

Engineering Electricity Services of the Future: From Hierarchical to Open Access Systems

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Lecture outline

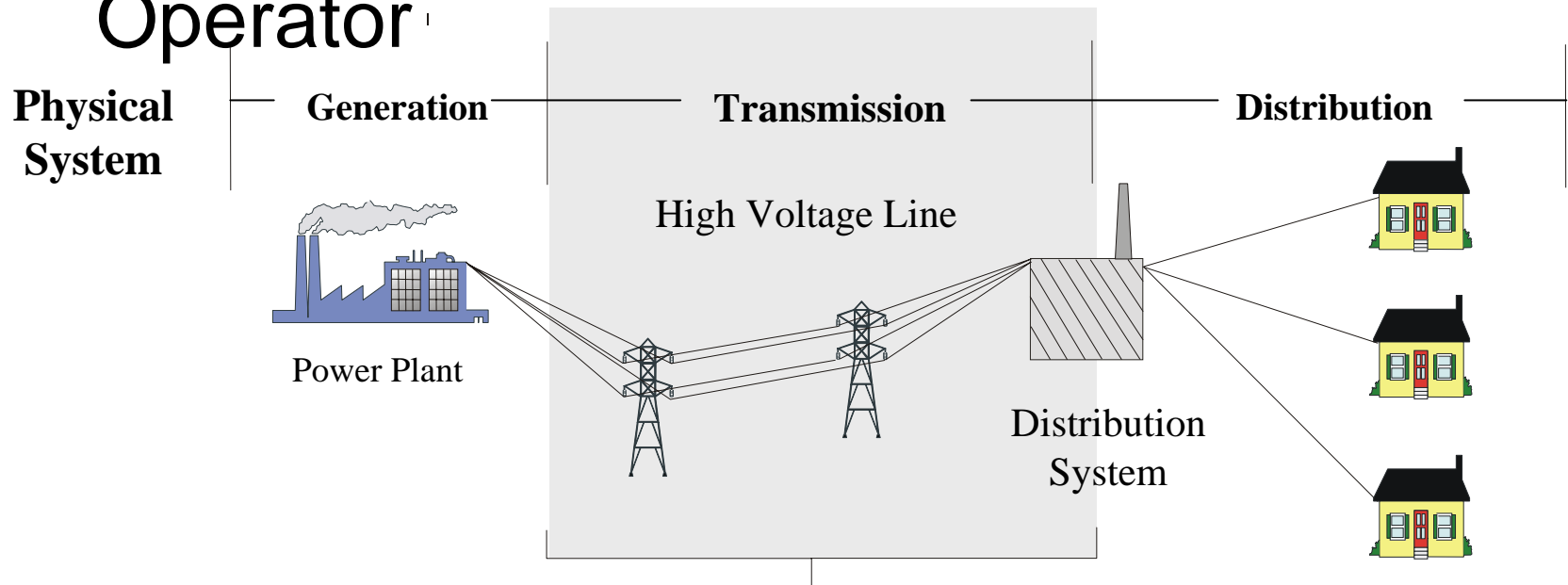
- **Evolving public needs in the electric sector**
- **A systems engineering point of view (new technologies and institutional arrangements)**
- **Evolution from current to more reliable and flexible organizational structures**
- **Change from hierarchical to multi-layered industry (aligning markets and operations)**
- **The challenge of managing change**

Evolving public needs in the electric sector

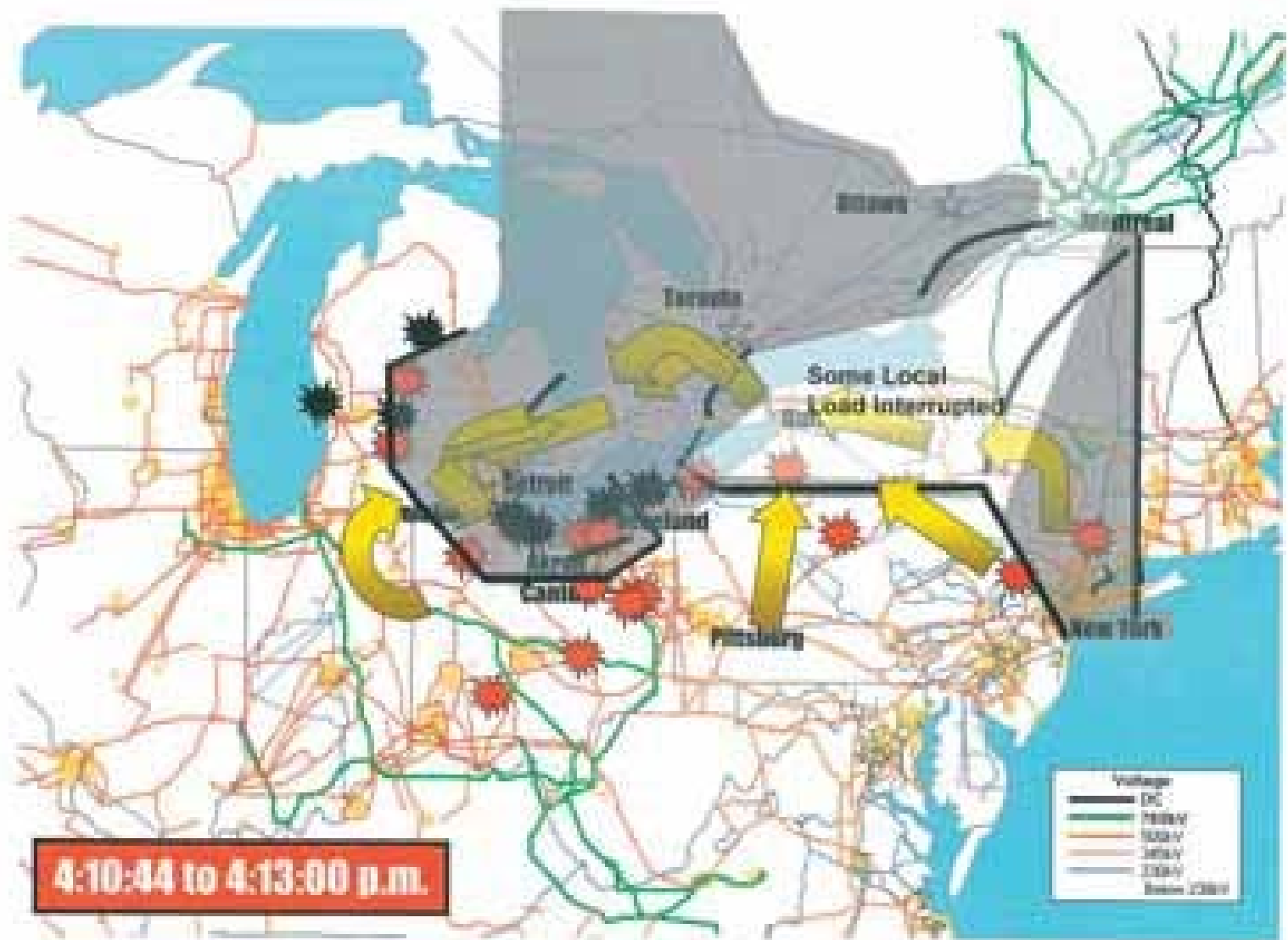
- **Large backbone infrastructure already in place**
- **Needs for maintaining the existing and gradually replacing/enhancing it by many distributed small-scale technologies**
- **Hard to make the case for new very-large scale new capacity (economies of scale vs. economies of scope)**
- **Instead, huge need for extracting efficiencies reliably in highly flexible just-in-time (JIT) and just-in-place (JIP) ways (role of info processing and decision making)**

Structure of a Power System

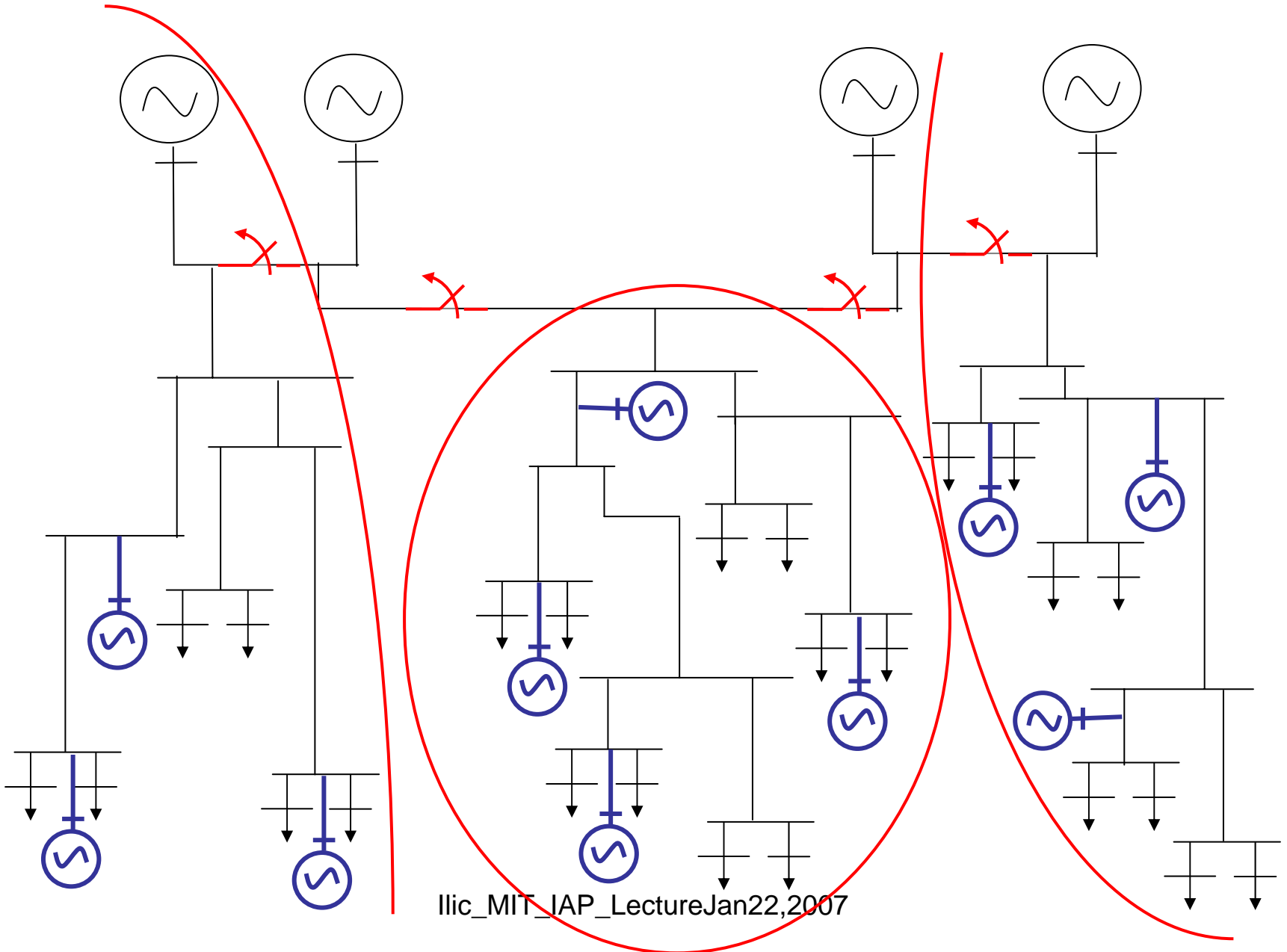
- Traditional Utility: Generation, Transmission, Load and System Operator



System Operator

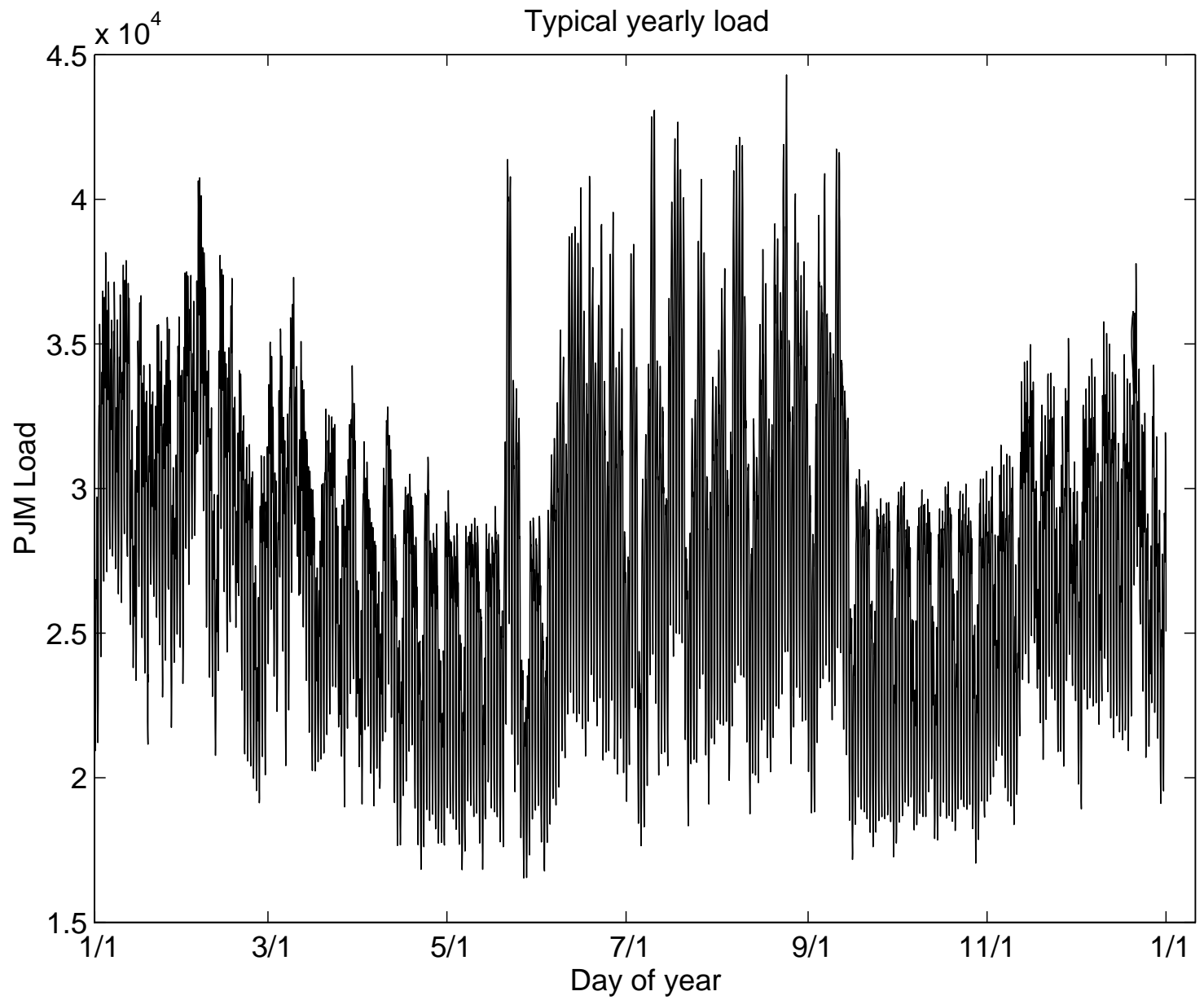


Today's Hierarchical Systems

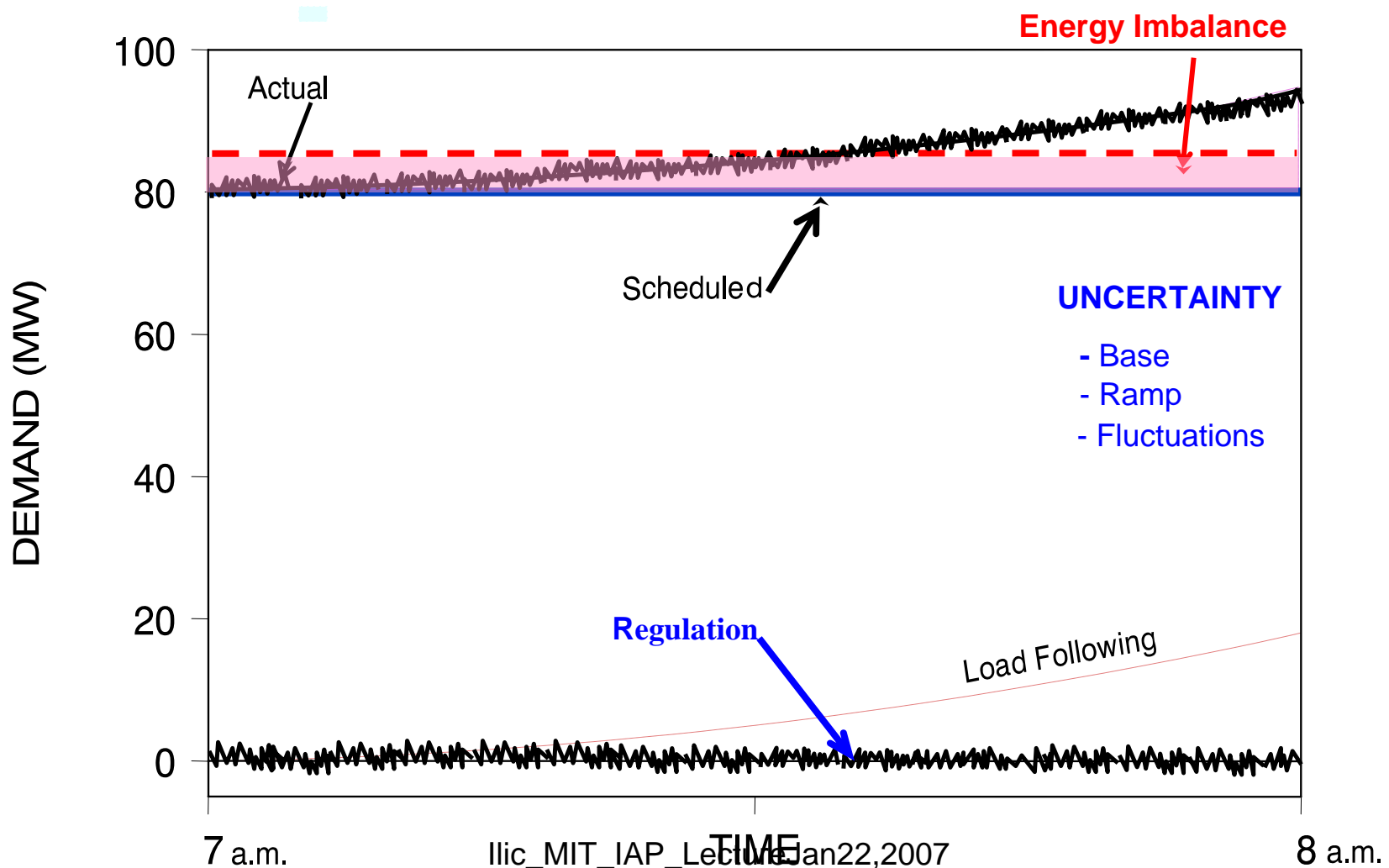


Design, Operation and Control of Power System

- Objective: Produce, Deliver and Consume Electricity **Reliably** under **Normal** Operating Conditions with Possible Occurrence of **Plausible Contingency**
- Continual Balance of Supply and Demand
 - Lack of Practical Means of Storage
 - Long Distance Transmission
 - **Uncertainties** in **Load** and **Equipment Status**



Continual Balance between Supply and Demand under Normal Condition with Load Uncertainty



Key Features under Regulation

- Operations and planning separate tasks
- Hierarchical operations and control based on temporal and spatial separation
- Generation and transmission planning done sequentially and statically
- Average price reflecting total capital and O&M (not an actively used signal)
- Customer not an active decision maker
- No direct incentive for right technologies

Ongoing Changes

- Technological (cost-effective small and smart power supply, direct line flow control devices (FACTS), Internet, customer automation)
- Organizational (competitive power generation, electricity markets, customer choice, potential for PBR-based transmission businesses; open access)

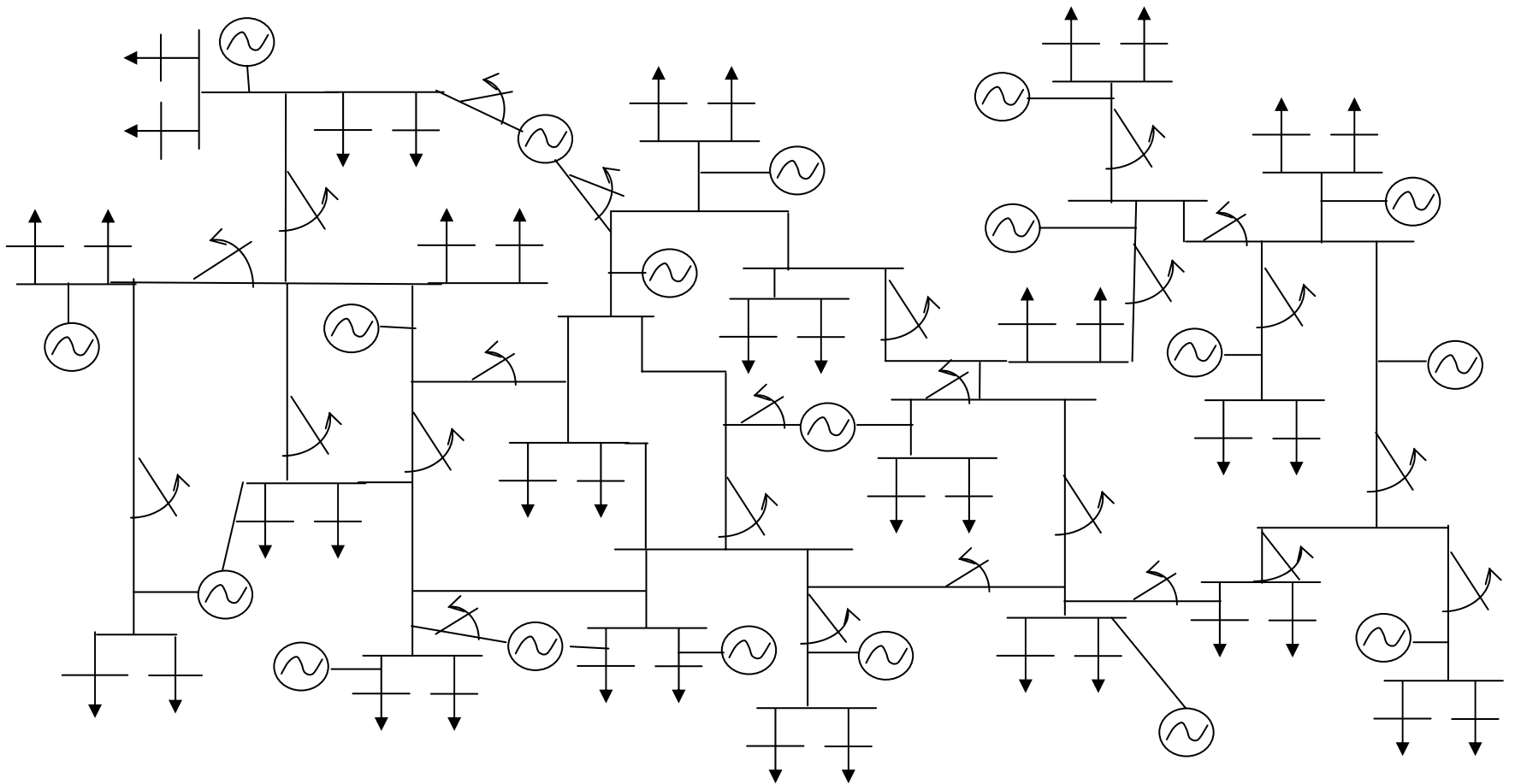
Change from Hierarchical to Multi-Layered Organizations

- **1. Existing paradigm: Centralized, large scale**
- **2. Transitional paradigm: Aggregation across non-traditional boundaries**
- **Likely end state paradigm: Very decentralized, large number of small scale actors**

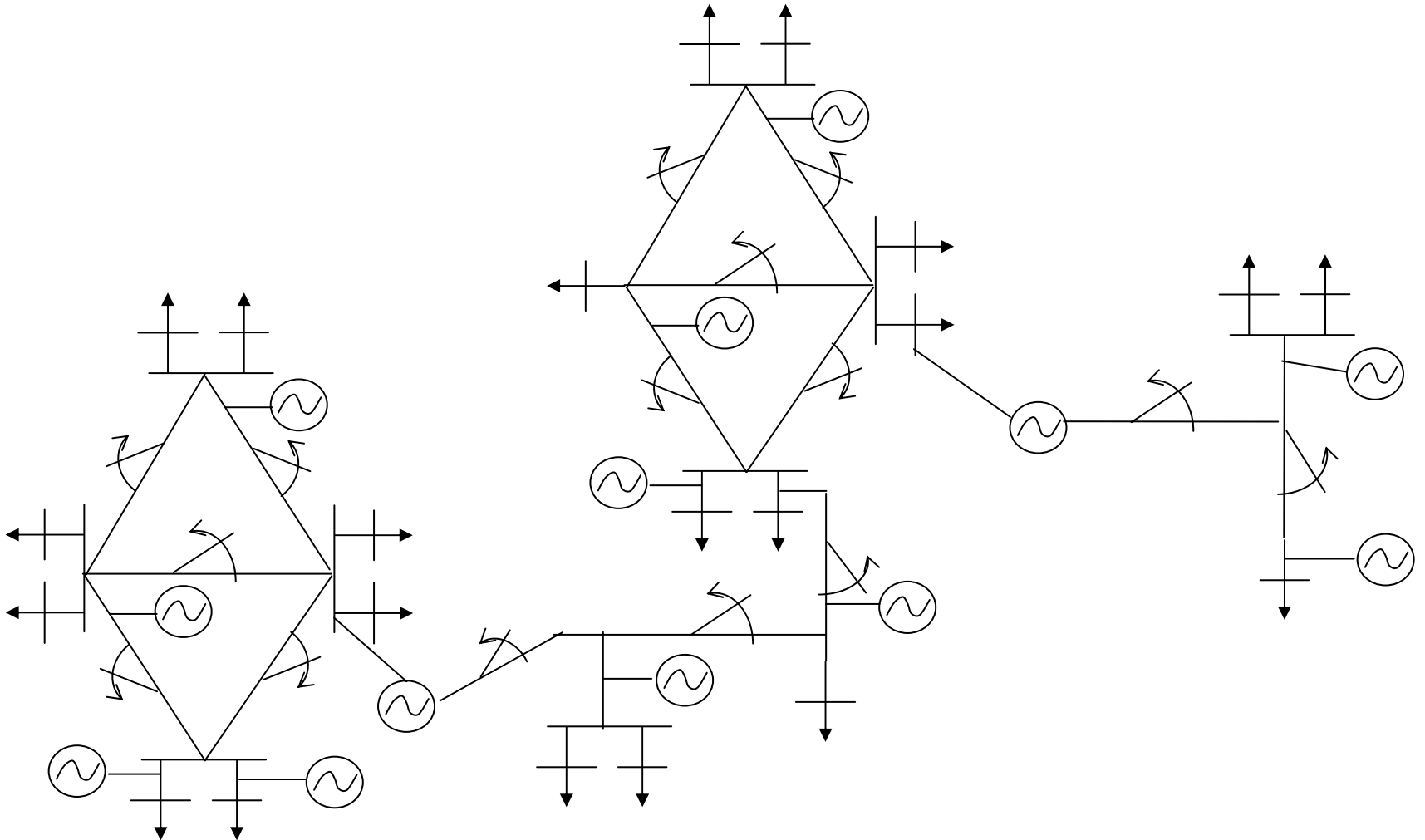
The \$M Question: Is it possible to provide secure, efficient and clean service at the same time??

- **Secure performance requires the worst case design, much reserve (inefficiency, aggregate level thinking). TRADITIONAL OVER-DESIGN**
- **Efficient performance requires dynamic response/adaptation to changing conditions so that the overall resources are used most efficiently (distributed decision making, much flexibility at ALL level of the grid). This is closely related to reducing greenhouse effects since more efficient service requires less power production to supply the same load.**
- **THE ONLY WAY TO MAKE THE SAME SYSTEM ROBUST, EFFICIENT AND CLEAN IS TO HAVE HIGHLY RESPONSIVE (“SMART”) GRID AND RESPONSIVE END USERS. THIS IS A QUALITATIVELY DIFFERENT MODE FROM THE CURRENT OPERATING PRACTICES.**
- **DISTRIBUTION OF SMALL SCALE ACTORS REPLACING VERY LARGE FEW ACTORS HELPS.**

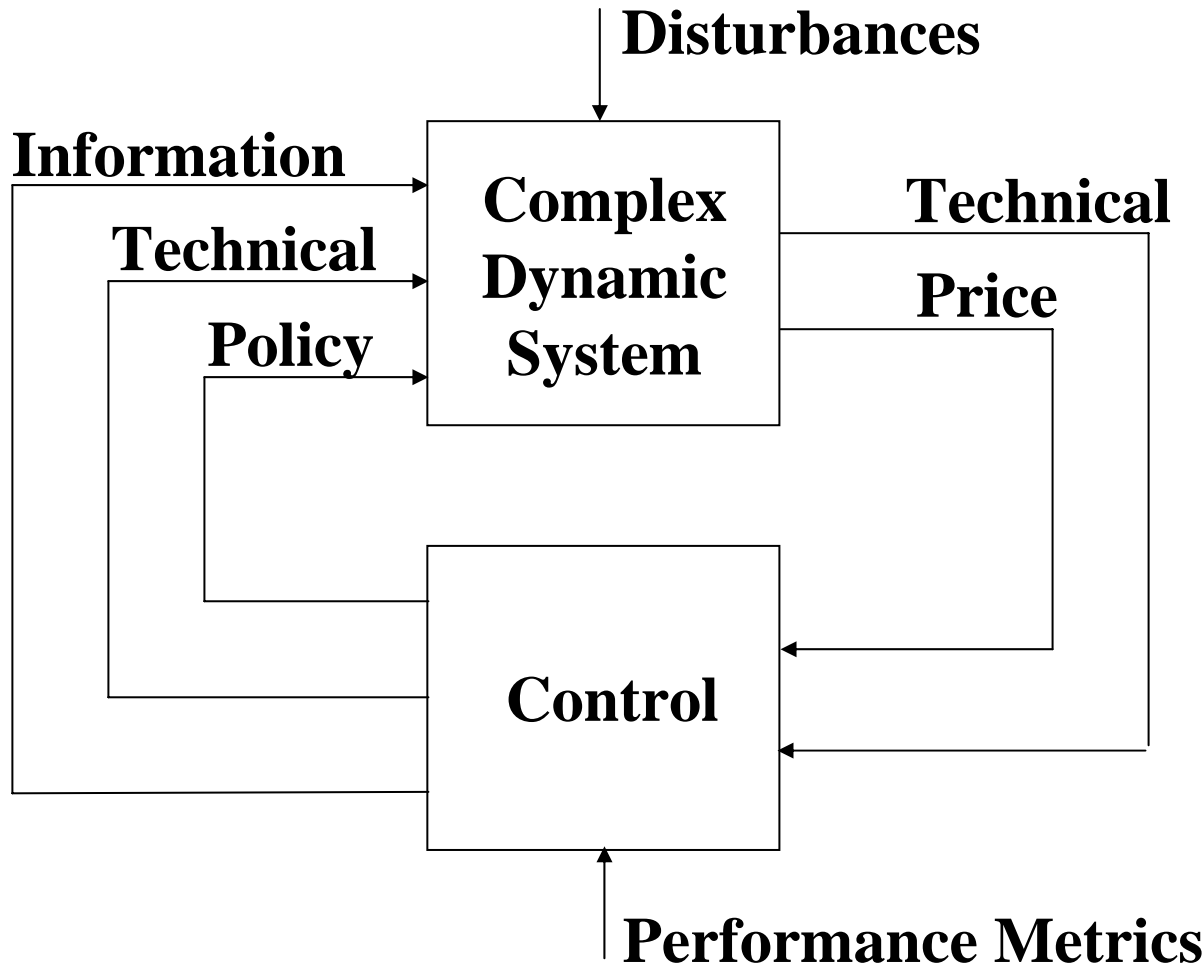
Decentralized Paradigm



Re-aggregation

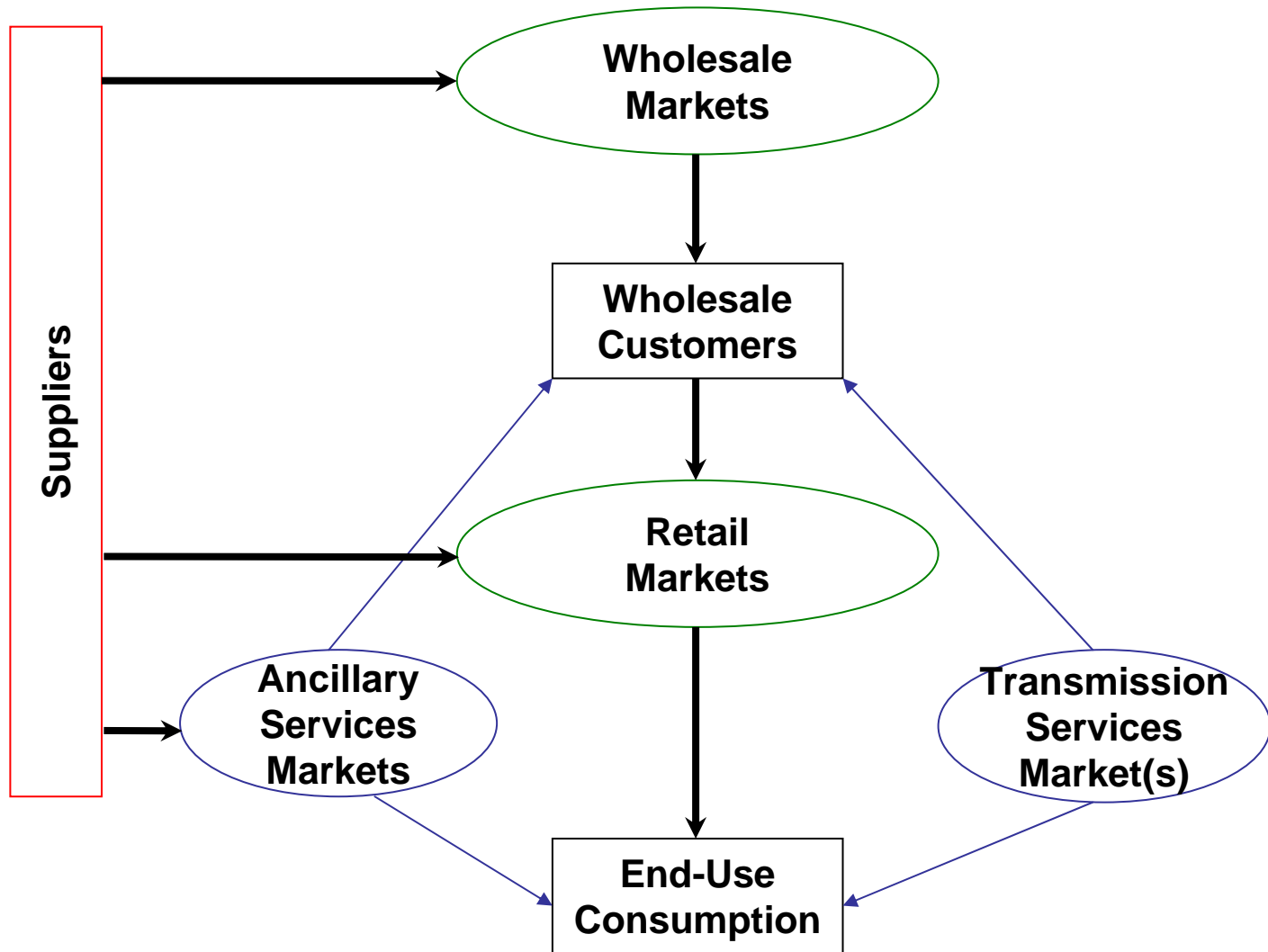


A systems engineering point of view



- **Temporal and spatial complexity**
- **Evolving structures**
- **Reliability and flexibility metrics**
- **Environmental impact metrics**

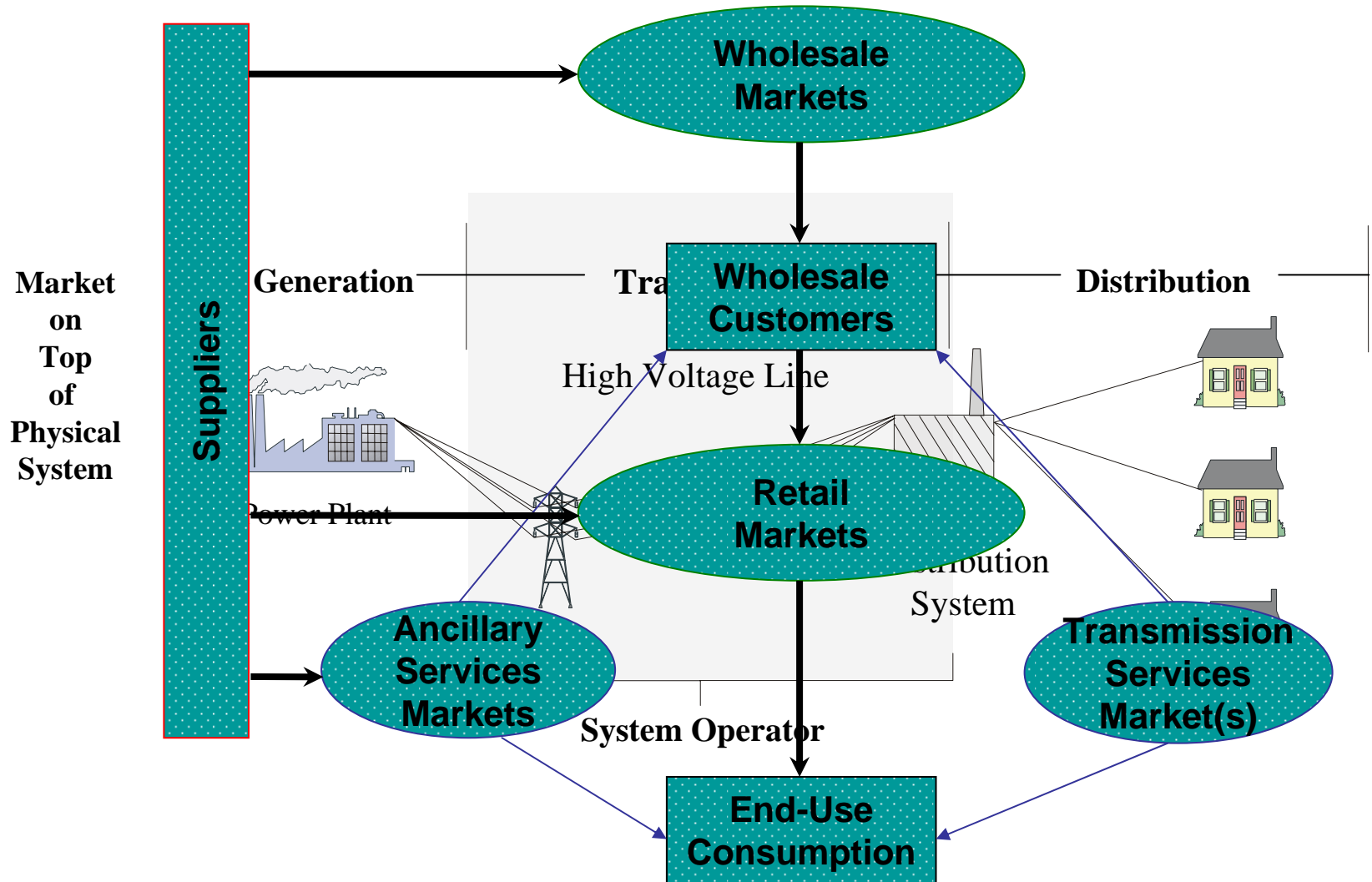
Regional Electric Markets



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Source: DOE Electricity 2002 Conceptual Design

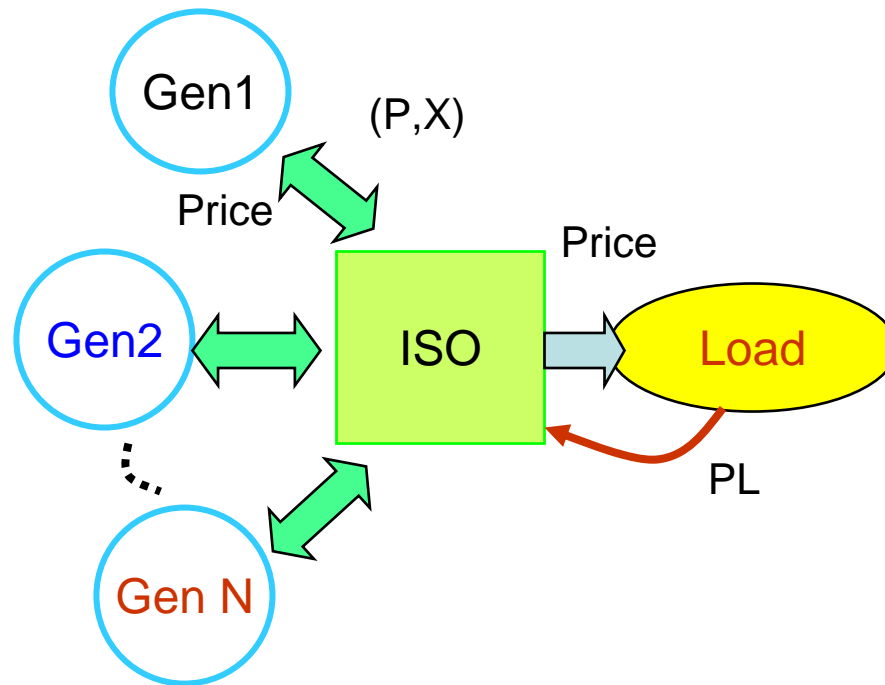
Regional Electric Markets



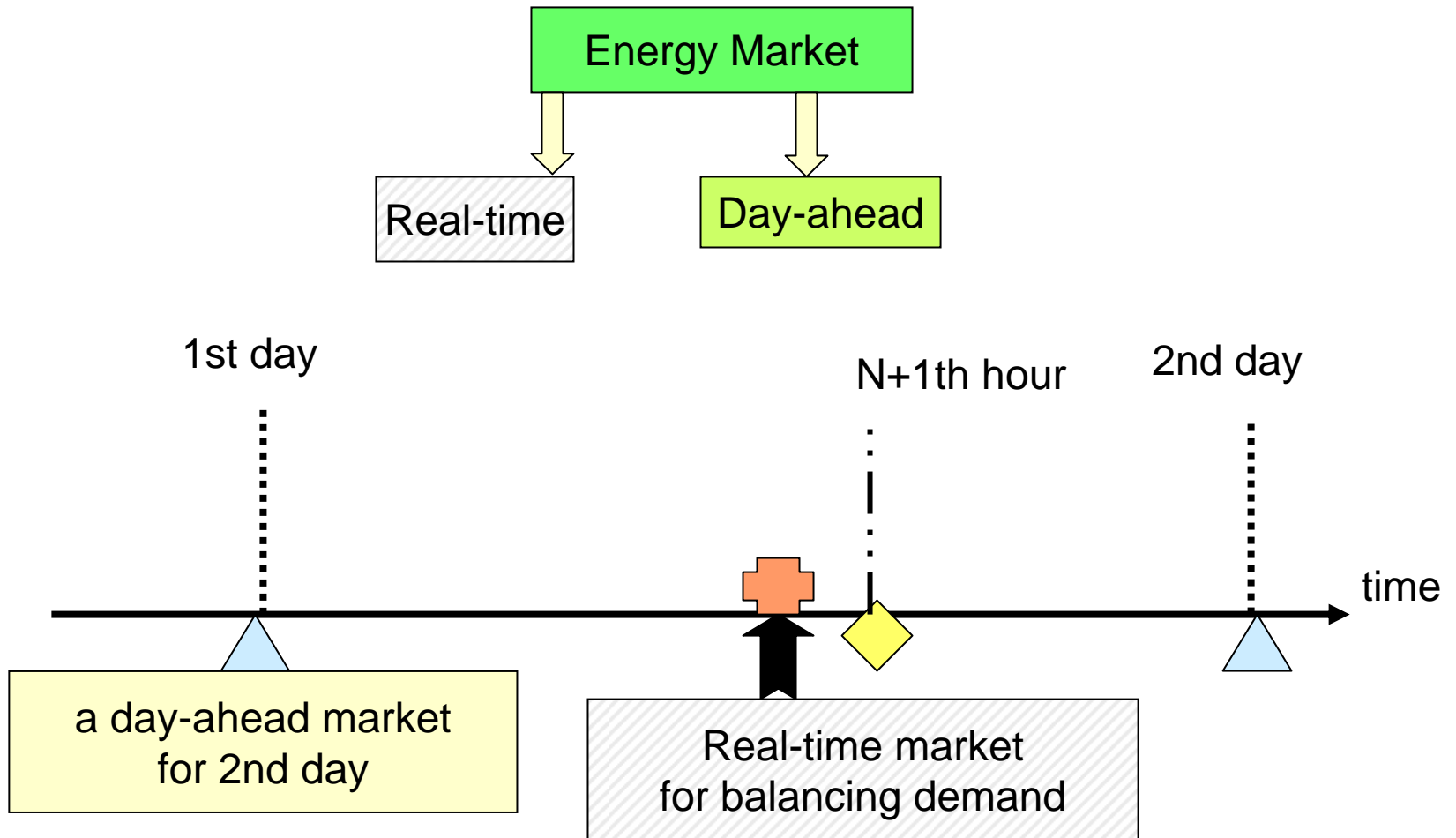
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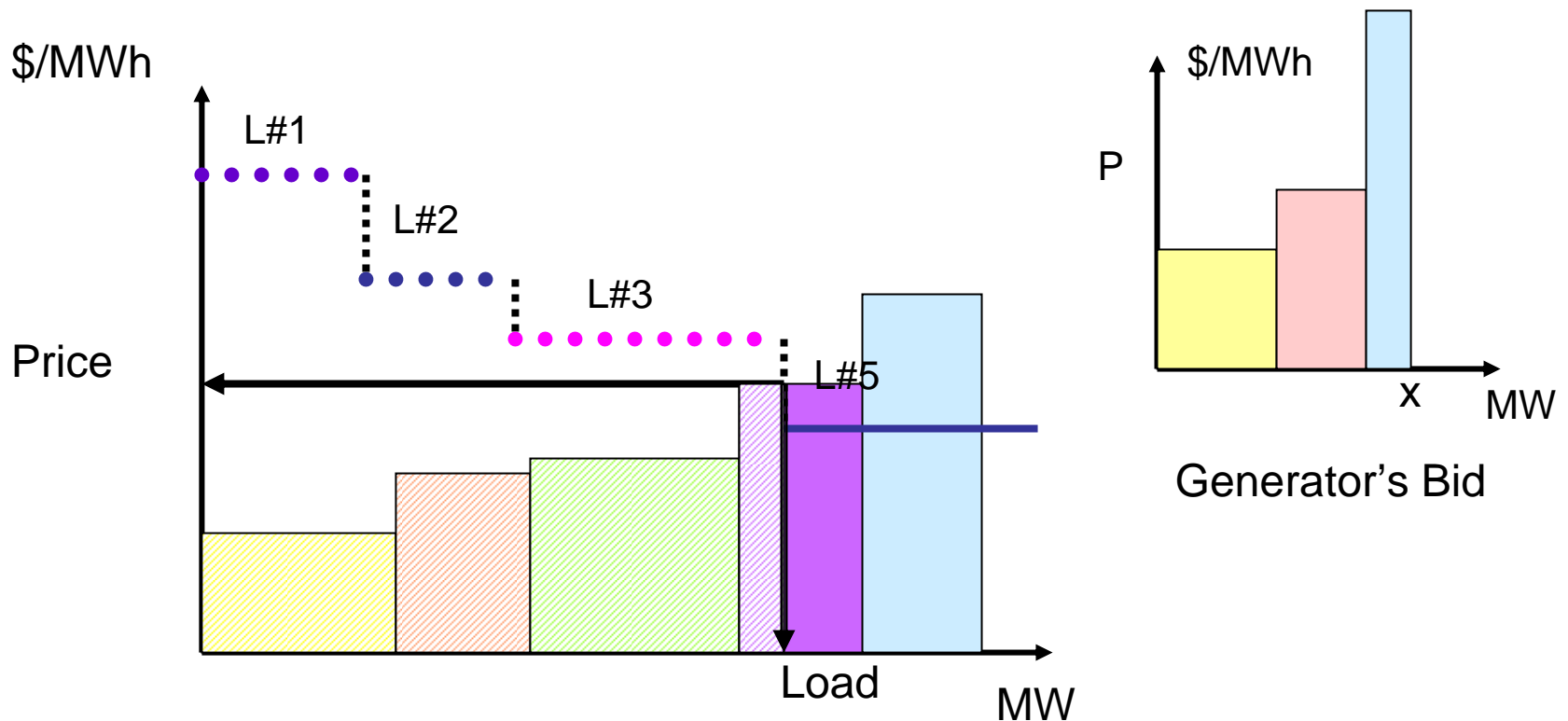
Characteristics of Electricity Spot Markets



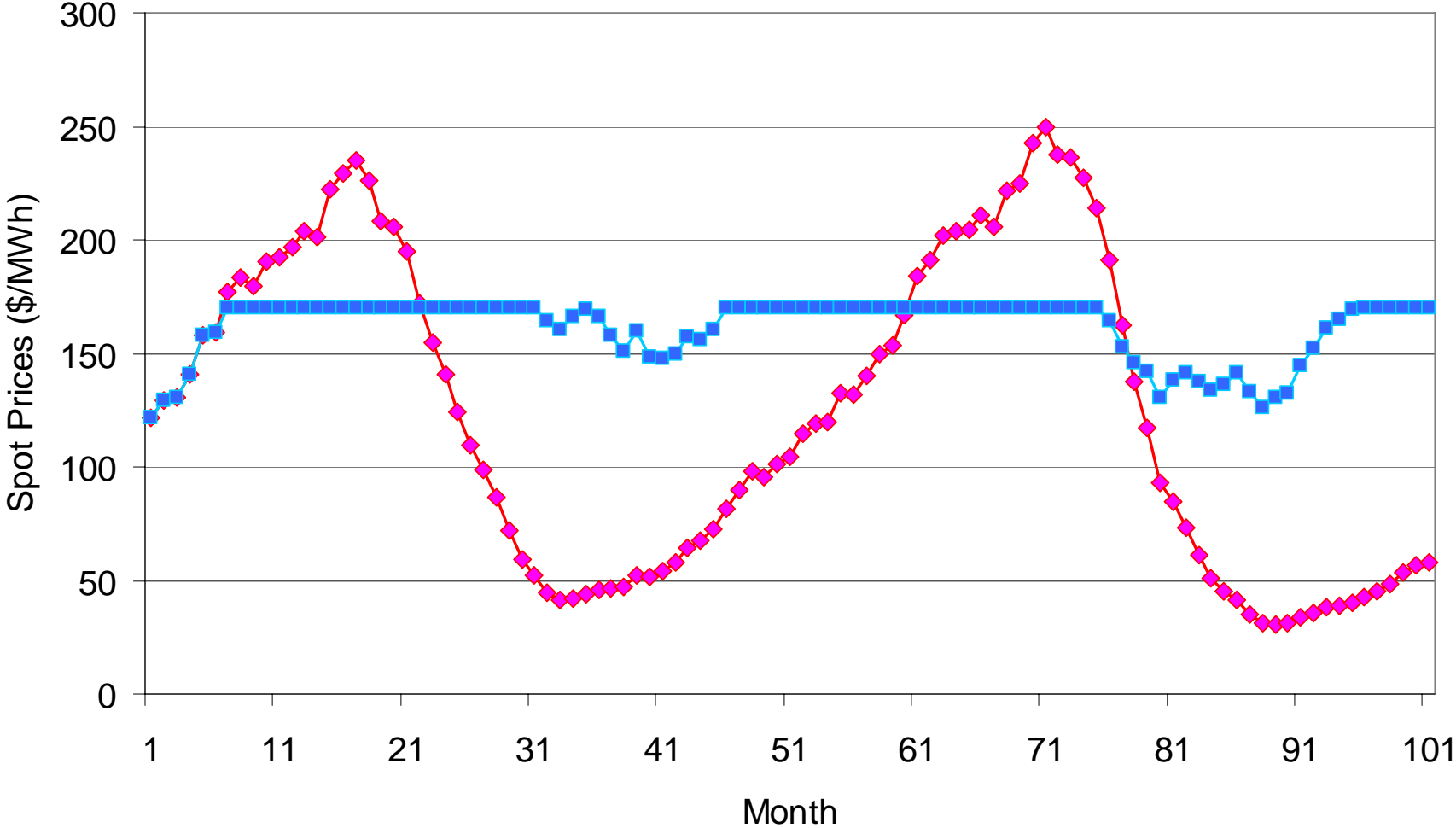
Characteristics of Electricity Spot Markets: Repeated Auctions



Characteristics of Electricity Spot Markets: Demand-Supply Balancing with Uniform Price

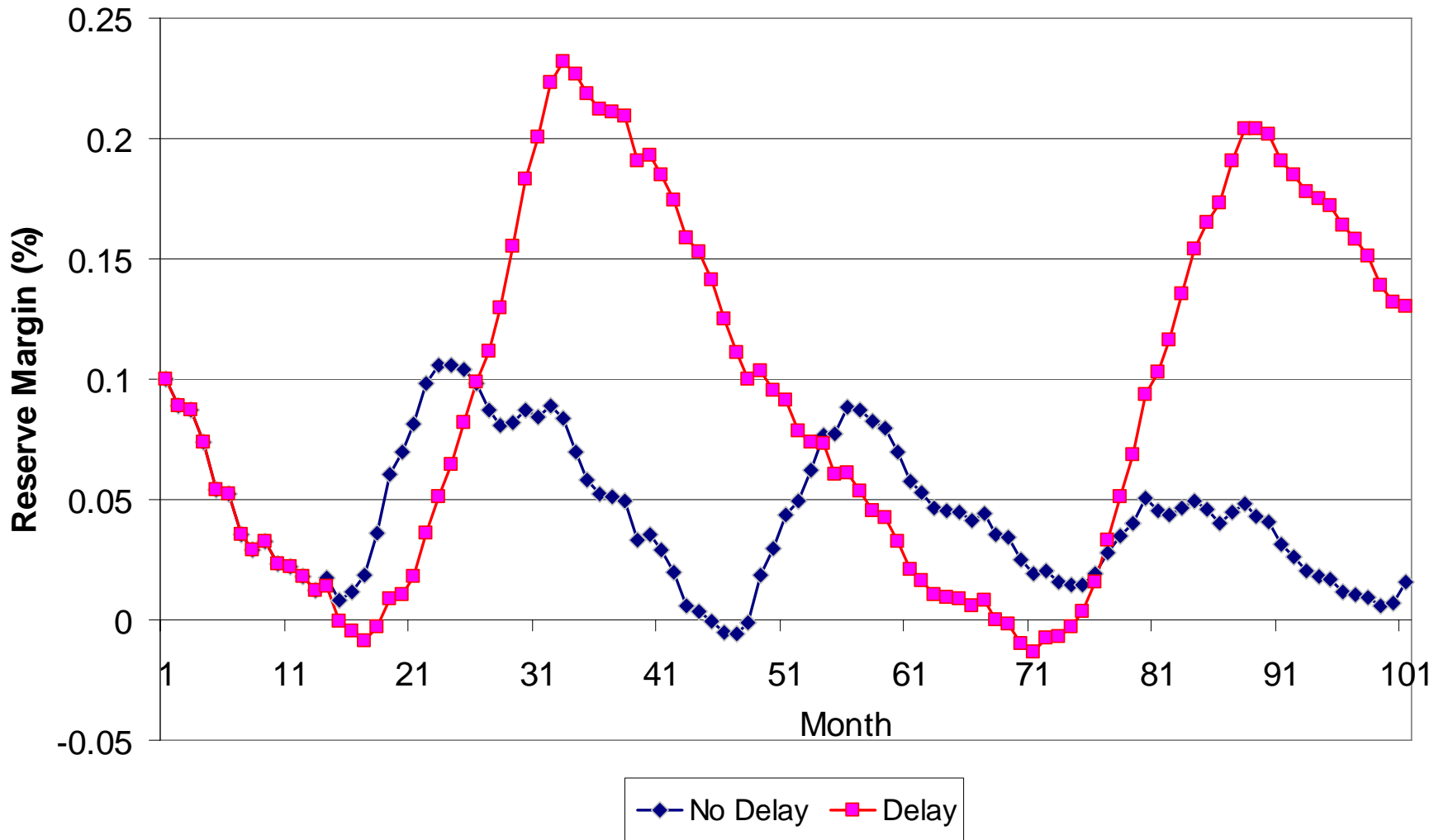


Spot Price Comparison under Price Caps

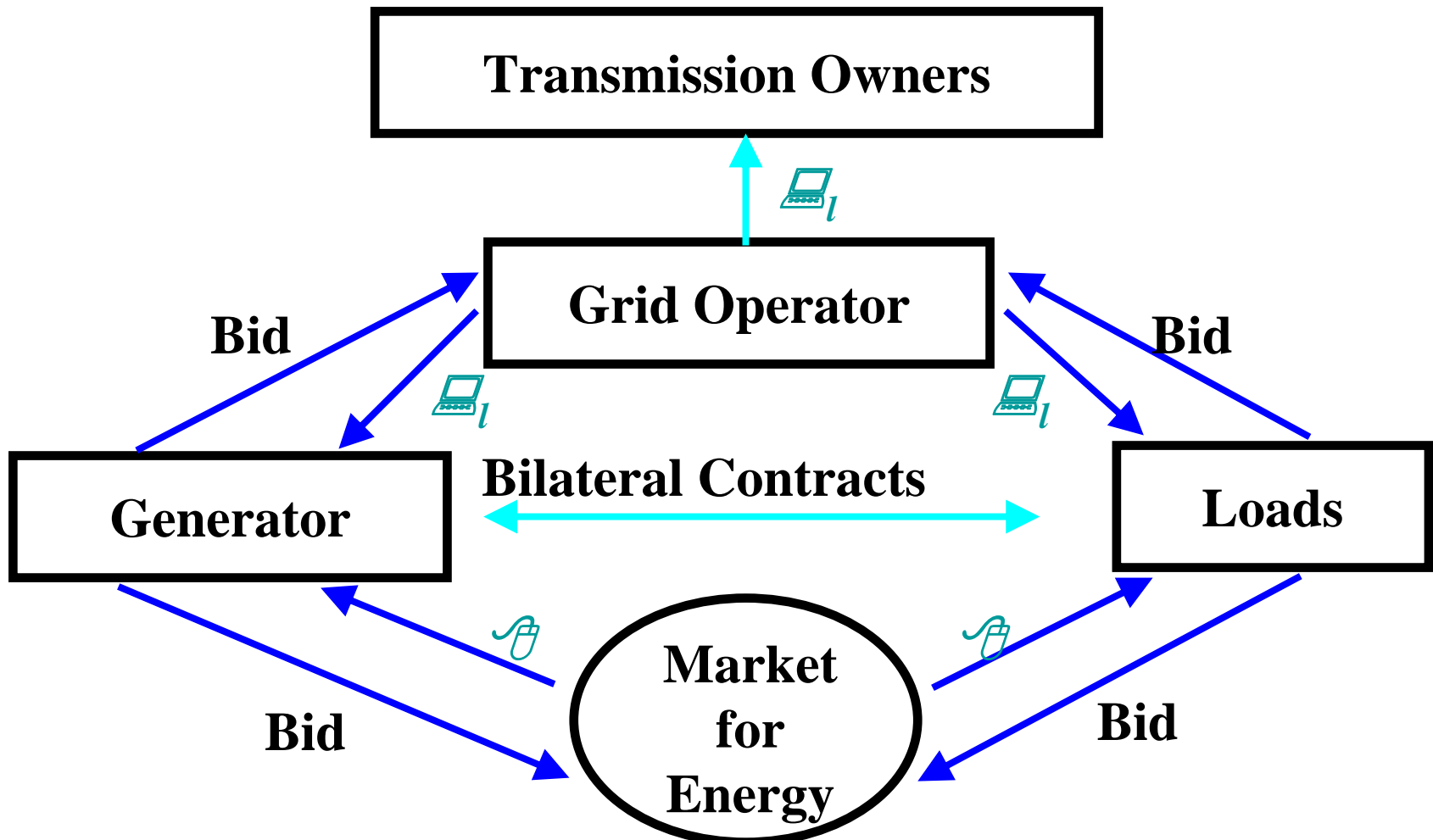


◆ No Cap ■ With Cap

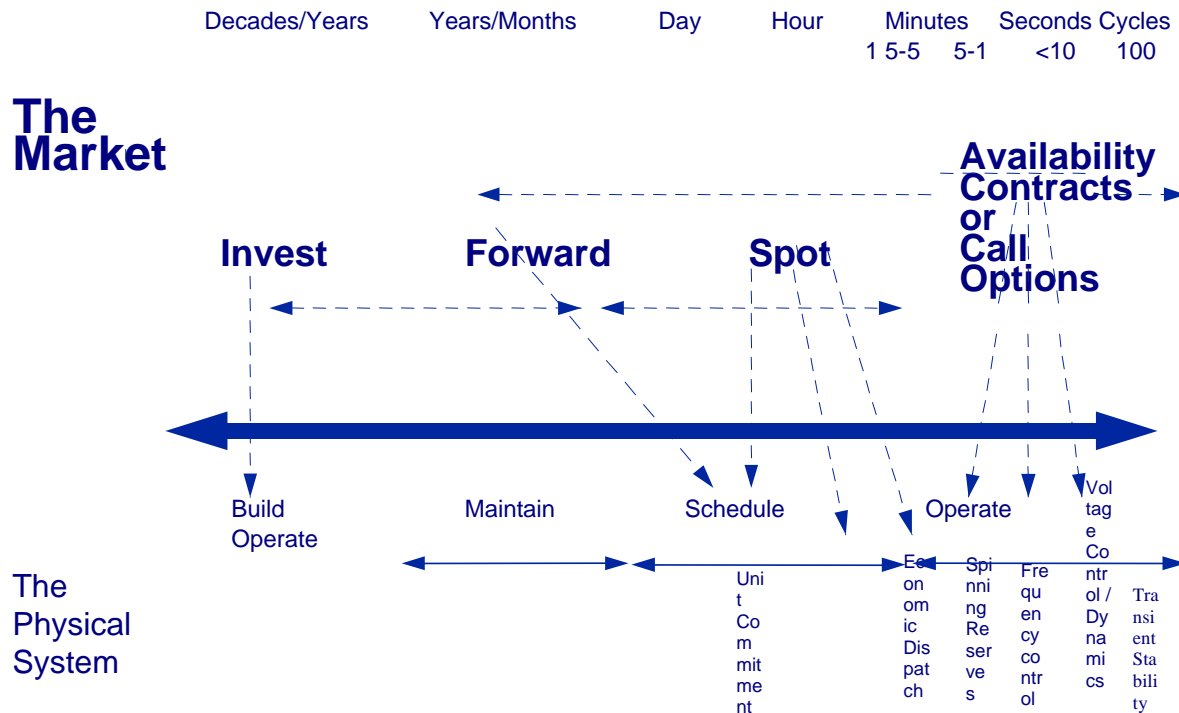
Reserve Margin



Interaction between Market and Physical System



Electric System Time Line: Market and Physical¹



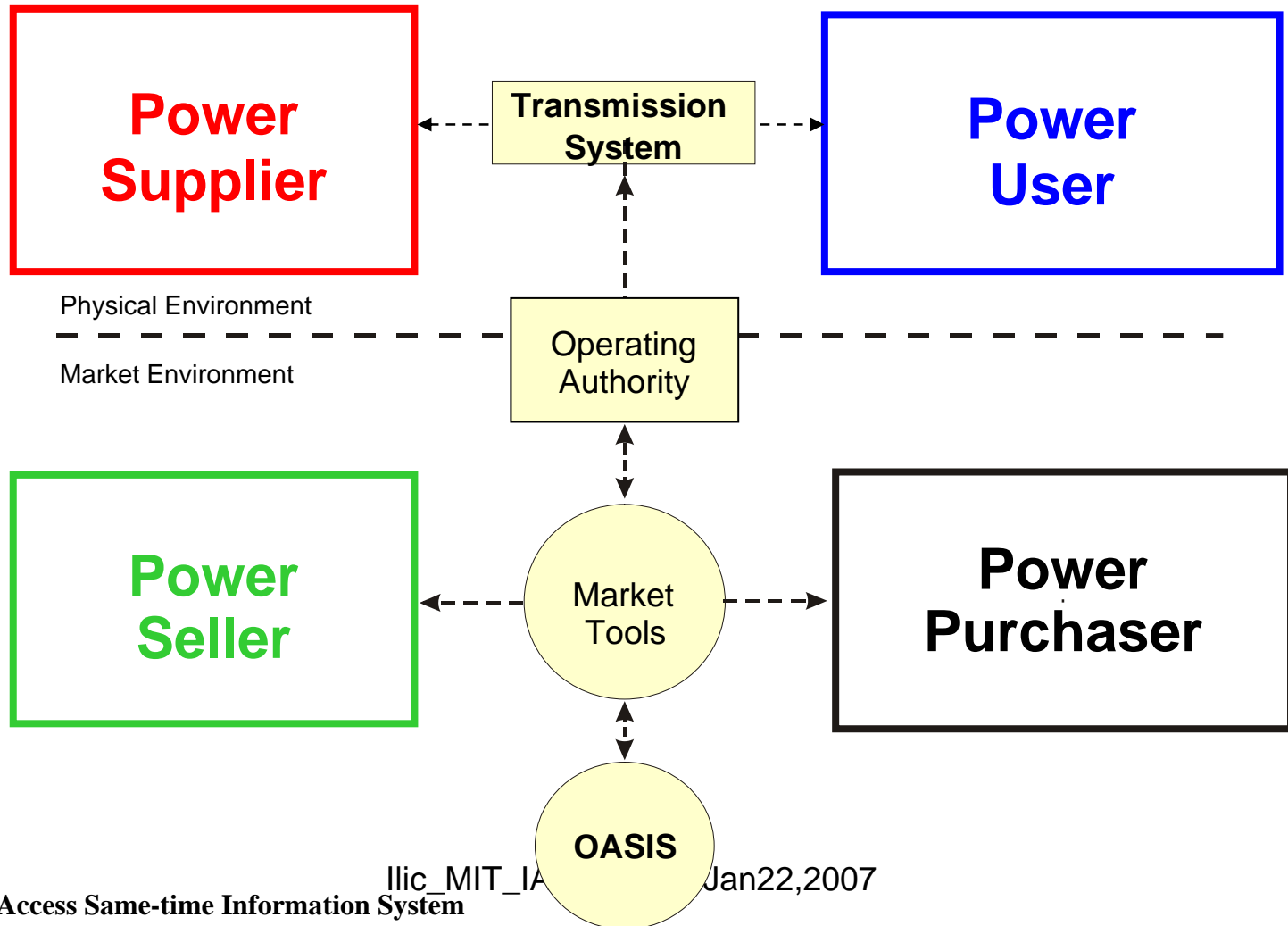
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¹ Shimon Awerbuch, Michael Crew, Paul Kleindorfer

Need for long-term load estimator- **FORWARD MARKET**

- **Spot market does not provide long-term signals.**
- **A forward demand characterization by the large customers participating in wholesale electricity markets, the utilities and other evolving load aggregators (on behalf of smaller customers); cap and trade specification in parallel with forward electricity markets and/or separable.**
- **In order to have incentives for investments one needs longer-forward markets (like in the Nordpool, for example)**

Functional Unbundling of Regulated Utilities



Key Features Under Competition

- Power supply, delivery and consumption separate functional and/or corporate entities (own objectives)
- Decentralized decision making under uncertainties
- Active use of price signals (temporal and spatial)
- Potential for valuing right technologies
- Issues with reliability and long term system evolution

Decentralized Decisions

- Qualitatively Different Mode
 - Multi-stage, Decentralized Decisions
- Smart Components and Smart Control
 - Supplier
 - User
 - Transmission
- Role of Information Technology (IT)

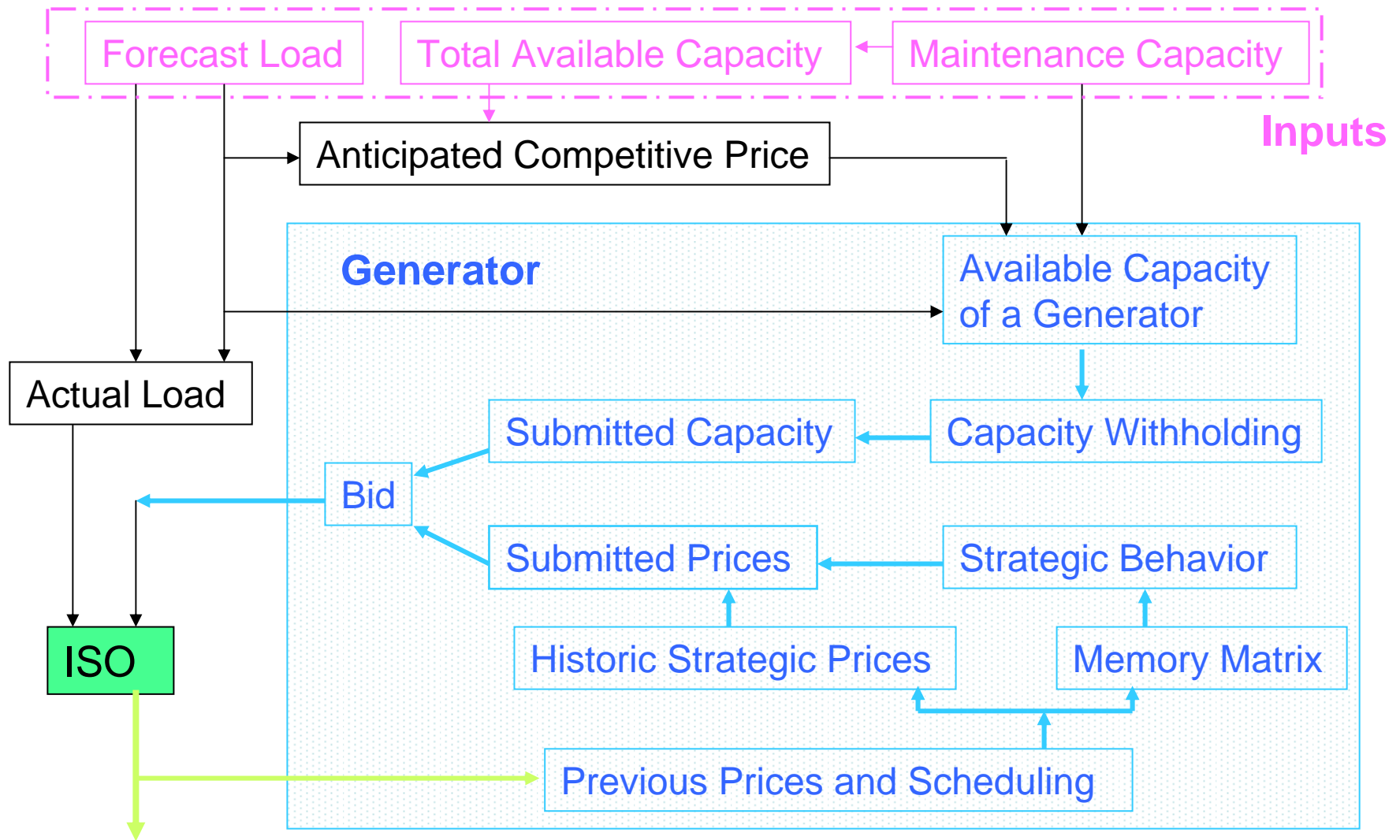
Smart Power Suppliers

- Profit maximization and risk management
- Decentralized stochastic optimization
- Value of a given **technology** and its dependence on industry structure
- Relating physical characteristics and financial decisions (unit commitment and financial commitments)
- Sizing, technology, purpose (backup, ancillary, energy, clean energy)

Value of New Generation Technology

- Increased Efficiency
- Flexibility (DC Technology)
 - Real and reactive power flexibility
- Modularity (Fuel Cells, Micro Turbines)
- Decreased Lead Time on Installation
 - Ability to expand capacity
- Movable Technology
 - Ability to capture locational prices (eg. North-south trend in California)
- Zero Emission Technology
 - Eliminates Requirements for purchasing emission rights

Information flow and decisions by the power supplier



Smart Power Users

- Benefit maximization
- Quality of service specifications
- Choice of provider
- Value of metering
- Value of automation
- Coalitions

Smart Transmission Networks

- Owners not the same as real-time operators
- Two cases 1) Transmission remains a fixed ROR -based business; 2) Transmission is a PBR-based business
- Conjecture: The **IT tools** (software) play critical role in making this a viable business

Smart Transmission Provider

-- Fixed ROR

- Challenges (software for managing different requests for power delivery; firm, non-firm, long-term bilateral, short-term)
- Making information transparent to the users (data aggregation); from hierarchical to open access
- Non-discriminatory charges
- Congestion control (technical and/or price feedback design)

Smart Transmission Provider -- PBR-Based

- Insurance-like company selling guaranteed delivery at a price; non-linear pricing
- What is the demand for delivery?
- What is it worth?
- Auctions and/or top-down valuing
- Implementing simultaneous transactions over various time horizons without violating operating constraints (TLR problem)

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TLR: Transmission Loading Relief

Smart Networks

- Definitive need for designing communications, computer, physical, financial networks to meet a specified performance (embedded software)
- Modeling, analysis and control approaches for power systems potentially useful to the newer networks
- Research needed on common underlying principles
- Major question: **Scalability**

IT-related Questions

- Type of data required to be made public for reliable and adequate industry (by the EIA, FERC, NERC)
- Design of internet-based information structures
- (Network) data aggregation for transparency; from hierarchical to open access
- Embedded software to implement smart suppliers, users and delivery services

Flexible Information Architectures

- Once the models/software exist for making the transmission providers smart, one employs internet to provide the relevant information on-line
- System users observe the status of the system, and internalize into their distributed objectives
- This is how **coordination** takes place under competition

Distributed Power Systems

- The power grid evolution from strong EHV large power plants to a much weaker EHV grid and very many distributed power suppliers closer to the users
- Smart wires, users and suppliers interacting through **IT**
- Distributed reliability provision
- Question: How does one get from here to there?

Some difficult R&D questions

- **Choice of performance criteria for various layers (trade-offs between reliability margins and economic efficiency);**
- **Minimal information structure between the layers to guarantee that the performance criteria are met;**
- **Limits to decentralization of primary controllers (smart, adaptive decentralized gadgets and/or fast communications).**

- **TRADEOFFS BETWEEN COMPLEXITY AND PERFORMANCE.**

Evolution from current to more reliable and flexible organizational structures

- **Technological advances (from complex coordinating switching to many decentralized switches)**
- **Regulatory progress (from RoR through PBR to no regulation/competition type signals)**
- **Economic (pricing) processes (signals for dynamic investments into distributed technologies)**
- **Political forces (obstacle/catalyst-switches)**
- **Their interplay: Hybrid system**

Fundamentally New Opportunities in the Electric Power Industry Sector

- **POSSIBLE TO DEPLOY TECHNOLOGICAL TOOLS FOR FLEXIBLE AND ROBUST PERFORMANCE OF A COMPLEX SYSTEM, SUCH AS THE ELECTRIC POWER INDUSTRY.**
- **CONCEPTUAL CHALLENGES TO ENGINEERING SYSTEMS VARY VASTLY DEPENDING ON WHICH STRUCTURE IS IN PLACE. NO SINGLE “OPTIMAL” ARCHITECTURE.**
- **TREMENDOUS NEED FOR INSTITUTIONAL SUPPORT OF THE RIGHT EVOLUTION.**

The challenge of managing change

- **Understand the value of various technologies under specific paradigms**
- **Develop operating, maintenance and planning decision tools (systems engineering) for all three paradigms and their transitions**
- **Value IT and computing for all three paradigms**

Critical concepts

- **Flexible reliability-related risk management**
- **Closely related to the questions of back-up power at times of price spikes/interruptions**
- **From extensive interconnections for reliability to distributed reliability provision; and, flexible (smart) delivery system.**

Conclusions

- Systematic development of protocols is an important interplay of economic, technical, environmental, policy and IT signals, all evolving at the well understood rates
- Only products/services specified in protocols are provided/sold; critical to have a complete set to provide service as desired by customers; regulated industry particular case
- Software supported, flexible implementations
- Without this, it may be impossible to perform both in an efficient and secure way.