Control and Electricity Markets

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Outline

- **Current Market Practice**
  - Goals
  - Tools and timeline
- **Smart Grid Implications**
- **Control & Electricity Markets**
  - Current Mechanisms – LMP, TOU, CPP
  - Emerging Framework: Transactive Control
  - Simulation studies

Power Grids: Goals

Maintain balance between generation and load

- Generation = Demand + Losses
- Voltage & Frequency regulation

Main Tools:

- Economic Dispatch - determines set-points
  - Generation resources dispatched from least to most expensive, based on demand projections
  - Use reserves to meet actual demand
- Regulation
  - Automatic Generation Control (AGC)
    - Secondary and Primary Control

Electricity Market

Goals of Market Operation

- Ensure a reliable and secure grid
- Facilitate economical operation

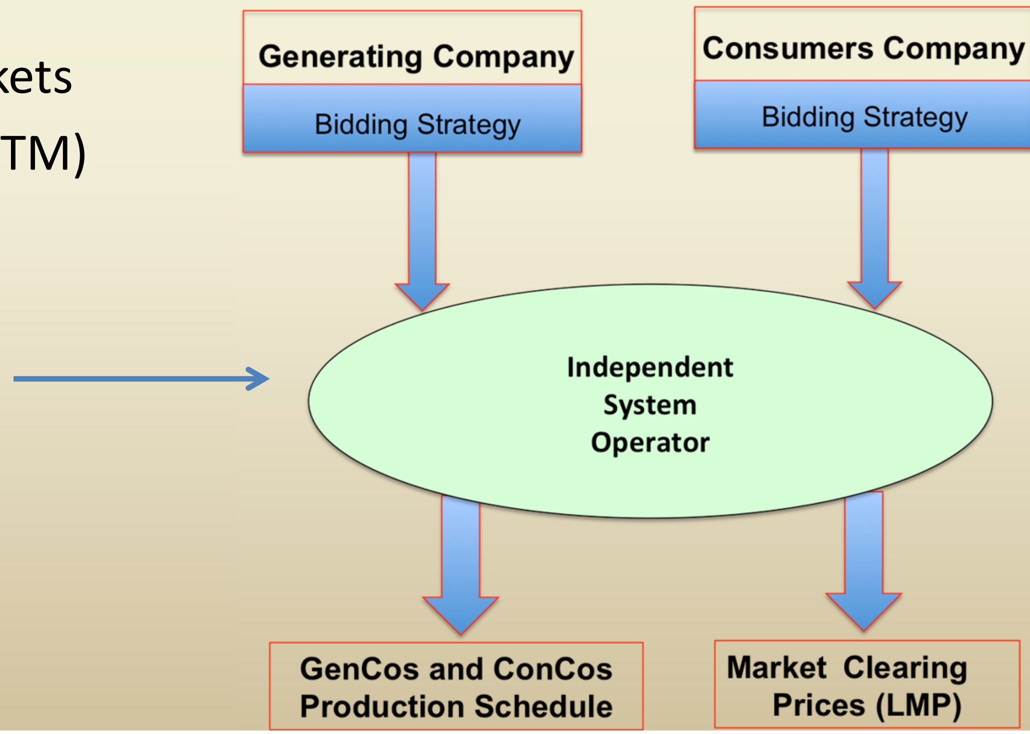
Reliability

Affordability

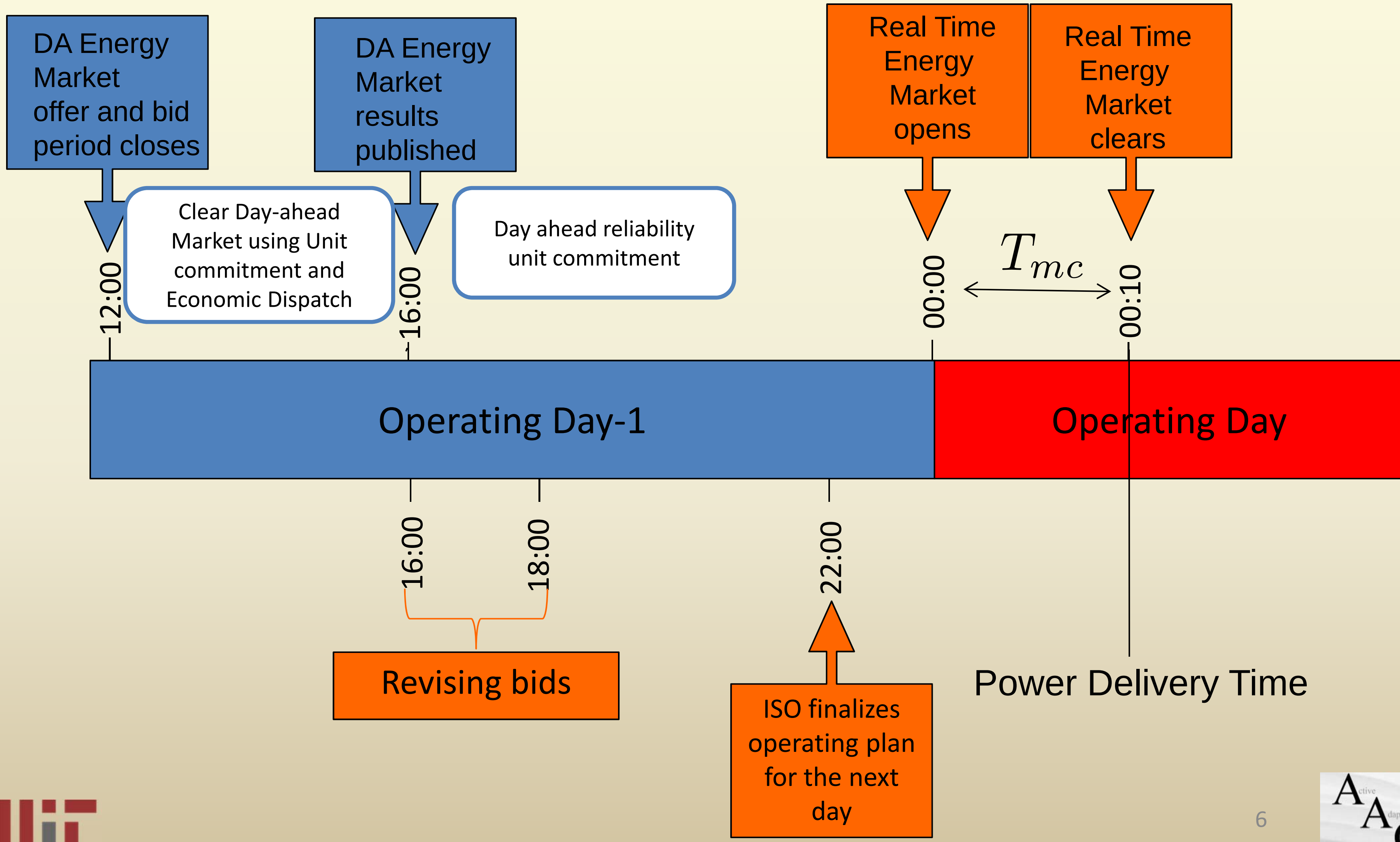
Electricity Market

- Centralized mechanism that facilitates trading of energy between buyers and sellers.
- The market operator conducts an auction market and schedules generators based on bids received.
- Determines a market clearing price (Locational Marginal Price (LMP)) and provides commitments and schedules based on security-constrained unit commitments
- Day-ahead (DA) Markets
- Real-time Markets (RTM)

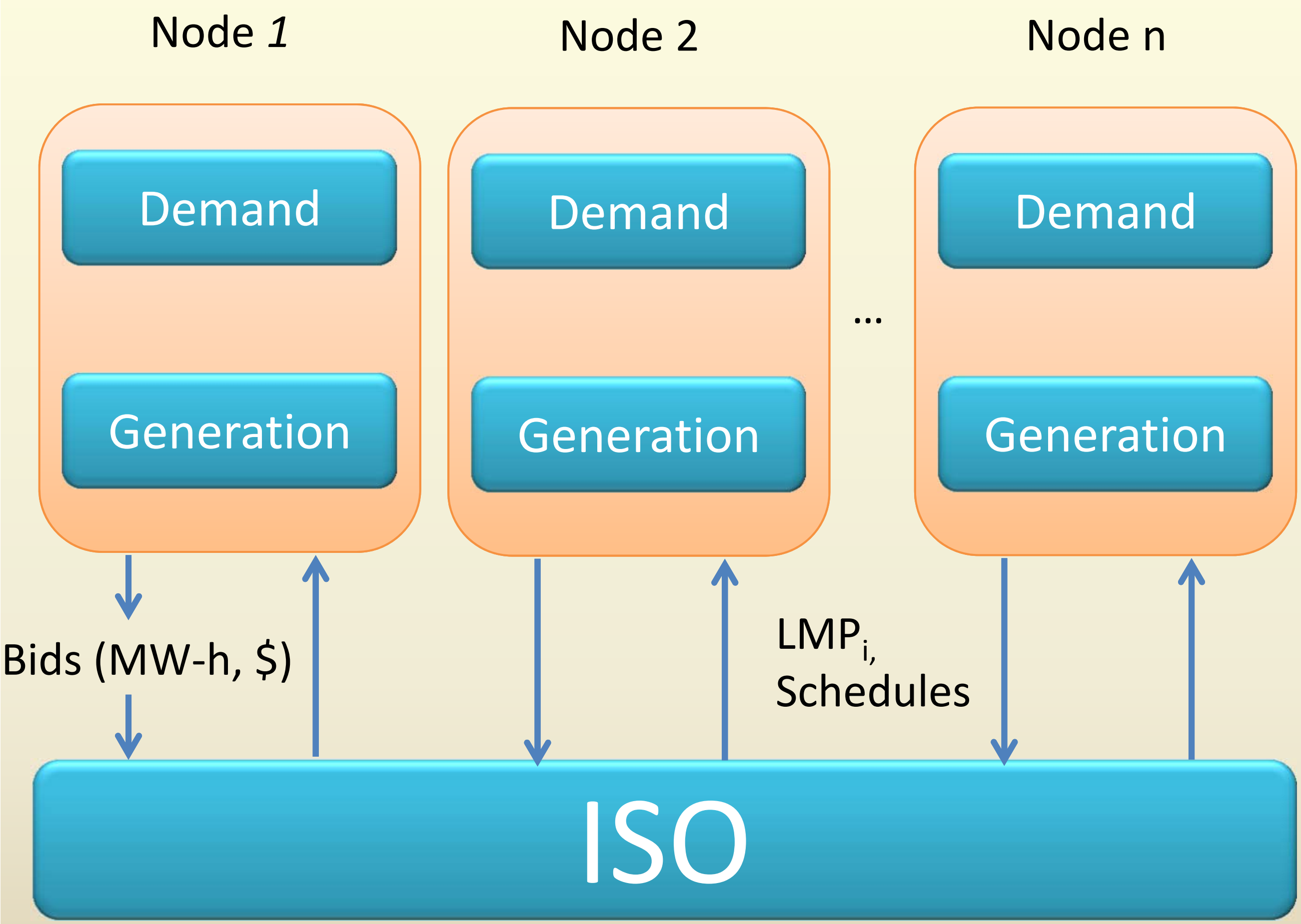
Wholesale Market

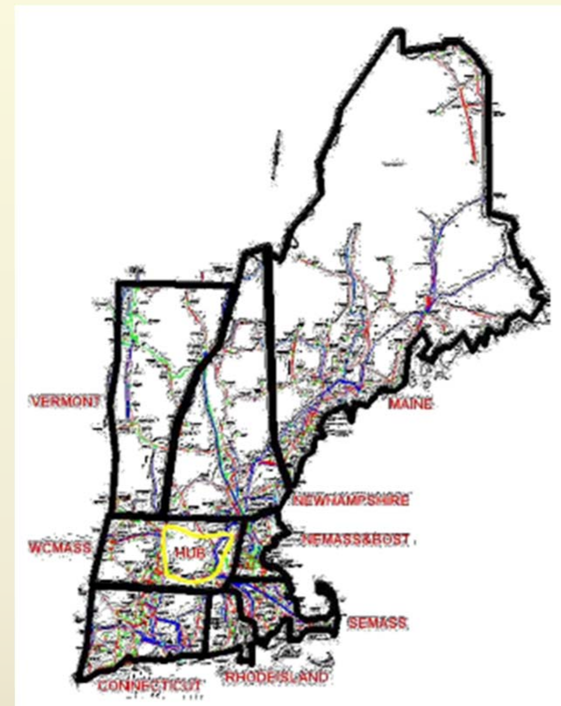


Wholesale Market: A Dynamic System



Market Mechanisms - LMP





Nodes in New England, USA

Wholesale Market: Constrained Optimization

$Min. \sum_{i=1}^{N} C_i(P_{gi})$ → Economic Dispatch → P_{gi}, ρ, μ

Subject to:

$B = \sum_{i=1}^{N} P_{gi} - \sum_{j=1}^{L} C_i(P_{lj}) - Loss = 0$ System balance

$T = \sum_{i=1}^{N} S_{ki} P_{gi} \leq T_k^{max}, k = 1,2, \ldots, K$ Transmission constraints

$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max}, i = 1,2, \ldots, N$ Capacity constraints

Equivalent to

Min $L = \sum_{i=1}^{N} C_i(P_{gi}) + \rho B + \mu(T - T_k^{max})$ (if no capacity constraints)

P_{Gi}: Generation Schedule at Node i, ρ: LMP, μ : Congestion rent

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Smart Grid Implications

Goals

- Reliable and affordable power
- Voltage and frequency control
- Security

Drivers

- High penetration of Renewables
  - Decarbonization
  - Climate changes
- Increasing demand for energy

Challenges

- System of Distributed Systems
  - Heterogeneous
  - Intermittencies and uncertainties
  - Time-scales: Seconds to seasons
  - Synergy between power & communication

Emerging Tools

- Demand Response
  - Adjustable demand in response to grid/market conditions
- Smart meters/ PMUs
- Transactive Control
  - the use of distributed communications to send an incentive signal and receive a feedback signal within the power system's node structure.

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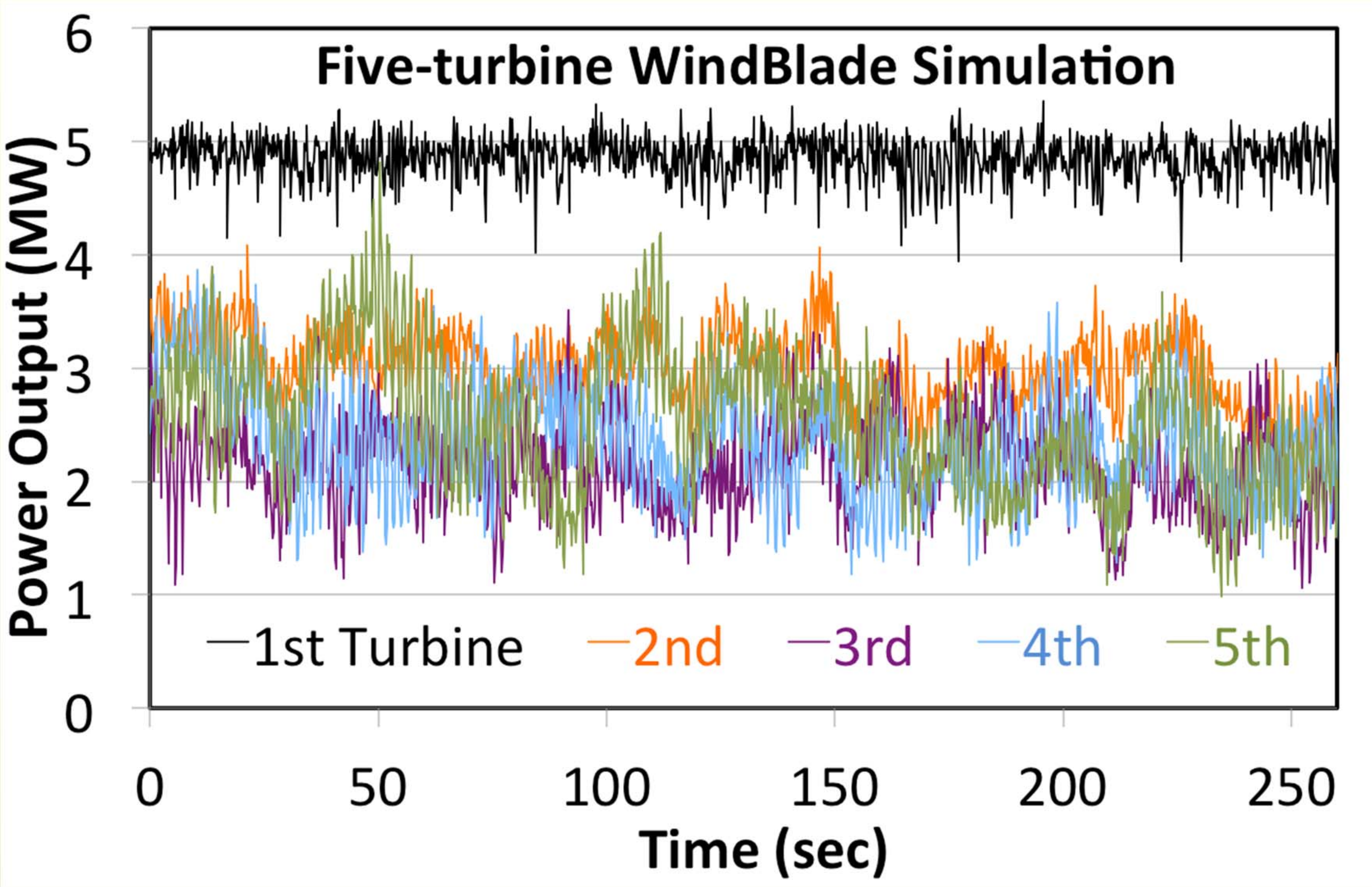
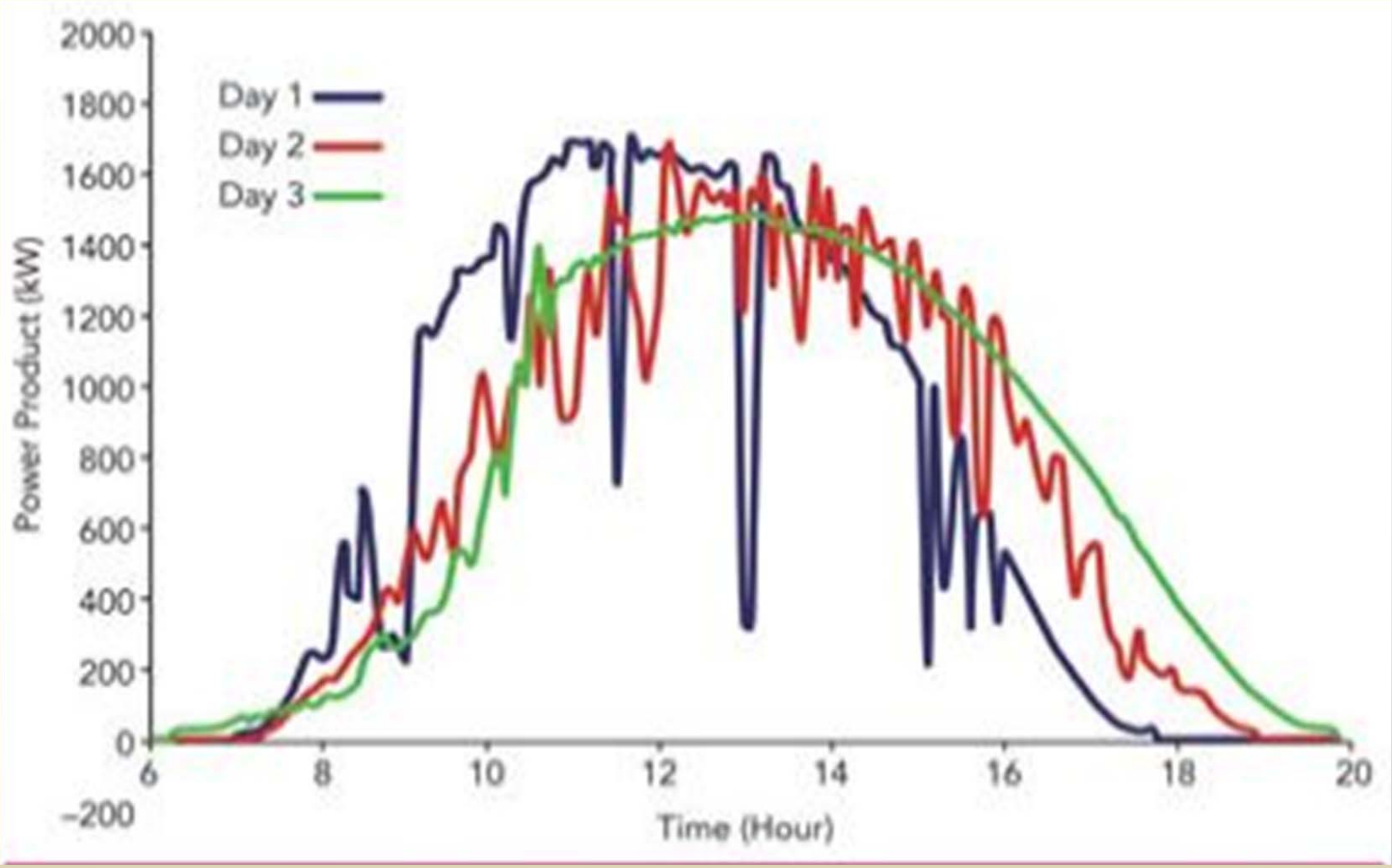
Renewable Energy – Intermittency & Uncertainty



Courtesy of the Los Alamos National Laboratory

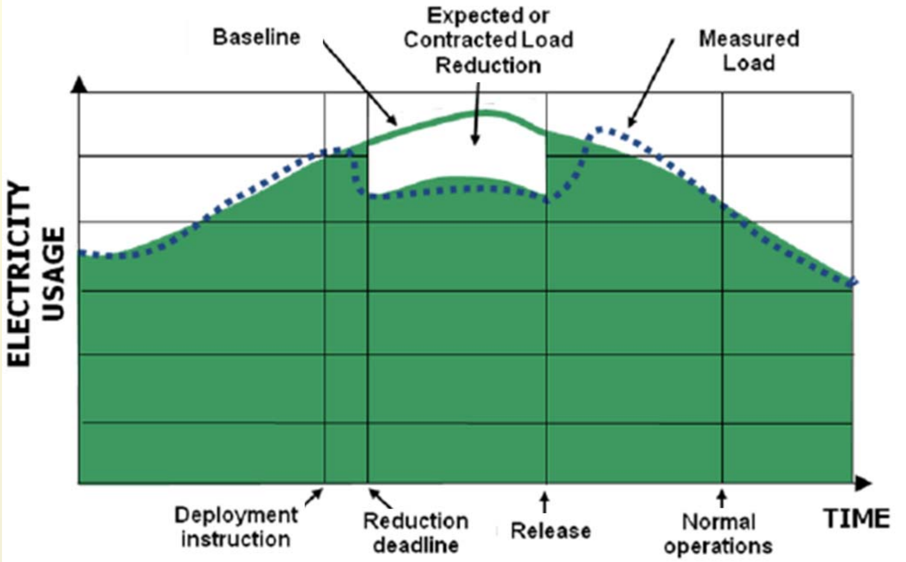
Renewable Energy – Intermittency & Uncertainty

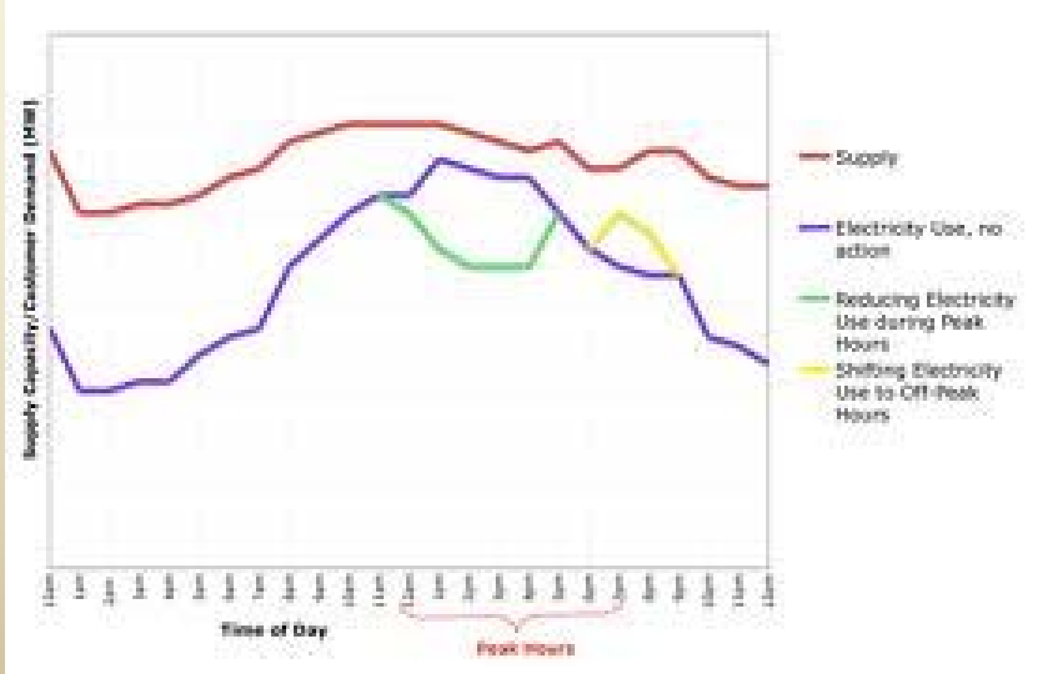


Courtesy of the California ISO PV output in 3 typical days Dec. 2-5. 2011

Demand Response – “Actuators”

- Customers reduce consumption in response to
    - Reliability events, wholesale prices
- Ways of reduction
    - Load reduction for a specific time
    - Load shifting
- Incentives based on time and amount





Transactive control: An Emerging Paradigm

The use of distributed communications to send an incentive signal and receive a feedback signal within the power system's node structure

- Incentive Signal: Dynamic Pricing
- Feedback Signal: Adjustable Demand

- Grid-wise Implications

- Transactive Control ⟶ Control architecture that coordinates
  - ➢ Market Transactions
  - ➢ Active Control at the AGC level

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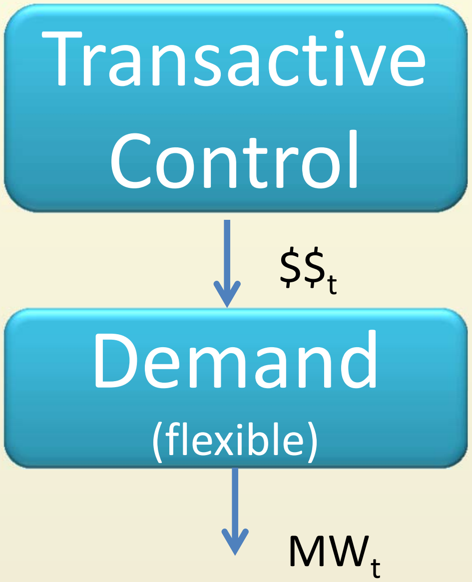
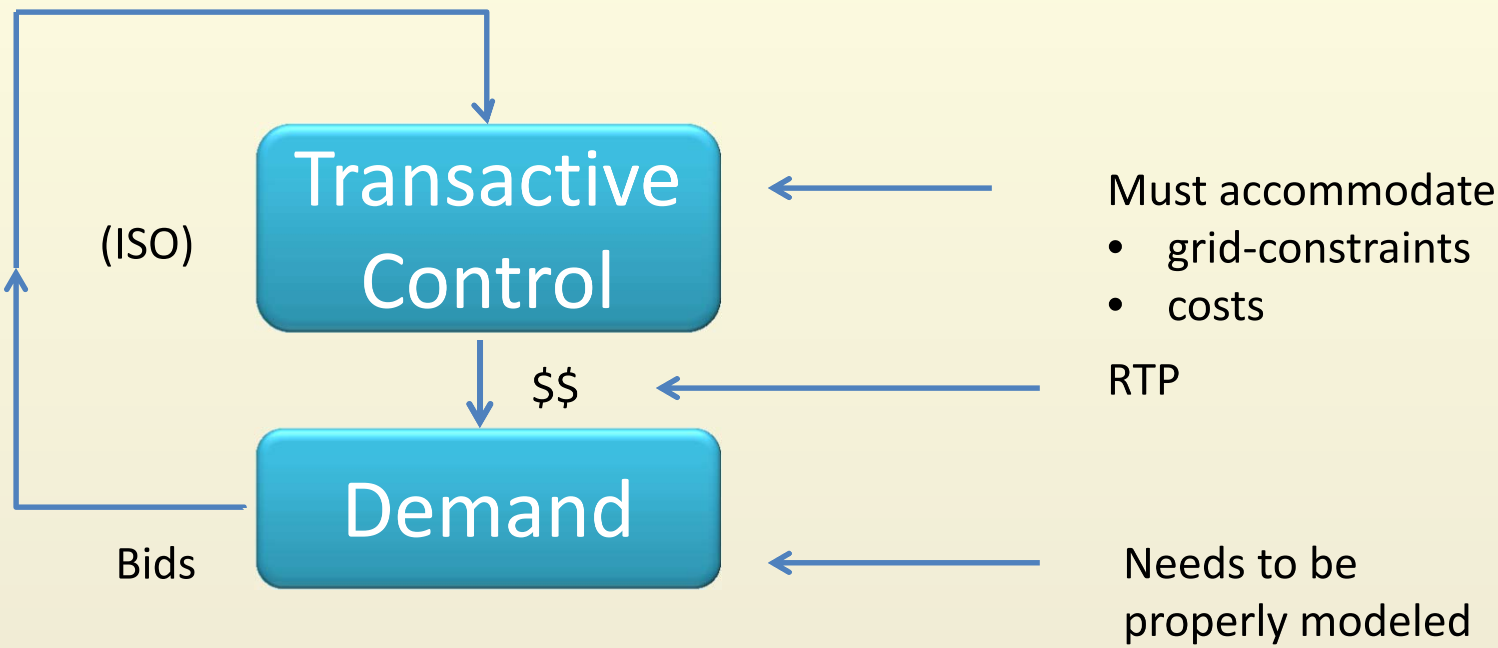
Transactive control: Dynamic Pricing



Some Examples:

- Critical Peak Pricing (CPP)
  - During scarcity in production
  - Power retailer can assign a high price
  - Sometimes linked with TOU
- Peak-time Rebate
  - Each customer entity has its own baseline calculated based on similar days surrounding event
  - Customer gets a bill credit for all reduction below their baseline
- Real-time pricing (RTP)
  - Assign the actual price of that hour for consumption

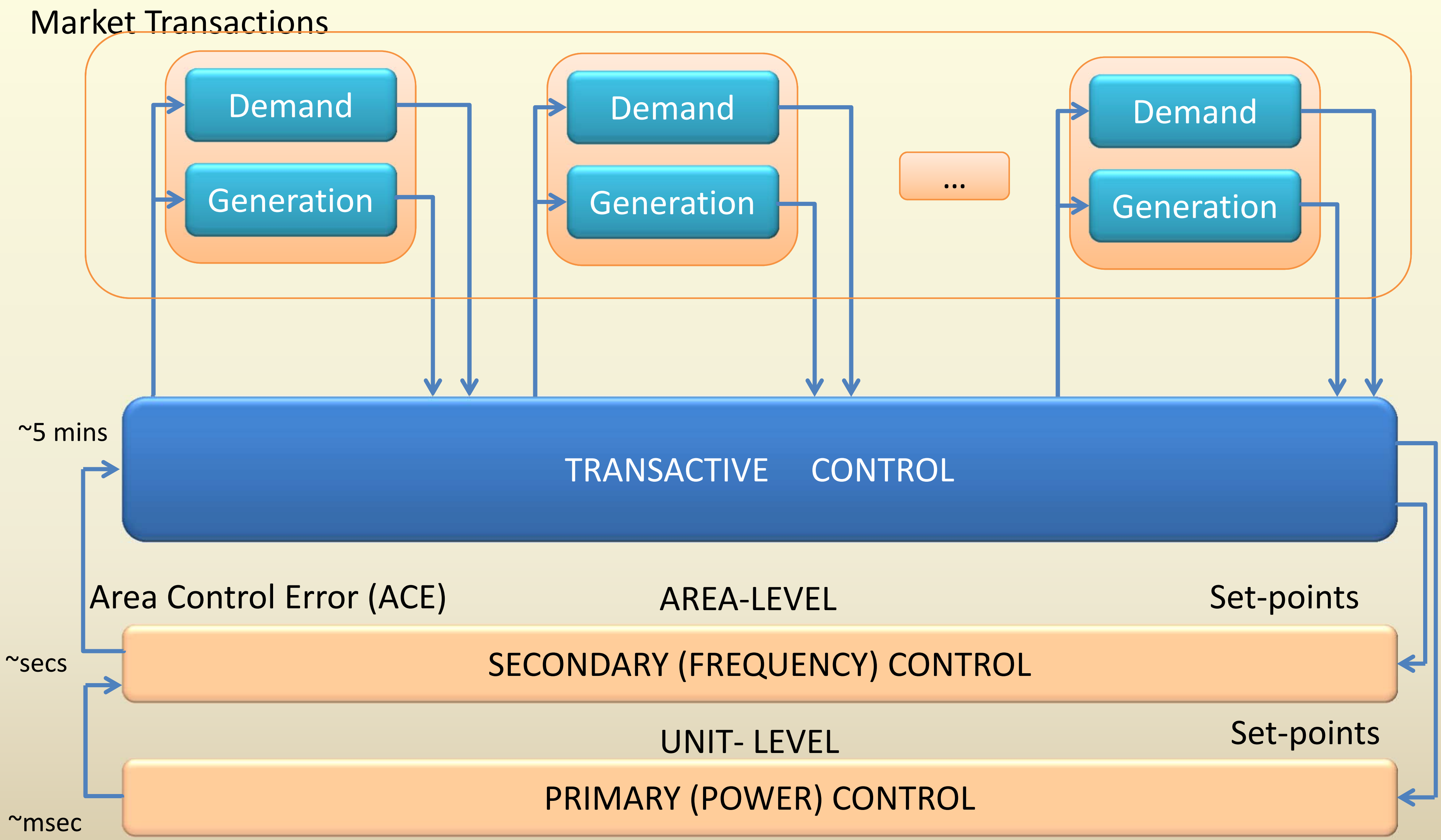
Transactive control: Introduces Feedback!



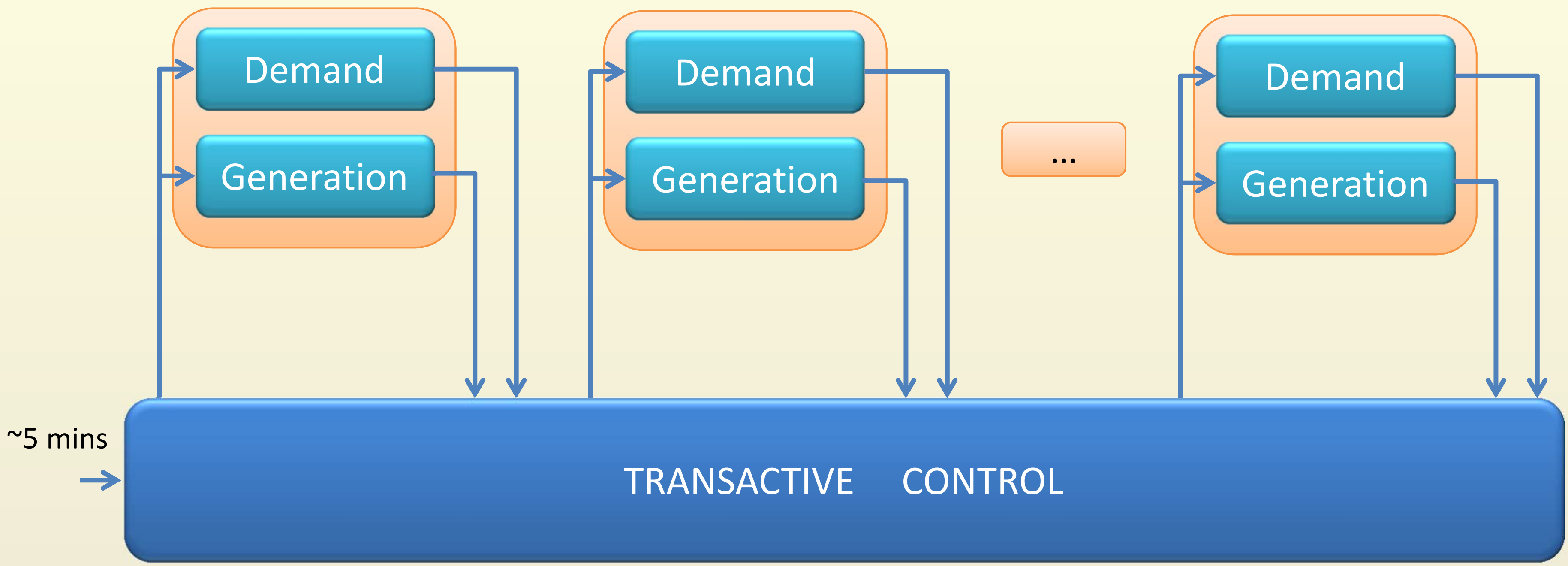
Goals

- Reduced congestion
- Integration of renewables
- Reduced utility cost

Proposed Transactive Control Framework



Transactive control framework: Market Level



$$L = \sum_{i\in G_f} C_{G_i}(P_{Gi}) - \sum_{j\in D_q} U_{Dj}(P_{Dj}) + \sum_{n=1}^{N} \rho_n B + \sum_{k=1}^{N_t} \gamma_k \left[T - T_k^{max}\right]$$

$$\Delta P_G(k) = -k_G \frac{\partial L}{\partial P_G}$$ (Generation)

$$\Delta P_D(k) = -k_D \frac{\partial L}{\partial P_D}$$ (Demand)

$$\Delta \rho(k) = k_\rho B$$ (Real-time Price)

$$\Delta \gamma(k) = k_\gamma \max(0, T - T^{max})$$ (Congestion)

Transactive Control: Market Mechanism

The overall dynamic model:

$$x[K+1] = (I_n + hA)x[K] + hk_\rho\Delta + b$$

$$x(K) = \left[\{P_G\}_i \quad \{P_D\}_j \quad \{\delta\}_n \quad \{\rho\}_n\right]^T_{(n)\times 1}$$

$$A = \begin{bmatrix} -k_g c_g & 0 & 0 & k_g A_g^T \\ 0 & k_d c_d & 0 & -k_d A_d^T \\ 0 & 0 & 0 & k_\delta Y^T \\ -k_\rho A_g & k_\rho A_d & k_\rho Y & 0 \end{bmatrix}$$

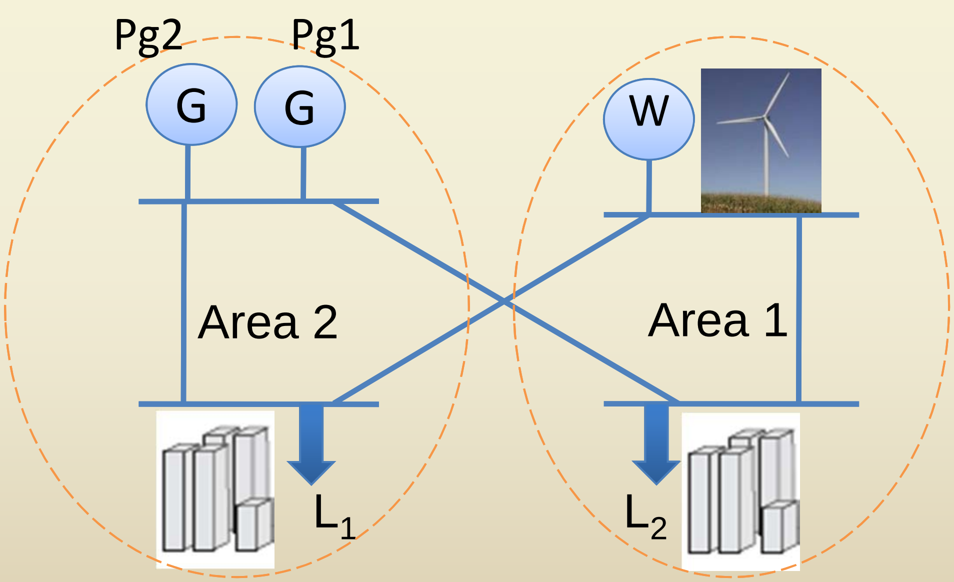
$n : N_g + N_d + 2N - 1 \quad N_g : \#GenCo \quad N_d : \#ConCo \quad N : \#buses$

$k_g, k_d, k_\delta, k_\rho$: Parameters of the RTM dynamic model

- Quantifies effect of volatility and stability
- Can help reduce reserve costs with wind uncertainty

Simulation Results

- 4-bus network with two generator units at node 1 and wind at bus 2 (P_{g1}: Base-load; P_{g2}: Reserve)
- L_1, L_2: DR-Compatible demand



Parameters with following values:

cg1 = 0.25; cg2 = 0.55; generator cost coeficientes

bg1 = 40.2; bg2 = 60; generator cost coeficientes

kg1 = 0.3; kg2 = 0.8; generator time constants

cd1 = cd2 = 0.4; consumer utility coeficientes

bd1 = bd2 = 70; consumer cost coeficientes

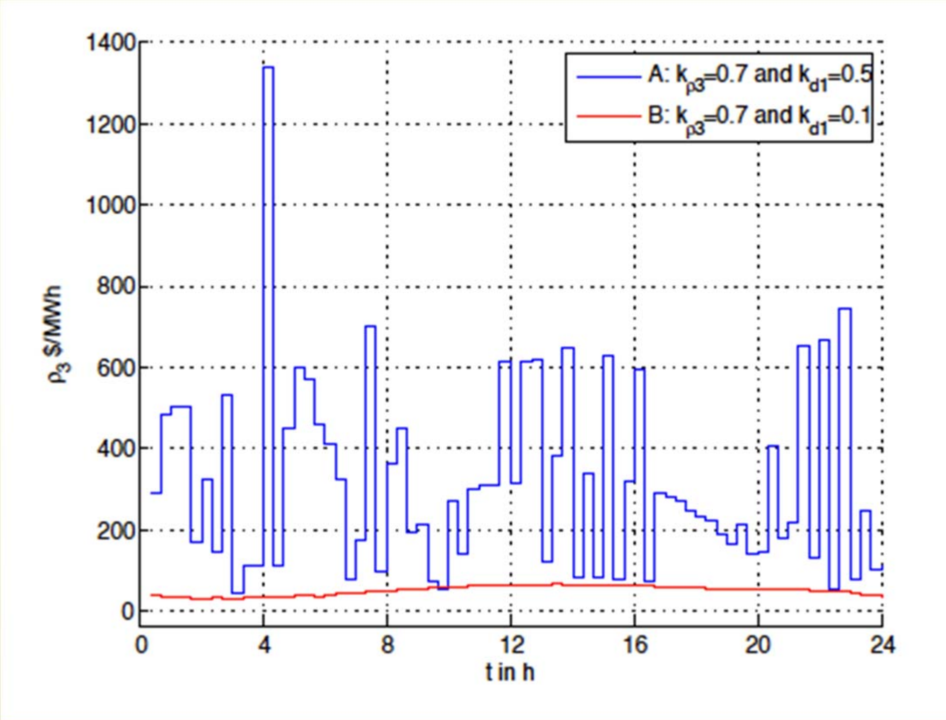
kd1 = kd2 = 0.3; demand time constants

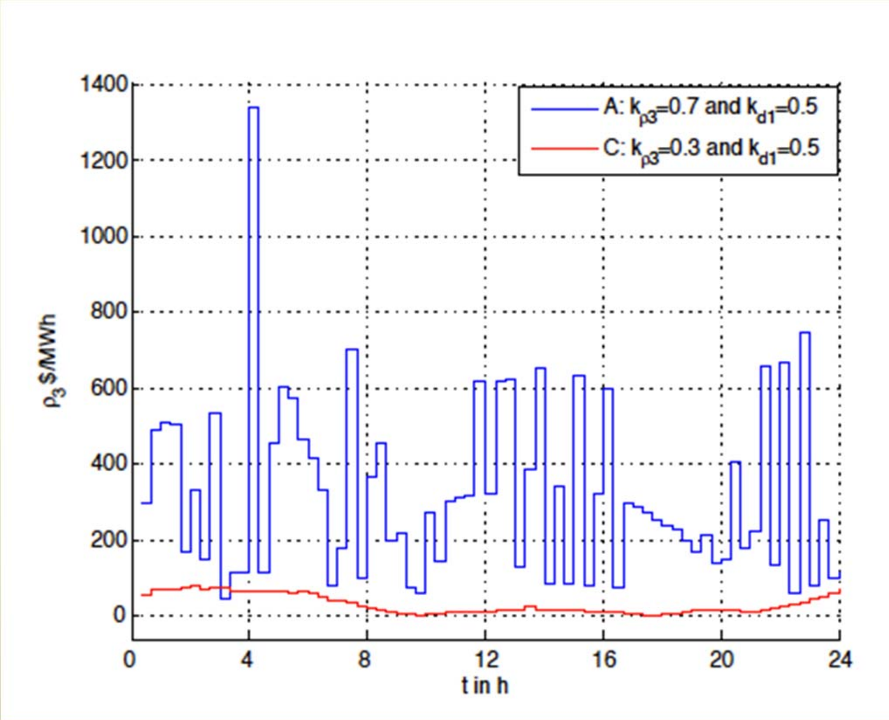
k = 0:7; LMP time constant (market time constant)

Simulation Results: Market Stability & Volatility

Volatility: With increased demand-elasticity (k_d)

Stability: With increased latency (k_ρ)

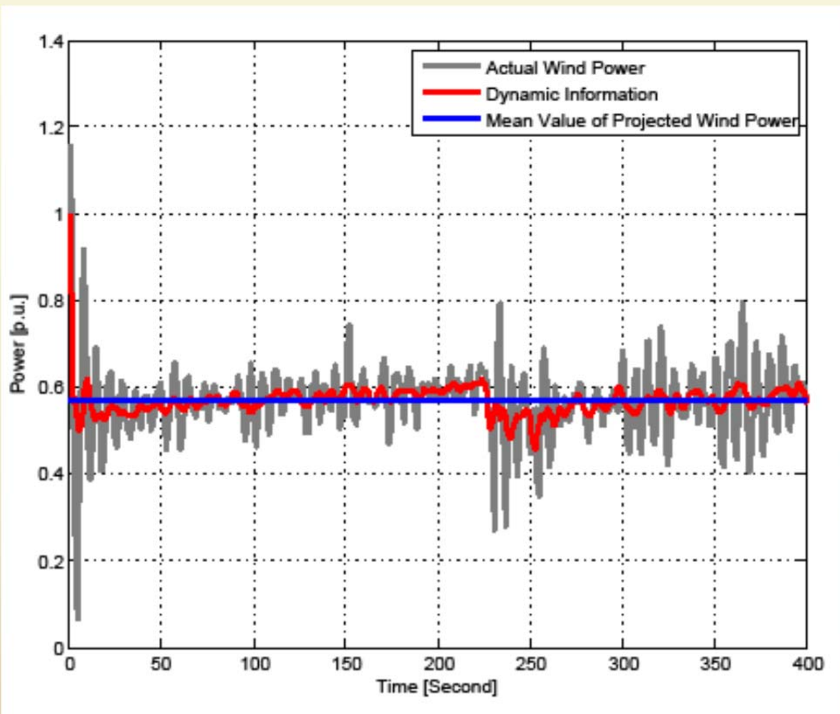


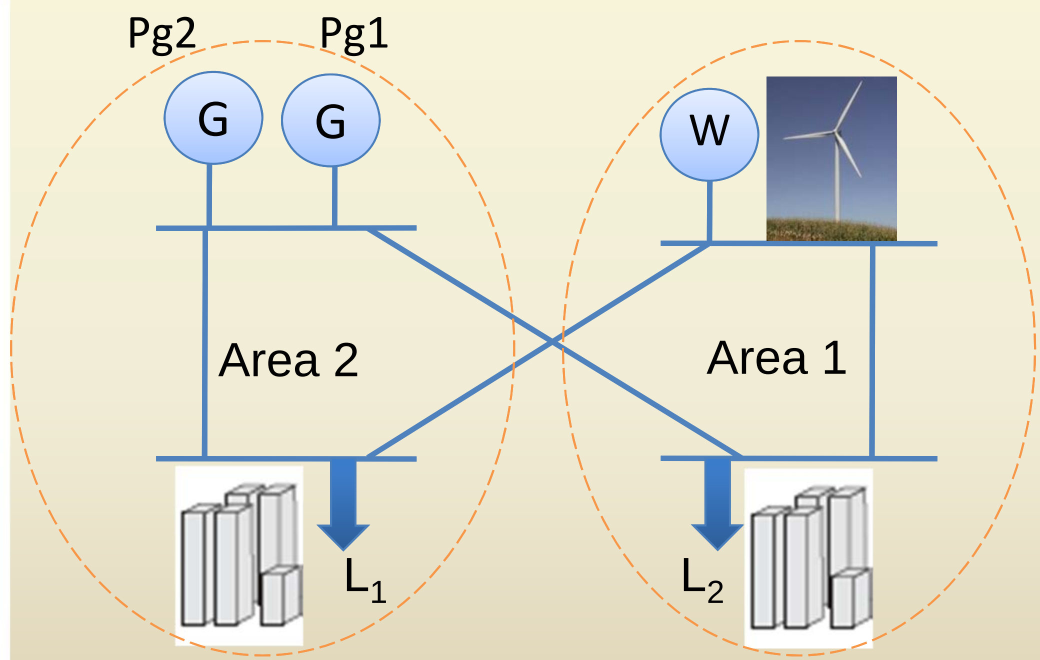


Simulation Results: Effect of Wind Uncertainty

Wind Properties:

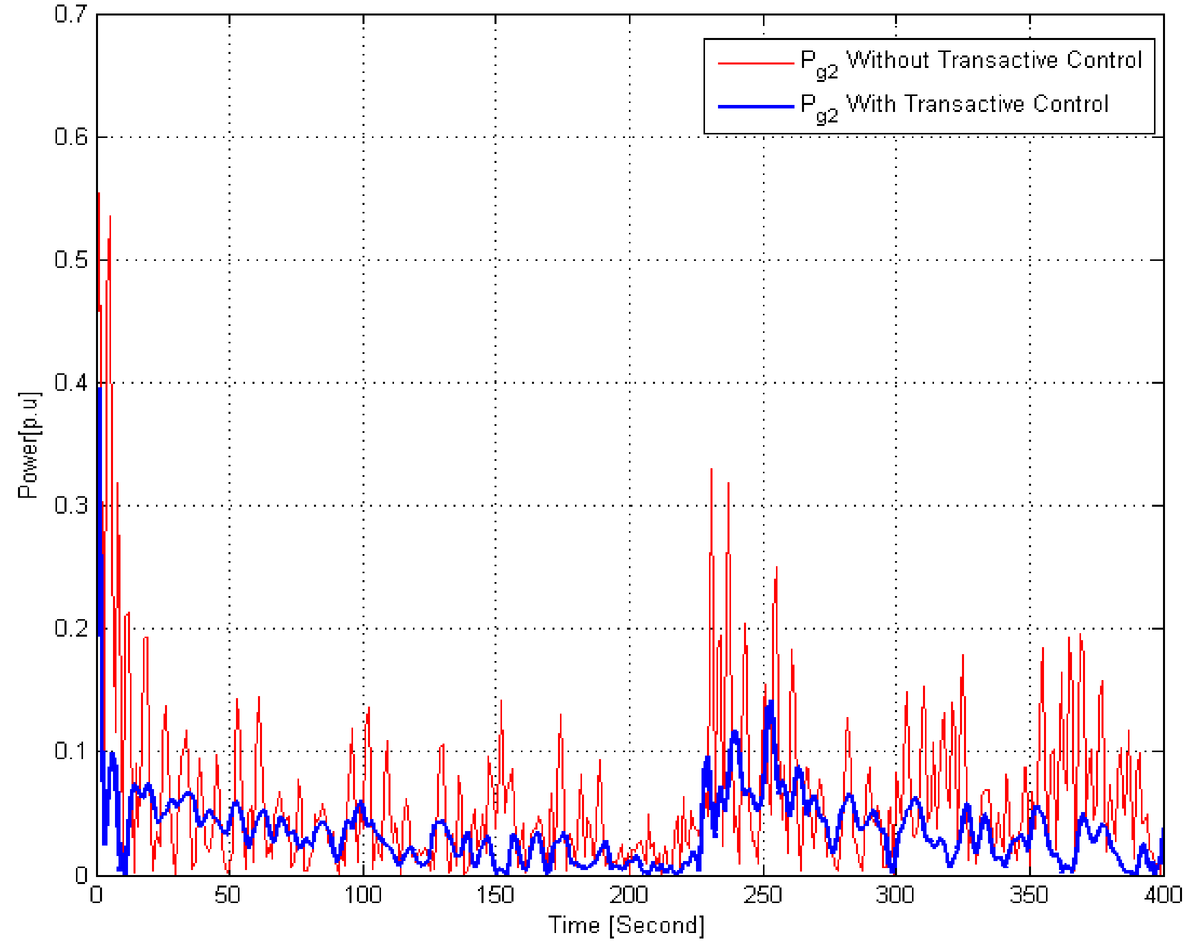
- : Actual Wind Power
- : Mean value of the projected wind. → Current Market Practice
- : ARMA model of the actual wind power. → With Transactive Control



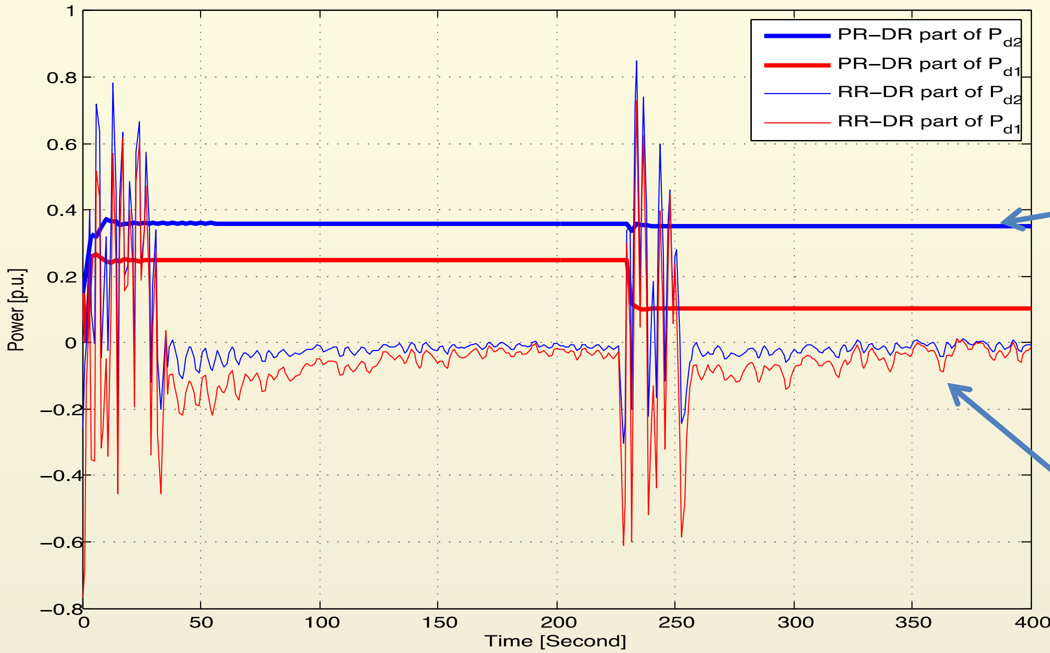


Transactive Control: Reserve costs

- Less reserve is required.

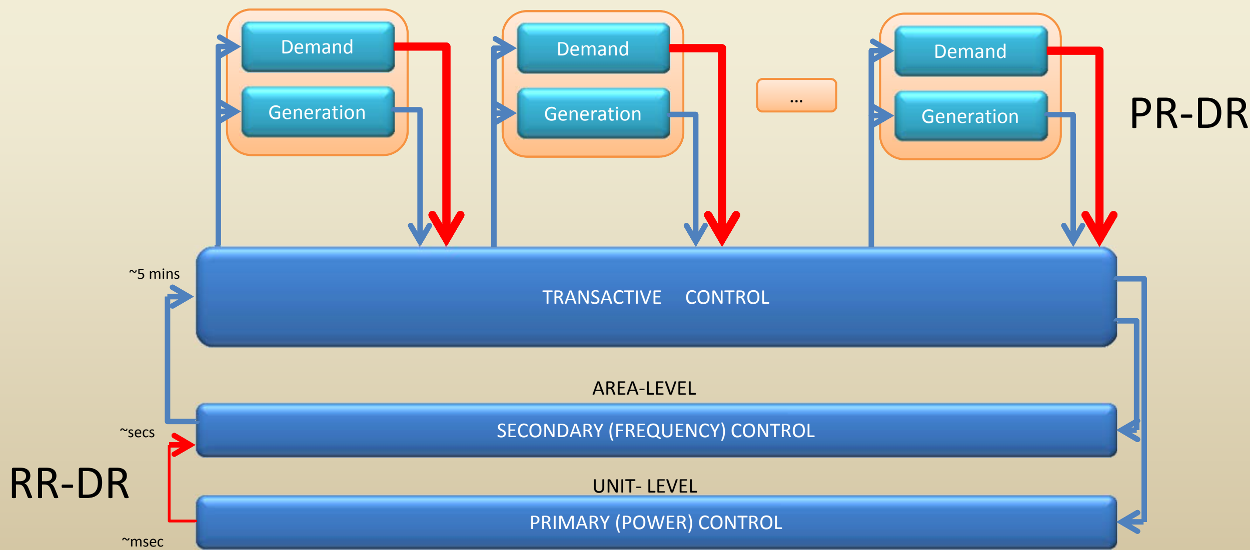


Transactive Control: Hierarchical coordination



Demand Response:
Tertiary level
(PR-DR)

Demand Response:
Secondary level
(RR-DR)



Summary

- **Current Market Practice**
  - Goals
  - Tools and timeline
- **Smart Grid Implications**
- **Control & Electricity Markets**
  - Emerging Framework: Transactive Control
  - Provides guidelines for volatility and stability
  - Helps reduce reserve costs
  - Hierarchical coordination