaiya, F. Wu, "Risk limiting dispatch for integrating renewable power," Intl J. Elect. Power & Energy Systems, Jan 2013.

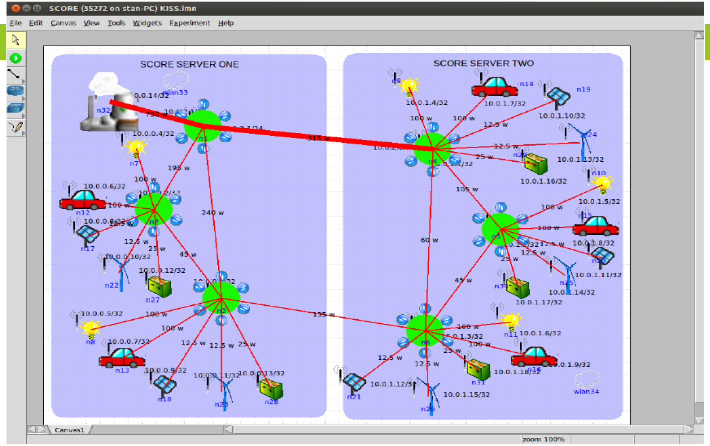
GridCloud: national scale grid monitoring

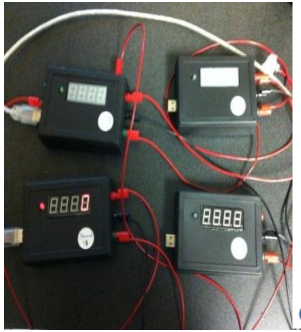


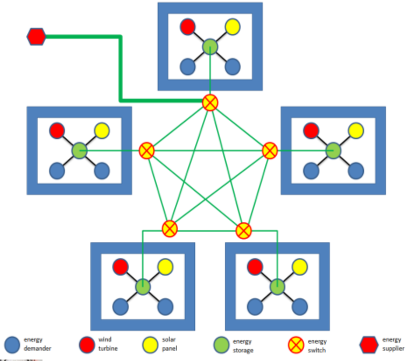
- **Goal:** cloud scale robust high performance monitoring infrastructure
- **Challenges:** CAP. Cyber security and privacy.
- **This project:**
  - Develop cloud infrastructure suitable for large scale monitoring and control.
  - Optimized tradeoffs

System testbed: SmartGridLab









Summary remarks: Not just a CPS

The grid is a Social Economic CPS!

CPS (circa 1950) → Economic (circa 1980) →Social (today!)

- Uncertainties are fundamental. Over provision may not be the right approach; imperfections and uncertainties must be part of the design.
- Time is critical. Deadline matters. Best effort may not be good enough.
- Data (big, bad, malicious) represent fundamental challenges for the future grid.