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

- **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

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What makes the future grid different....

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

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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-1 contingencies)

- **Locality:** information generated at different locations may be inconsistent, out of date, erroneous, even malicious.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

CAISO study: with 33% renewable

- Regulation capacity: 227MW $\rightarrow$ 1,135MW.
- Load following capacity: 2,292MW $\rightarrow$ 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

Related references

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.