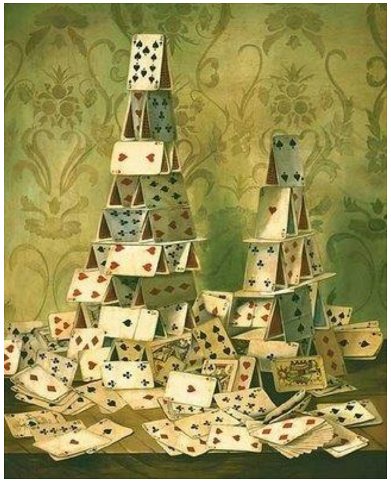
How Do We Manage the Complexity of the Grid?

ISO new england

Control at Large Scales: Energy Markets and Responsive Grids, Minneapolis



Eugene Litvinov

…complex systems are counterintuitive. That is, they give indications that suggest corrective action which will often be ineffective or even adverse in its results.

Forrester, Jay Wright

Reliability Is the Core of ISO New England's Mission

Fulfilled by three interconnected and interdependent responsibilities

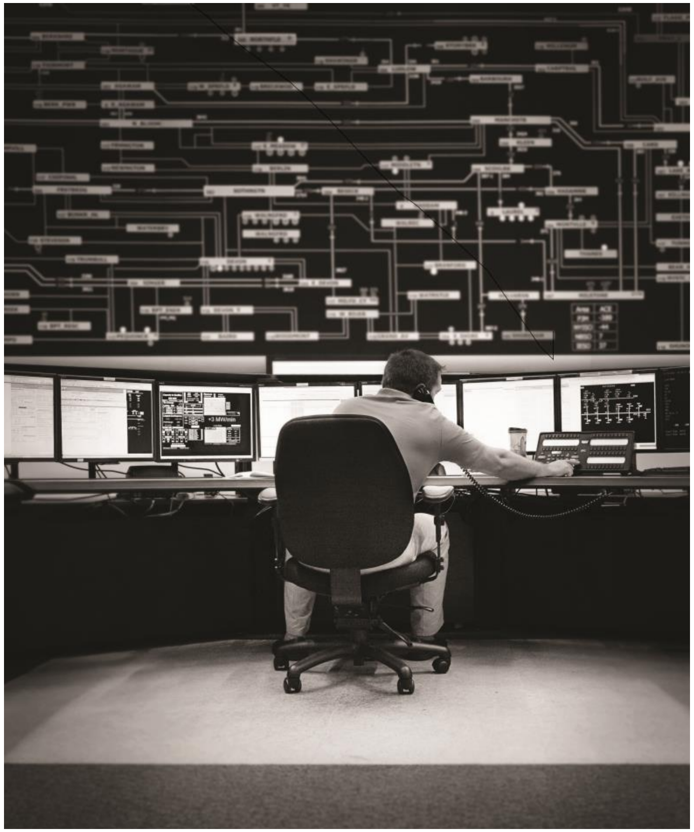
Overseeing the day-to-day operation of New England's electric power generation and transmission system

Managing comprehensive regional power system planning

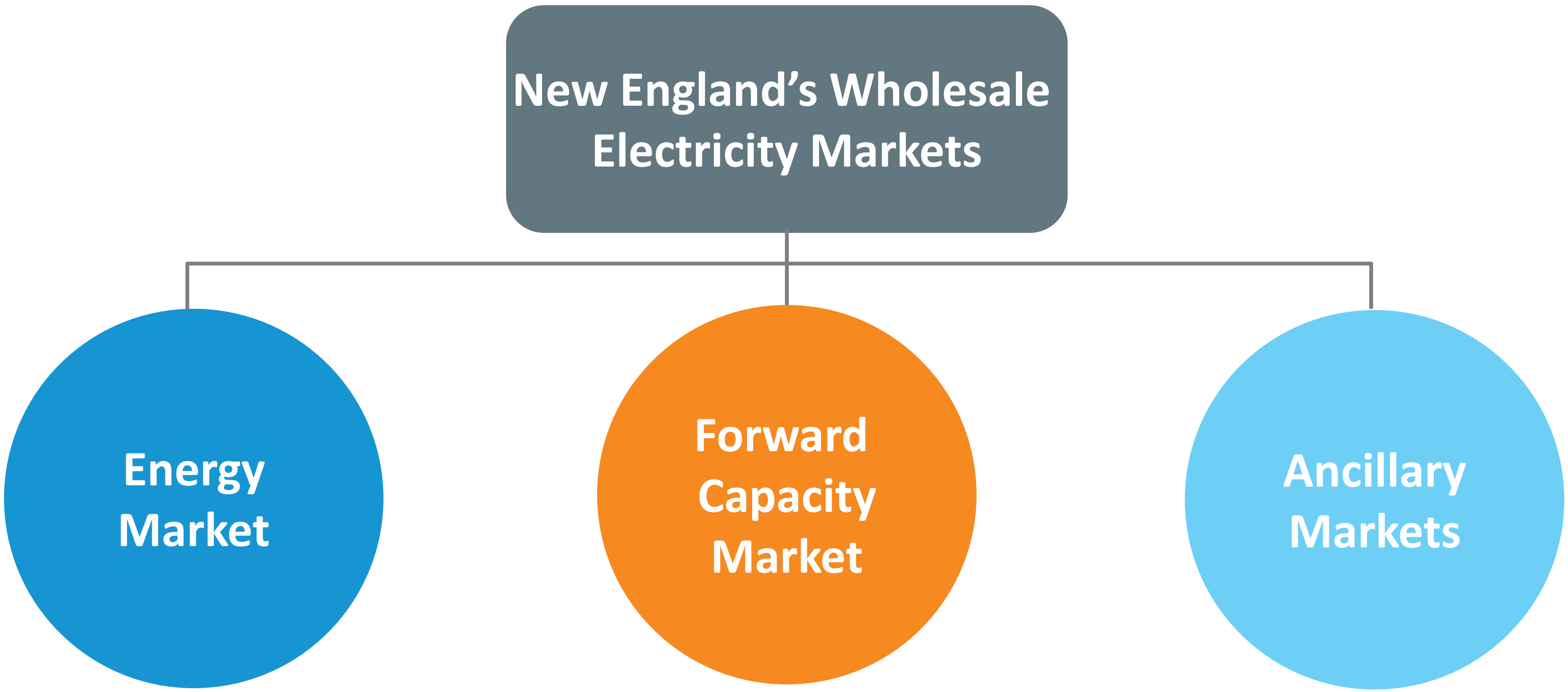
Developing and administering the region's competitive wholesale electricity markets

Ensuring Reliable Power System Operations Is a Major Responsibility

- Maintain minute-to-minute reliable operation of region’s generation and transmission system
- Perform centralized dispatch of the lowest-priced resources
- Coordinate and schedule maintenance outages
- Coordinate operations with neighboring power systems



Ensuring Fair and Efficient Wholesale Markets Is a Major Responsibility



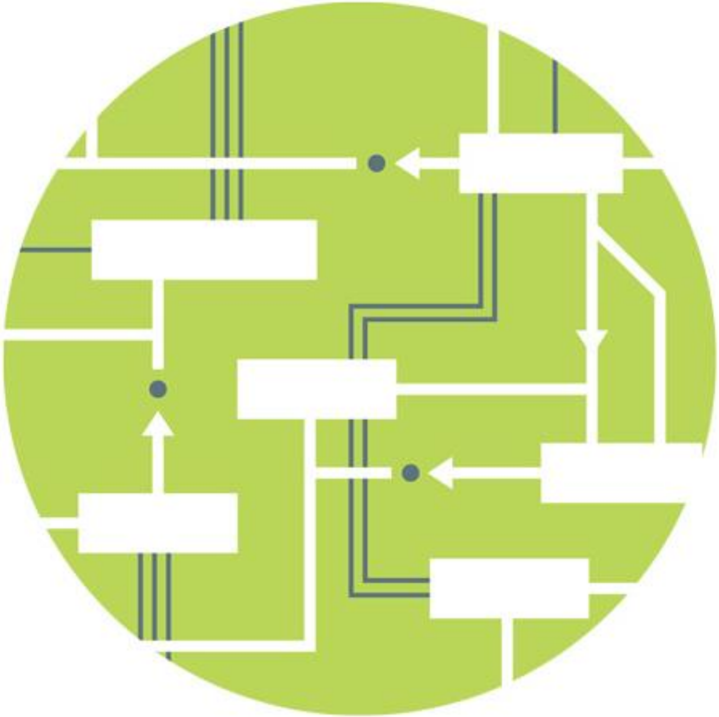
Energy Market: Daily market for wholesale customers to buy and sell electric "energy"

Forward Capacity Market: Three-year forward market that commits "capacity" resources to meet system resource-adequacy needs

Ancillary Markets: Reserves and regulation provide support for system operations

Managing Comprehensive Regional Power System Planning Is a Major Responsibility

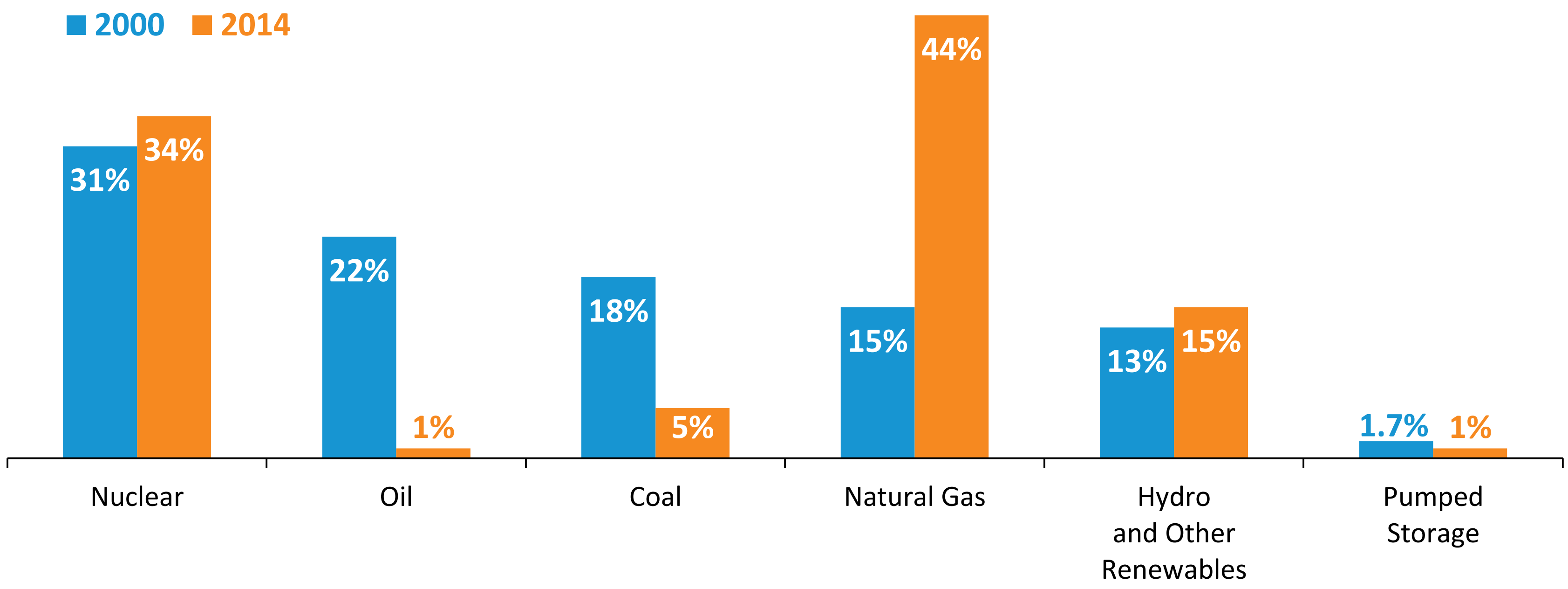
- Manage regional power system planning in accordance with mandatory reliability standards
- Administer requests for interconnection of generation, and regional transmission system access
- Conduct transmission system needs assessments
- Plan regional transmission system to provide regional network service
- Develop annual Regional System Plan (RSP) with a ten year planning horizon



New England Has Seen Dramatic Changes in the Energy Mix

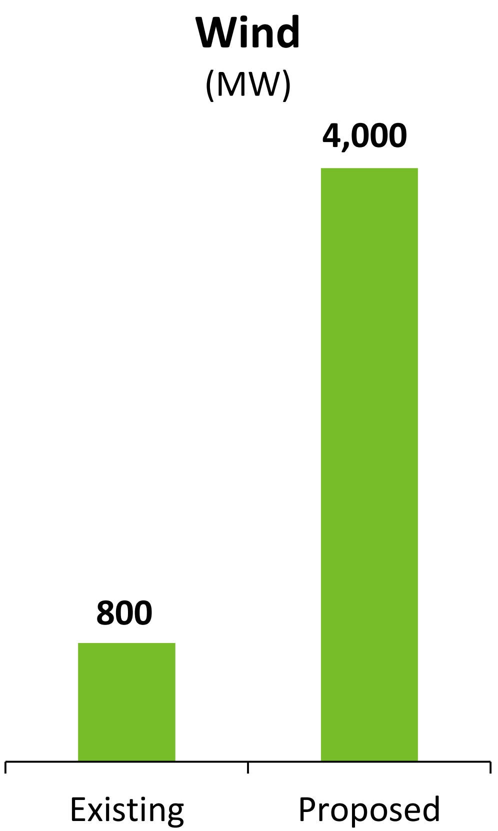
The fuels used to produce the region's electric energy have shifted as a result of economic and environmental factors

Percent of Total **Electric Energy** Production by Fuel Type
(2000 vs. 2014)

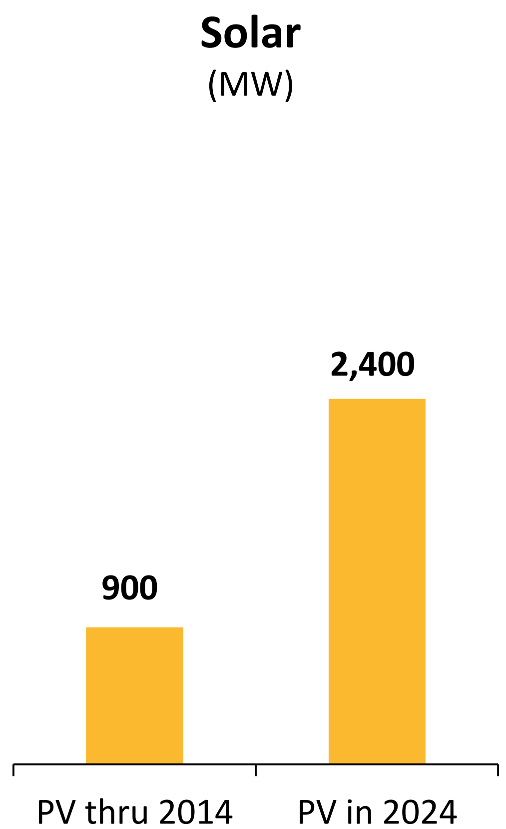


Source: ISO New England Net Energy and Peak Load by Source
Other renewables include landfill gas, biomass, other biomass gas, wind, solar, municipal solid waste, and miscellaneous fuels

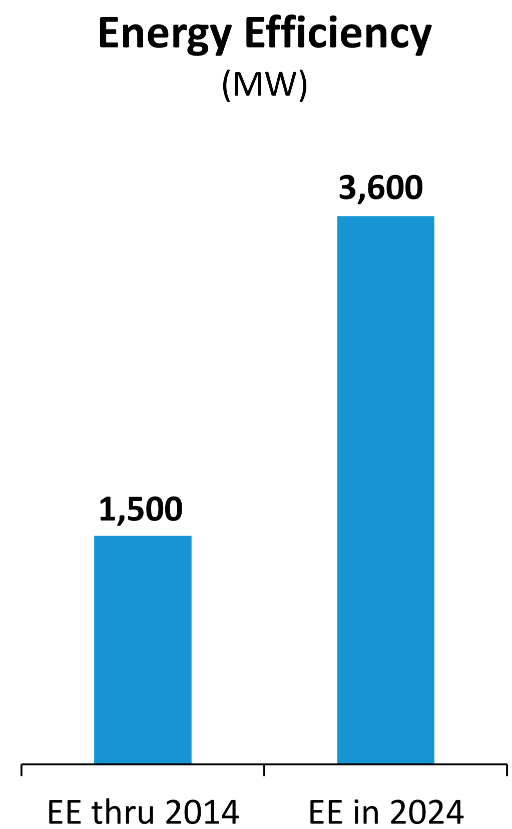
Renewable and EE Resources Are Trending Up



Nameplate capacity of existing wind resources and proposals in the ISO-NE Generator Interconnection Queue; megawatts (MW).

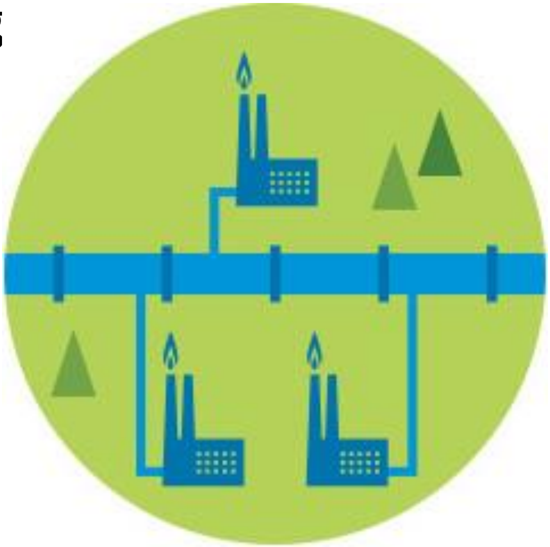


2015 ISO-NE Solar PV Forecast, nameplate capacity, based on state policies.



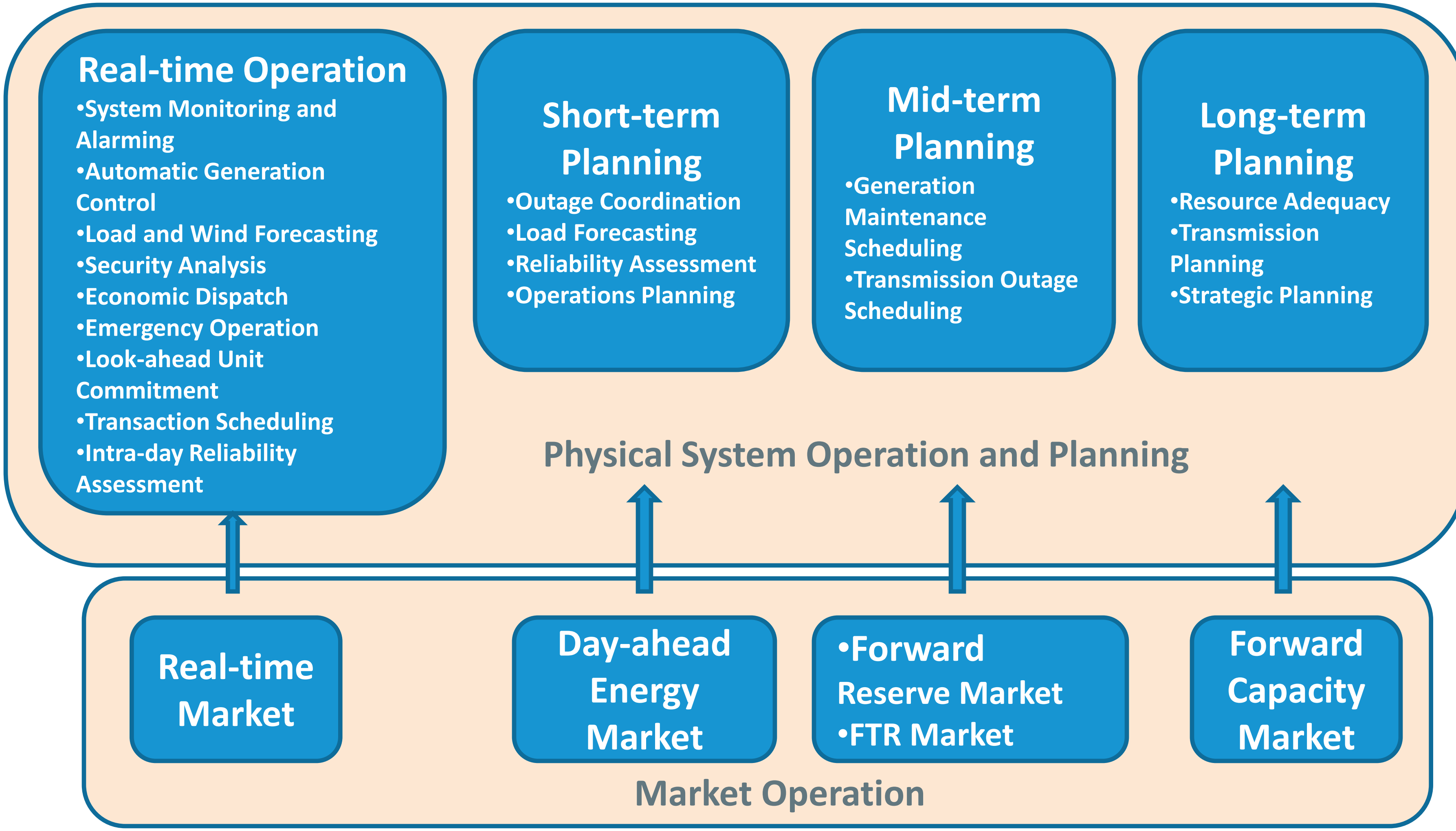
2015 CELT Report, EE through 2014 includes EE resources participating in the Forward Capacity Market (FCM). EE in 2024 includes an ISO-NE forecast of incremental EE beyond the FCM.

Resource Shift Creates Reliability Challenges

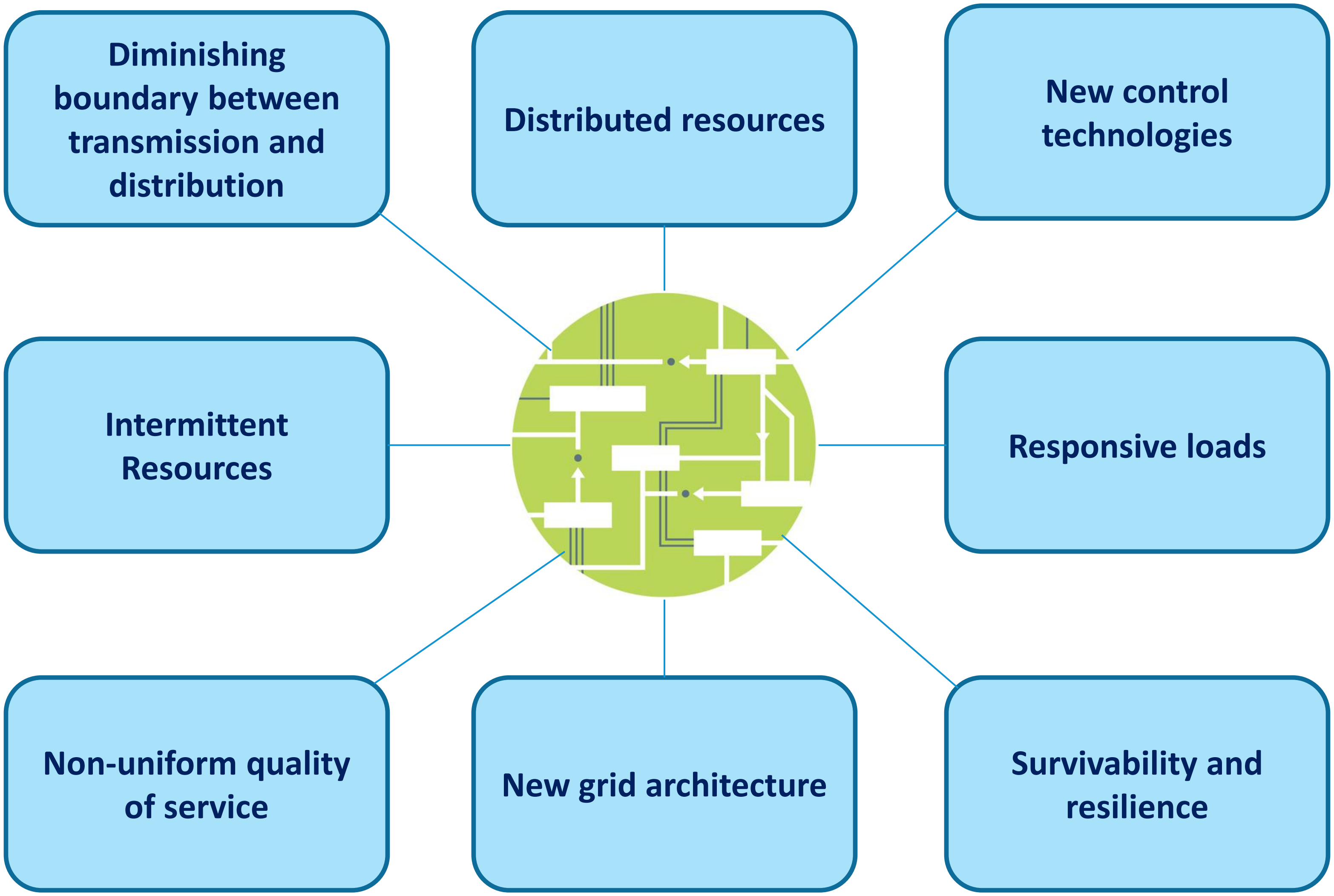


- New England's generation fleet is changing rapidly – older, fossil fuel-fired units are retiring and reliance on natural gas for power generation is increasing
- The ISO must rely increasingly on resources with uncertain performance and availability:
  - Intermittent resources (wind, solar) may not produce power at the times it is needed most
  - Natural gas resources lack fuel storage and rely on "just-in-time" fuel
  - Coal, oil-steam fleet is aging, prone to mechanical problems, subject to increasingly stringent environmental regulations
- Reliable operation of the New England power system is challenged by these developments, particularly during the winter

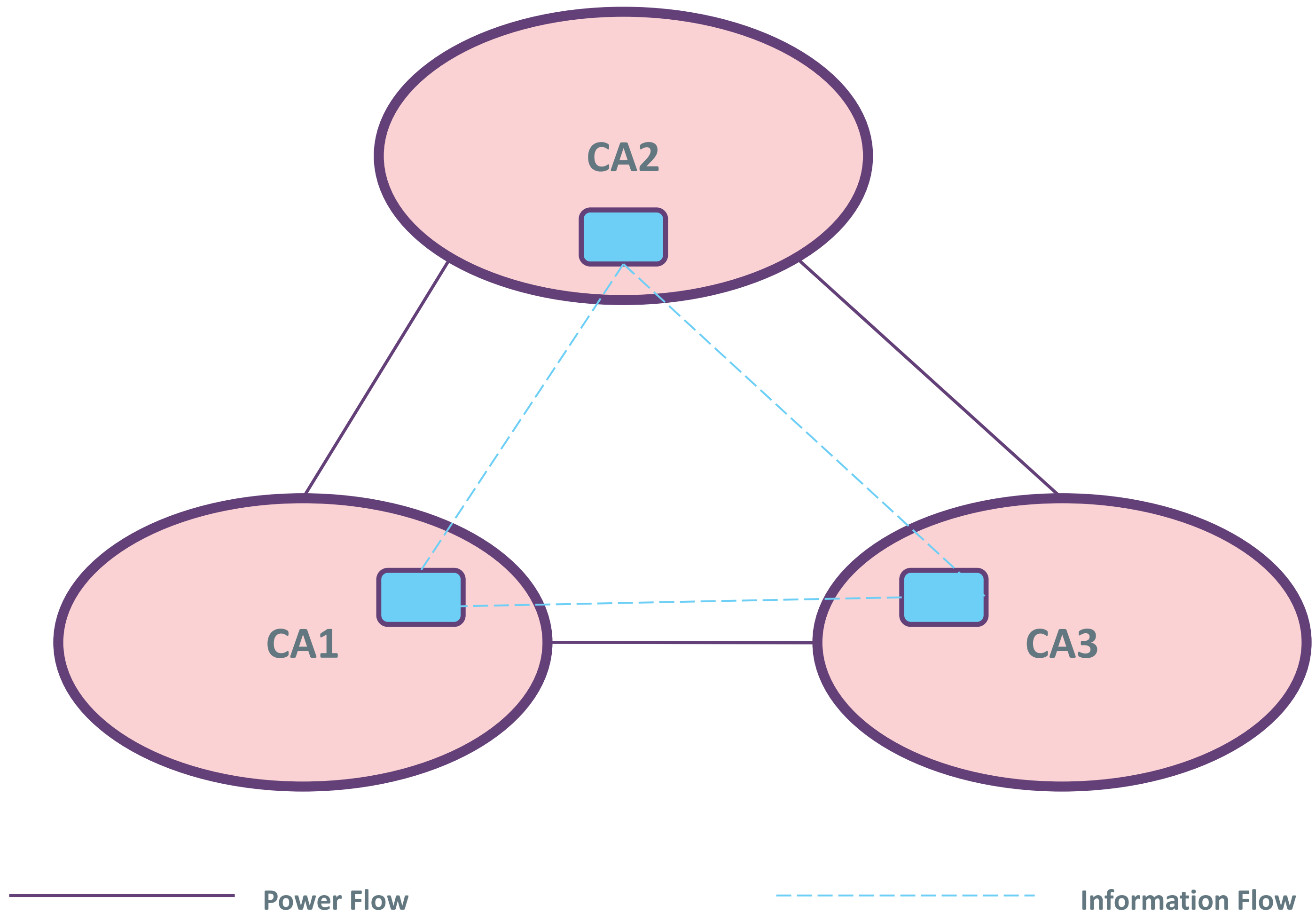
System and Market Operation



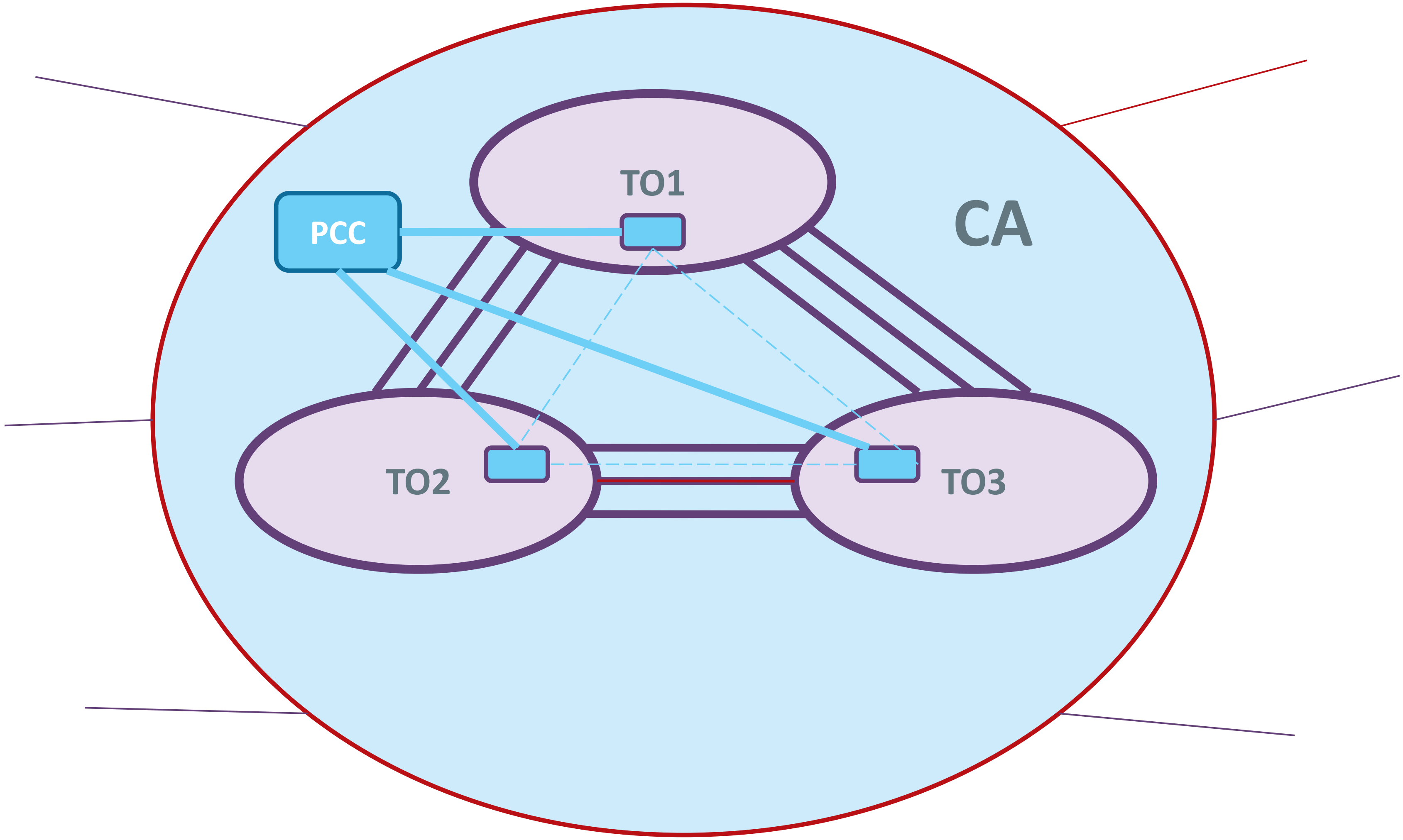
Features of The Future Grid



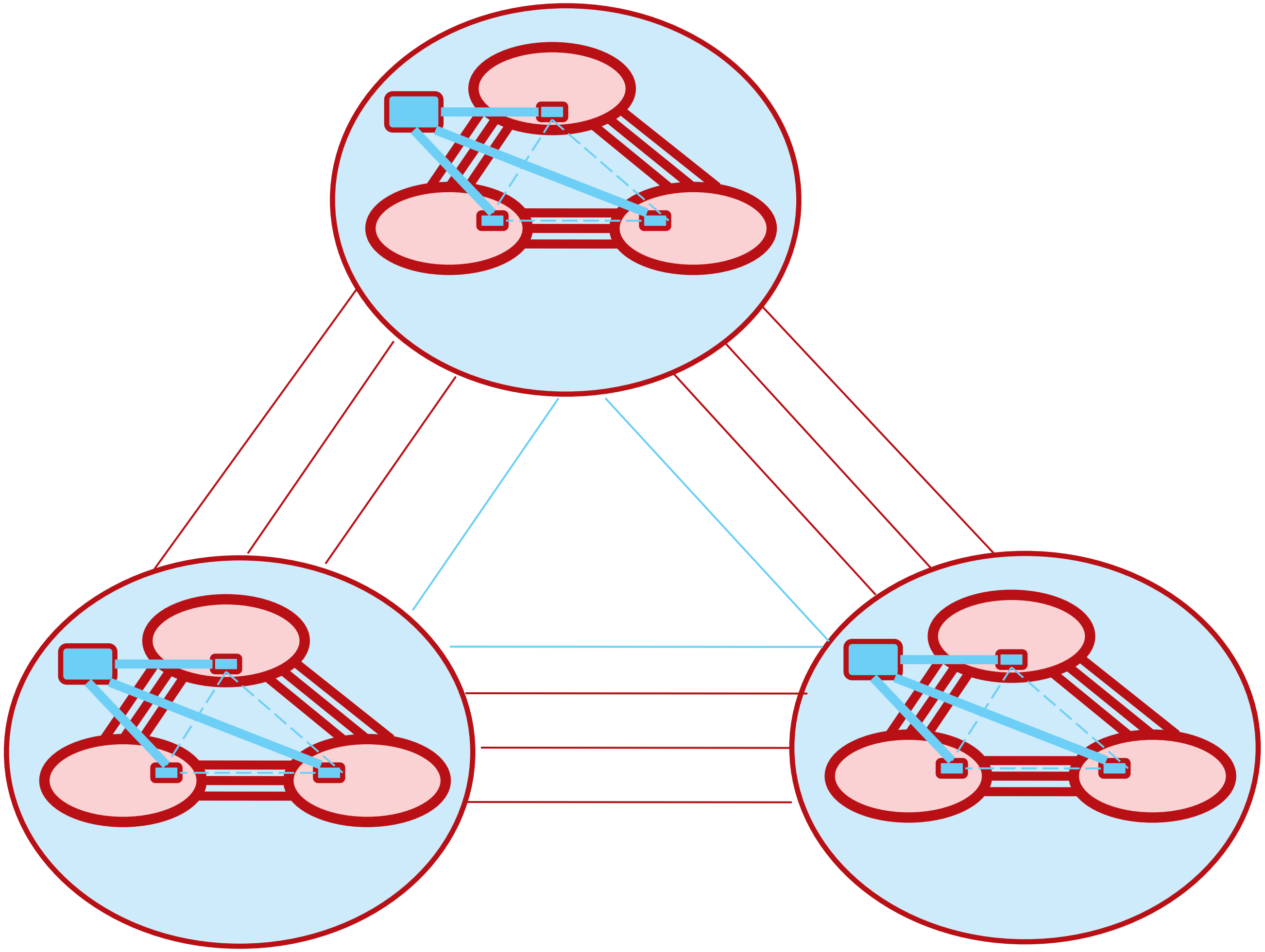
Power System Architecture Evolution (before 1966)



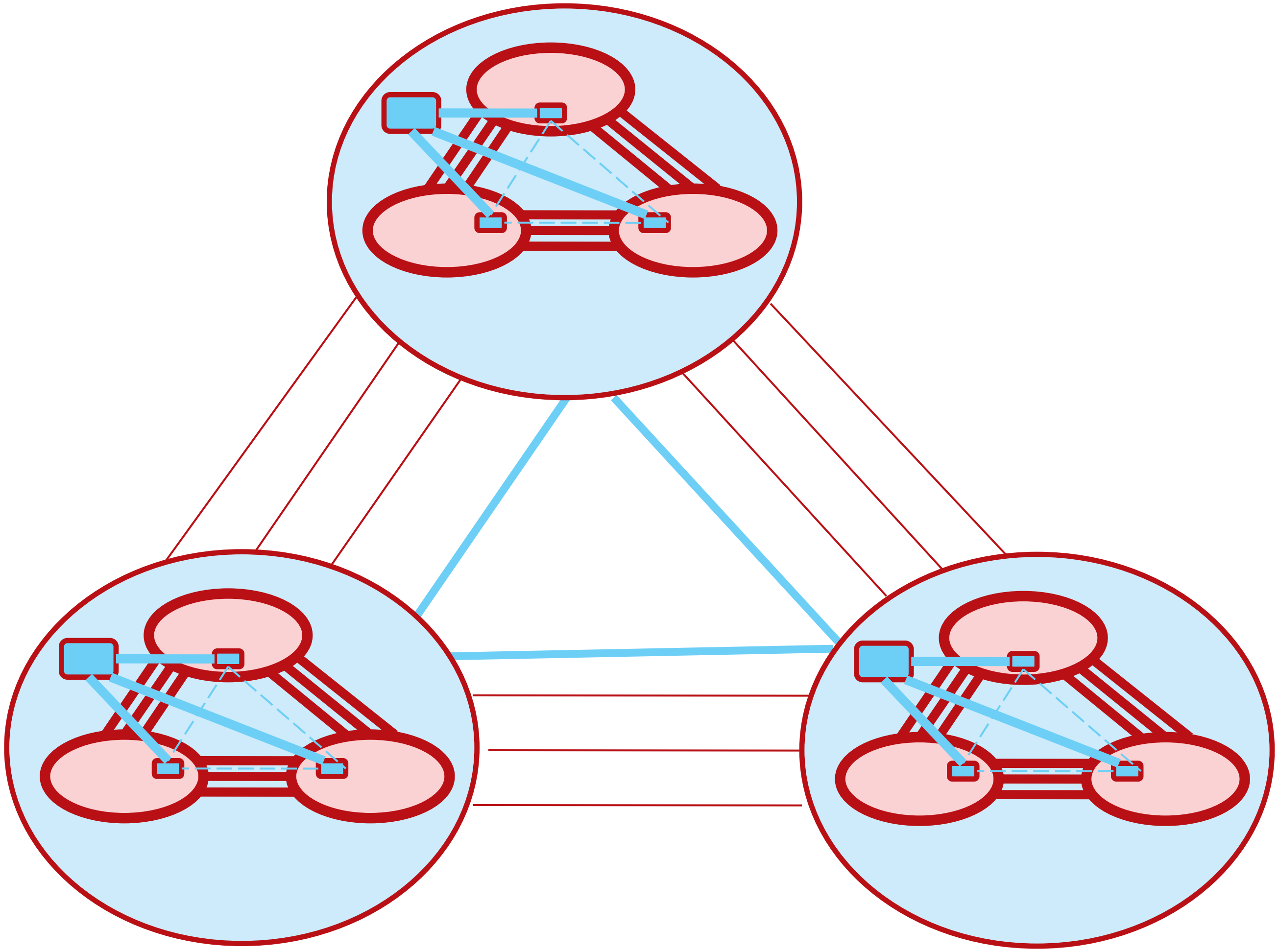
Power System Architecture Evolution (creation of pools)



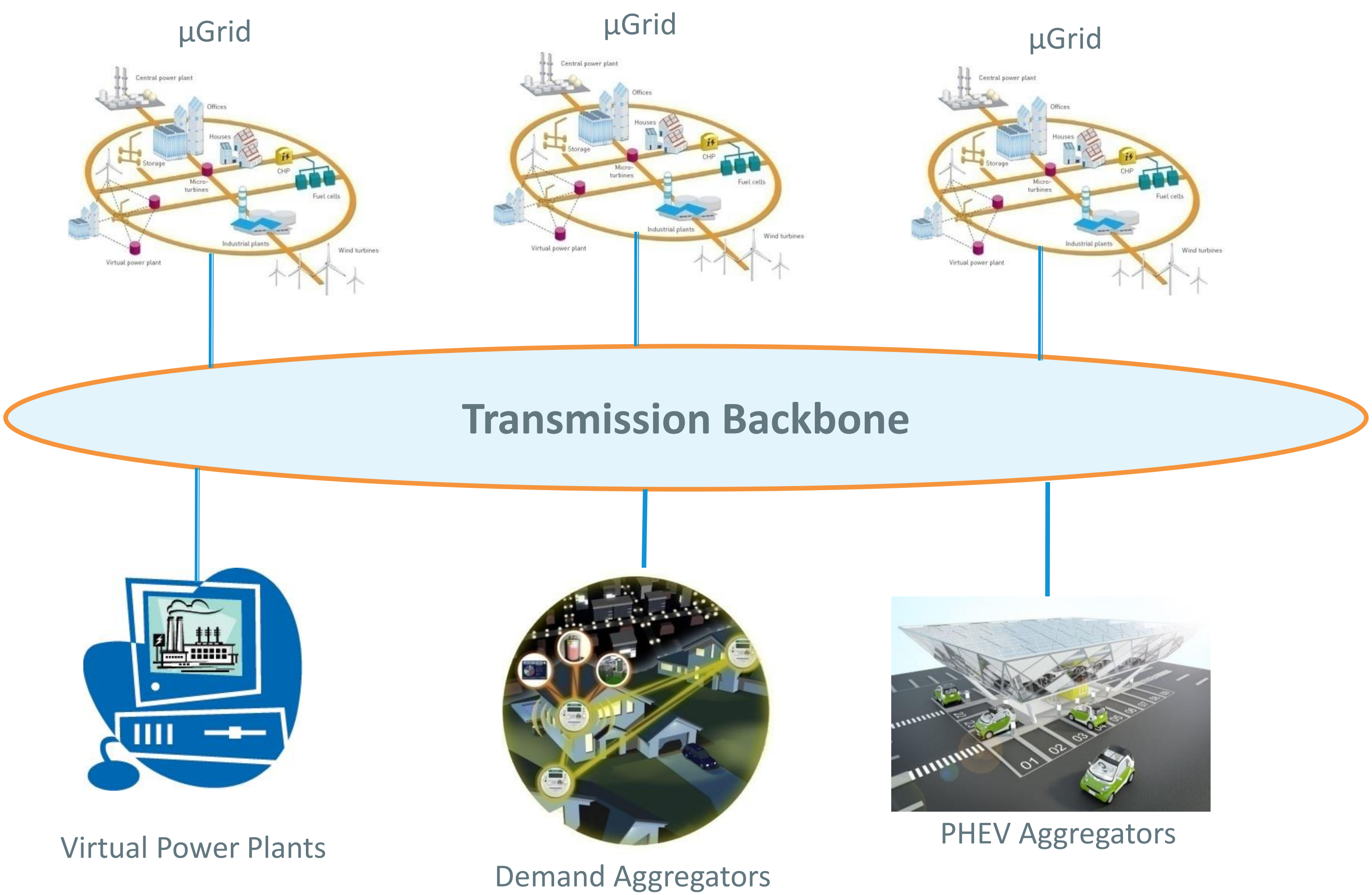
Power System Architecture Evolution (markets)



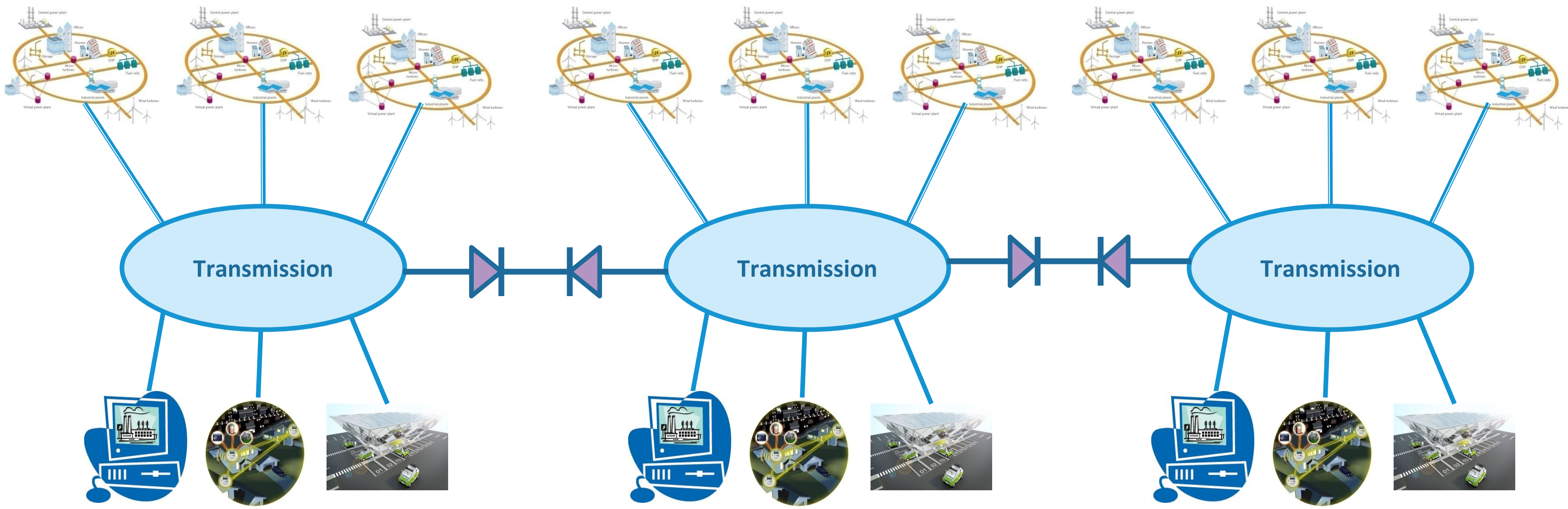
Power System Architecture Evolution (coordinated markets)



New Grid Architecture



Power System Control Evolution (what's next?)



Maybe this?

The Need for Greater Flexibility

New Planning and Protection Concepts

- Rapid response to different disturbances
- Greater reliance on corrective actions
- System integrity protection
- Power quality standards
- System survivability
- Flexible Control Architecture

New Transmission Technologies

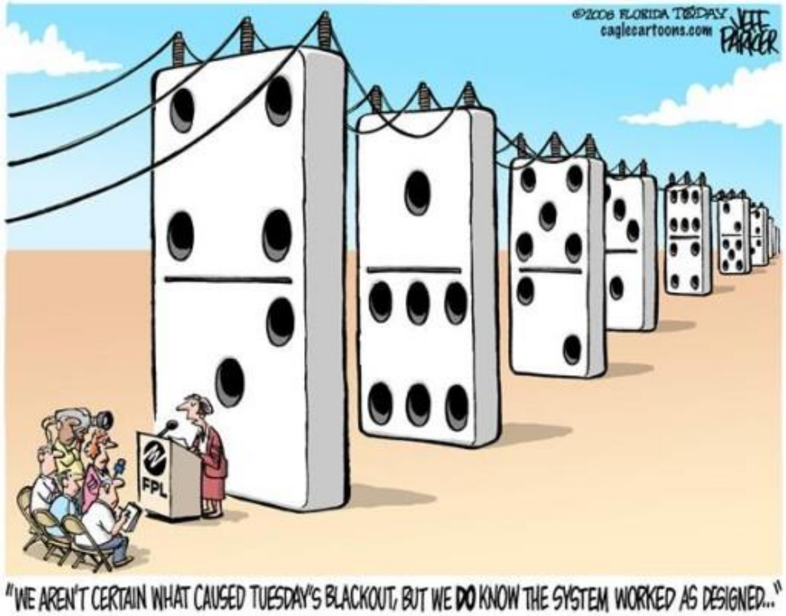
- Power electronics
- Energy storage
- Superconductors
- HVDC and HVDC-lite
- Nanotechnologies

New Operation and Control Strategies

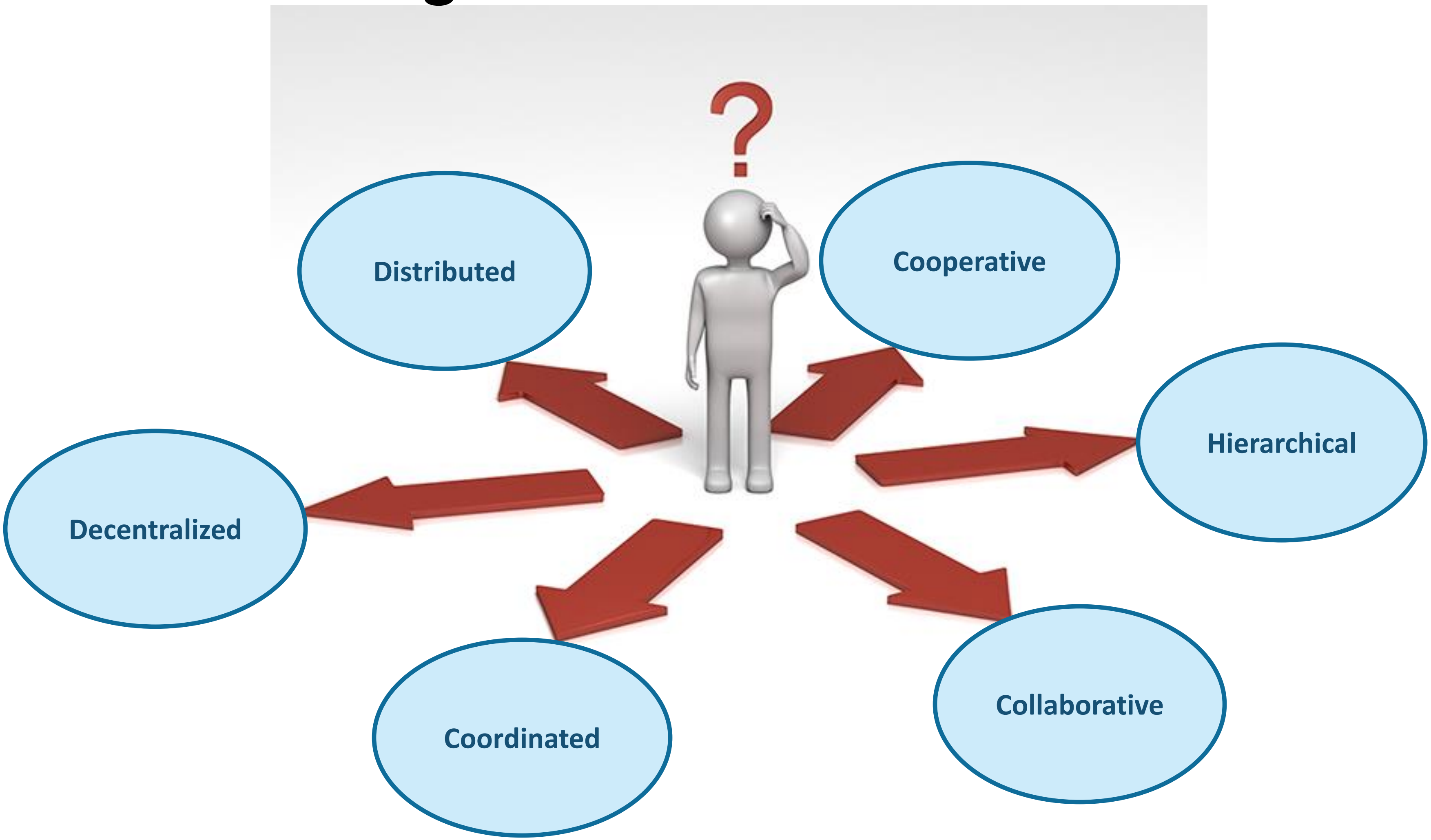
- Risk-based operation
- Wide-area monitoring
- Adaptive islanding
- Transmission switching
- Online constraints calculation
- Dynamic and adaptive line ratings
- Adaptive and distributed control
- New optimization algorithms: robust and stochastic optimization
- Probabilistic methods in planning and real time

What is the Right Control Architecture?

- With the evolution of the Grid architecture, how should the control architecture change?
- Too many moving parts
- Unobservable entities and events
- Perimeter disappearing
- Transactive energy initiative
- Ad hoc decentralization
- New type of contingencies
- High interdependence among different infrastructures (gas, communication, IT, etc)

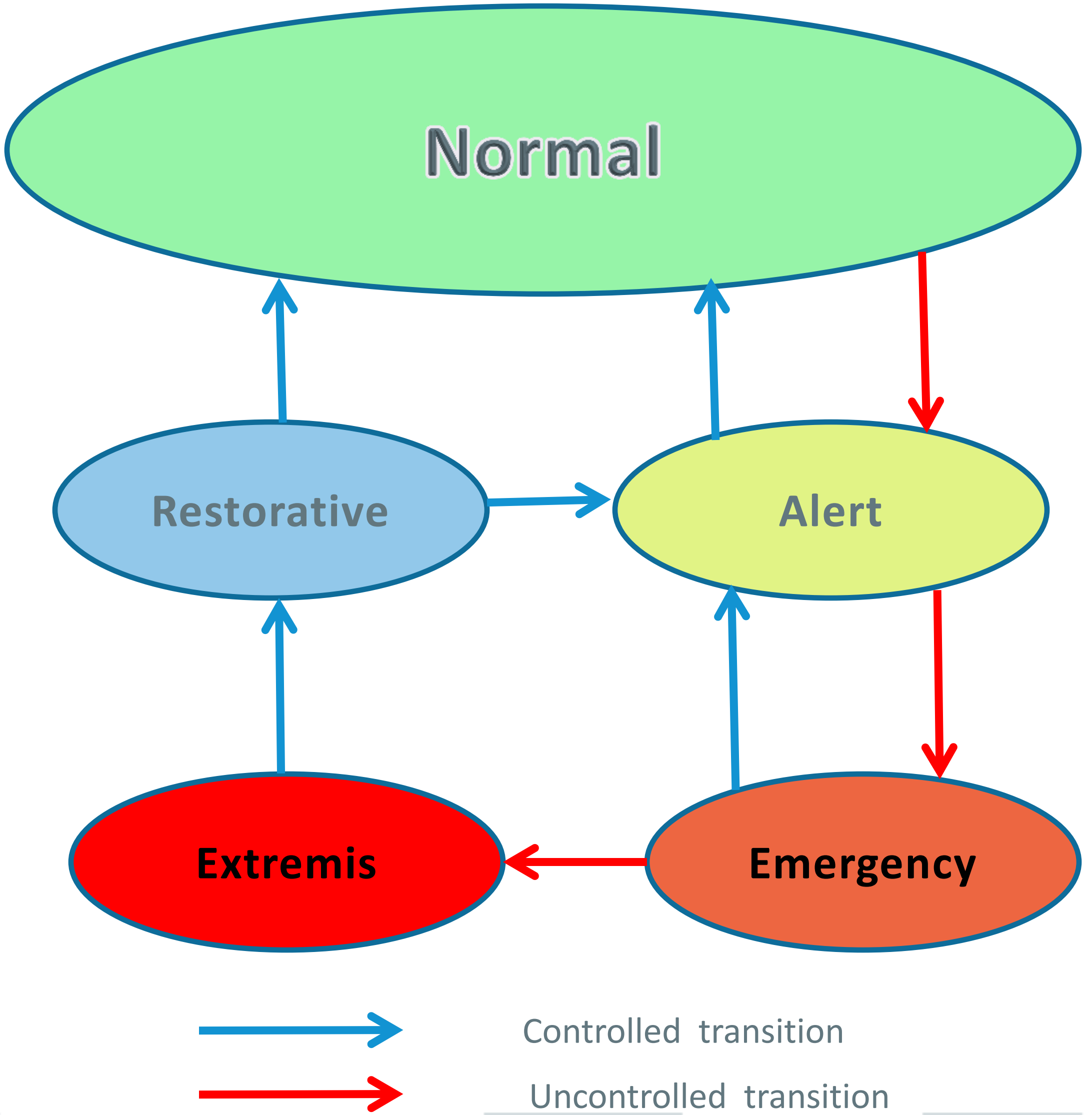


Control Paradigm Confusion



What is the difference? Need clear classification.

Power System State



Need for a Flexible Control Architecture

- For each state on the DiLiacco's diagram, a different control architecture may be required
- The concept of "Normal Operation" is changing
- Can we build flexible control systems that are capable to reconfigure?
- Can we build control systems capable of solving ad hoc objectives?
- What are the enabling technologies?
- Which processes can be controlled in a distributed way and which only require a centralized one?
- Which control architecture requires full system model?

Collaboration/Cooperation vs Coordination

- Collaborative or cooperative control seem to better fit the flexibility needs
- Need for information exchange protocols
- Need for physical interaction protocol to lower complexity
- “Do-not-Exceed” limit is an example – using robust solution to make sure that the impact on the rest of the system is limited to a predefined value
- Need formal flexibility metrics to be able to request and provide flexibility
- Need new reliability and resilience metrics to provide constraints to the controllers

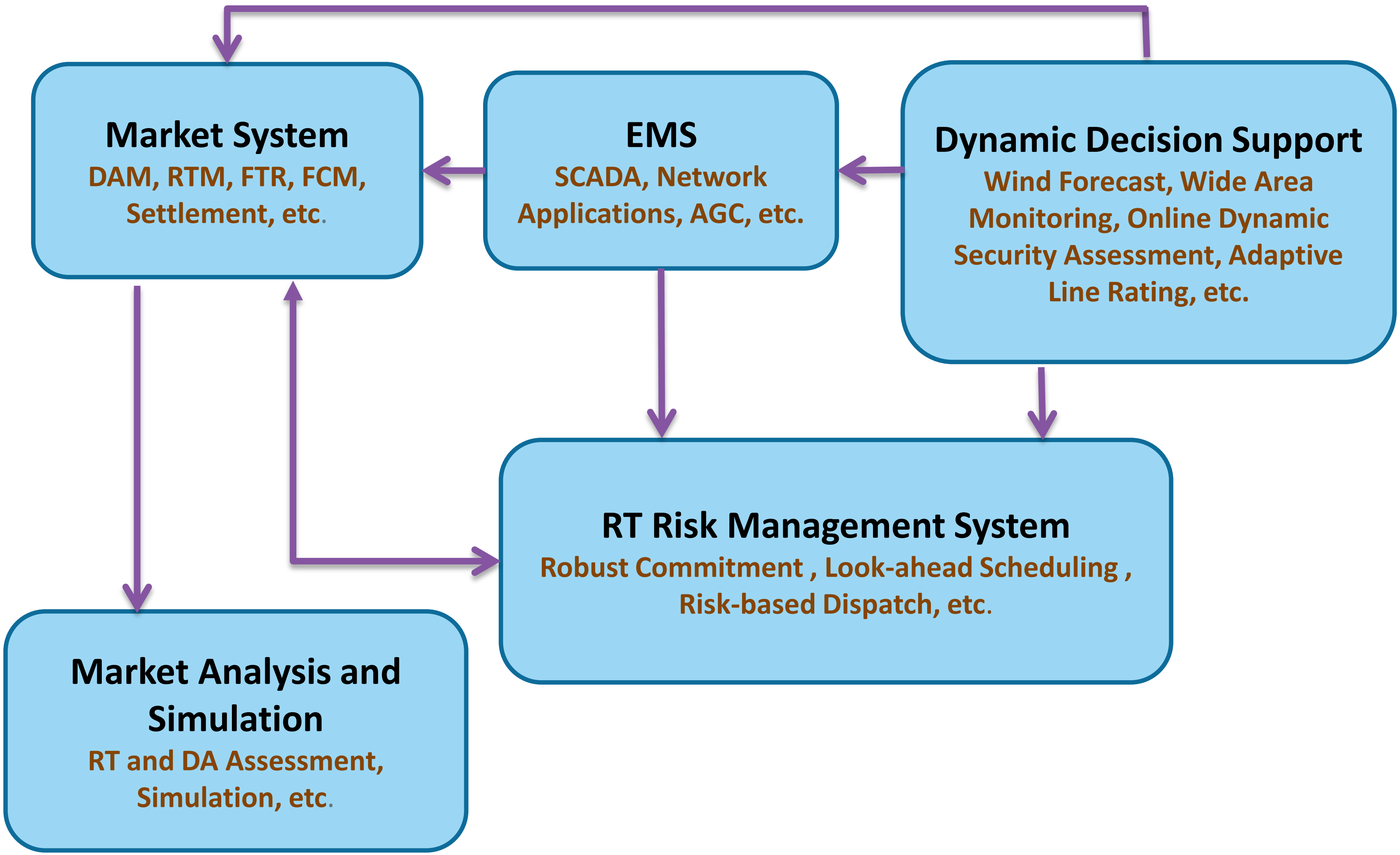
Cloud Technology Enables Collaboration

- Cloud can be used as a medium for collaboration and information exchange among distributed (decentralized?) agents
- Temporary ad hoc collaborators created in the cloud could help resolving specific situations
- Could go from very simple to quite complex problems
- Example: resolving anticipated imbalance caused by a major contingency with the help of neighboring systems:
  - Assembling model on the fly
  - Communicating coordination constraints (max imbalance allowed by participating entities), etc.
  - Once resolved, the temporary collaborator is dropped
- Potential to accumulate patterns of the best control actions and strategies (stigmergy)

Trade-offs

- We always make a compromise between complexity and controllability
- How do we measure complexity?
- Complexity of the models and control schemes may create negative effects and unexpected emergent behavior
- Introducing too much physics in the market models significantly increases non-convexities and, as a result, inefficient pricing
- Preventive vs corrective control
- Too accurate models with inadequate data quality will introduce more problems
- Centralized stochastic programming in market clearing vs decentralized in addressing uncertainty

System Components for Grid Operation

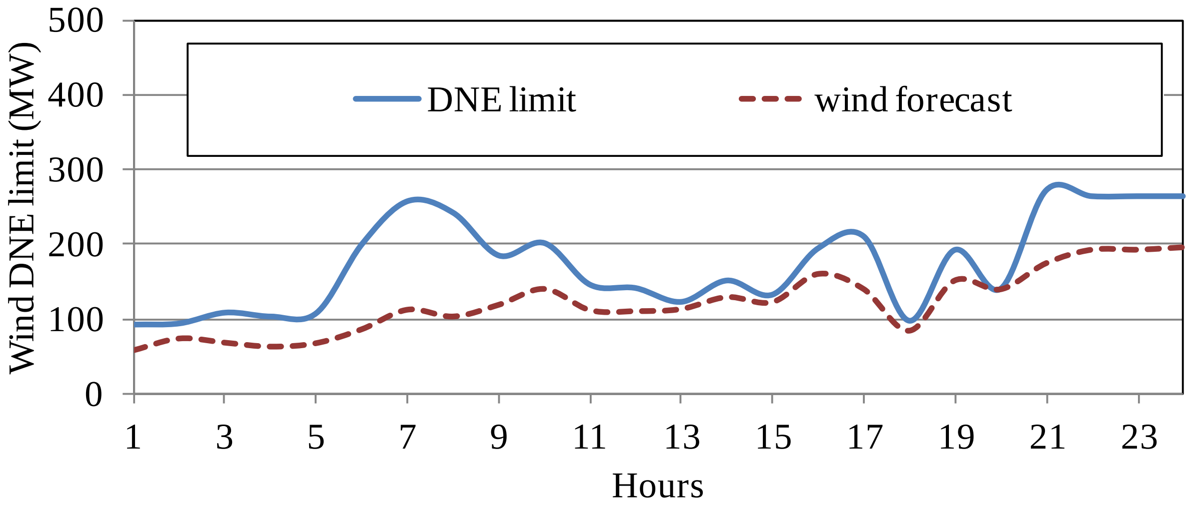


Managing Power System Uncertainty

- Power System Control Actions
  - Preventive Actions
    - Unit Commitment
    - Generator Dispatch
    - Demand Response Dispatch
    - Voltage Control
    - Transmission Limit Enforcement (static and dynamic security)
    - Maintaining Ancillary Service Requirements
  - Corrective Actions
    - Load Frequency Control
    - Corrective Generator Dispatch
    - Load switching and shedding, voltage reduction
    - Transaction Curtailment
    - Emergency purchase from neighboring control area

Do-not-Exceed (DNE) Limit

- The dispatch instruction for a wind generator is *a* ***dispatch range (DNE Limit)***
- The DNE limit is the maximum amount of wind generation that the system can accommodate without causing any reliability issues.



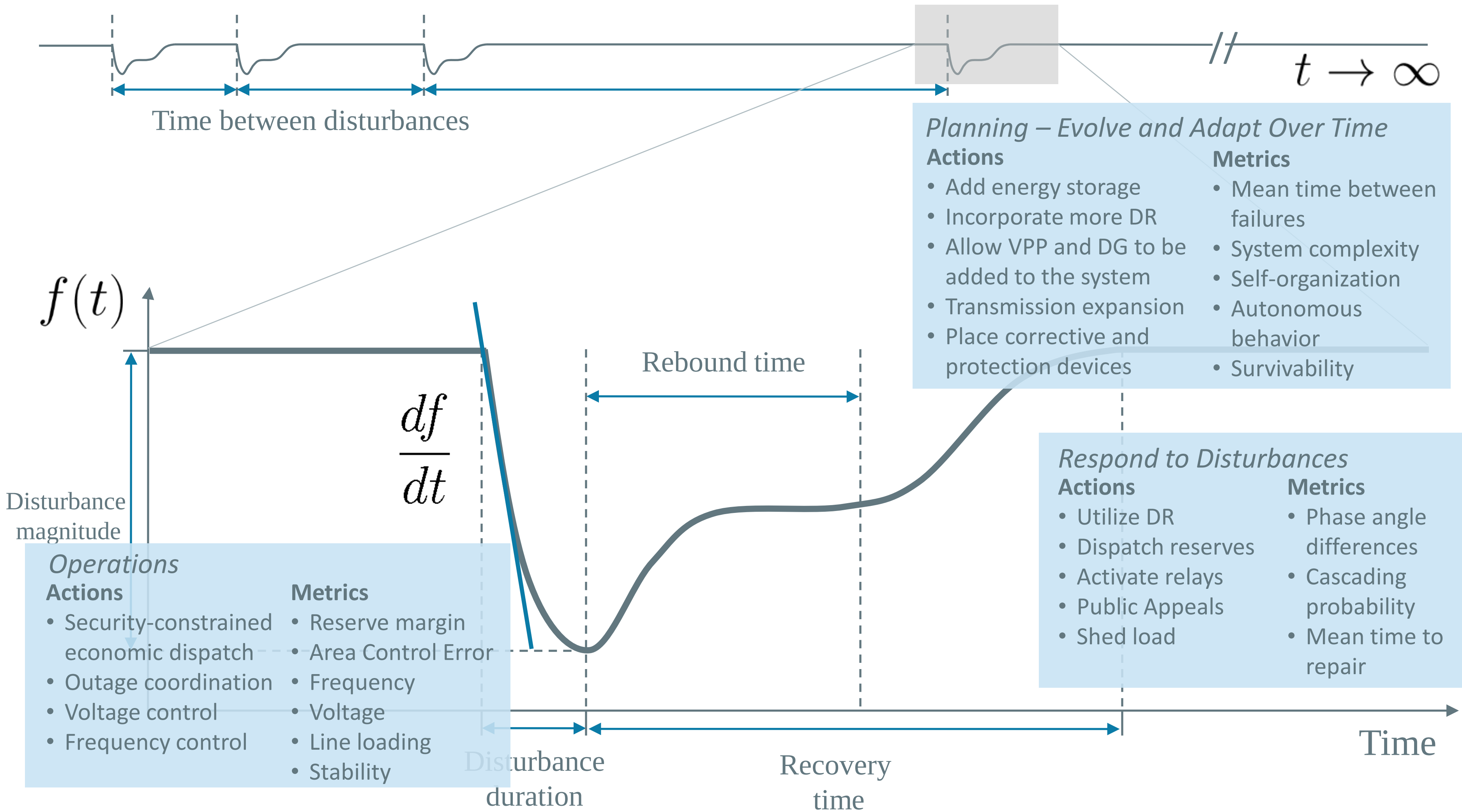
Market-to-Market Coordination

- Area power systems are interconnected
  - A System Operator (SO) has the most accurate information of its own area, but may not have other areas' accurate information
  - Individual area dispatches may *not* achieve the economic efficiency of the *overall* regional system
- The **goal** is to achieve total economic efficiency through the coordination between area dispatches

Survivability

- Advanced technologies and complex systems are more prone to catastrophic failures!
- New technologies will lead to emergent behavior – not necessarily positive
  - Self-Organized Criticality: Blackout cannot be avoided by tightening the current reliability criteria
- Concepts of survivability, resilience and robustness
  - Survivability is an *emergent property* of a system – desired system-wide properties “emerge” from local actions and distributed cooperation
  - The realization of a survivable system will rely on advanced detection, control and coordination techniques
  - How do you effectively model, simulate, and visualize survivability?

Survivability



Survivability

- Four properties of survivability:
  - Resistance to attack – system design, short term planning
  - Recognition of intrusion – local and wide-area monitoring
  - Recovery of essential or full service after attack – protection, emergency control, SPS/RAS, WASIP, reconfiguration
  - Adaptation/evolution to reduce effect of future attacks – cognitive systems
- Why is it so difficult to define the metrics for survivability? Rare but high impact events!

Survivability Characteristics

Survivability

	Disturbance prevention & System operation far from critical points	Ensuring Quality of Service, Value-delivery, & Rapid Recovery
Normal Operation	Stability	Reliability
Endogenous Disturbances (e.g. component failures)		
Exogenous Disturbances (e.g. weather, physical attacks, etc.)	Robustness	Resilience

time

- Evolution & Adaptation
- Improved reliability, stability, robustness, and resilience
- New functionality
- Ensure beneficial complexity (Self-organization, autonomous behavior)
- Cooperation versus coordination

Survivability and Resilience: early detection and fast recovery

Conclusions

- Need for developing clear classification for control and grid architectures
- Flexibility in power system has to be augmented by flexibility in control systems
- Cooperative and collaborative control principles fir better new grid architecture
- New formalized control metrics have to be developed for reliability, resilience, flexibility
- New protocols for interaction among different components have to be developed

Some References

- Z. Feng, E. Litvinov, T. Zheng. "A marginal equivalent decomposition method and its application to multi-area optimal power flow problems." *IEEE Transactions on Power Systems,* 29.1 (2014): 53-61.
- D. Bertsimas, E. Litvinov, X.A. Sun, J. Zhao, T. Zheng. "Adaptive robust optimization for the security constrained unit commitment problem." *IEEE Transactions on Power Systems* , 28.1, (2013): 52-63.
- J. Zhao, T. Zheng, E. Litvinov. "A unified framework for defining and measuring flexibility in power system." *IEEE Transactions on Power Systems",* 31.1 (2016): 339-347.
- J. Zhao, T. Zheng, E. Litvinov, "Variable Resource Dispatch Through Do-Not-Exceed Limit." *IEEE Transactions on Power Systems*, 30.2, (2015): 820-828.

Questions