Electricity Markets 101
Why?
How?
Who?

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Introductions

- What keeps me up at night?

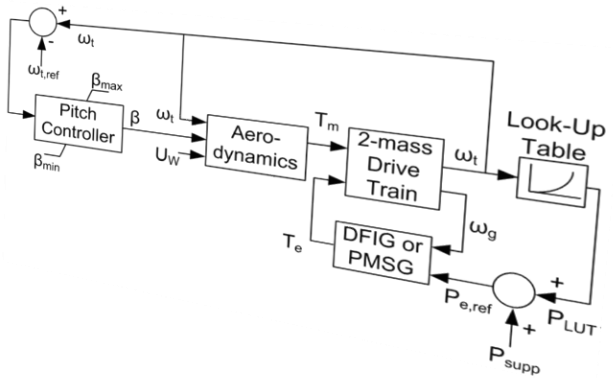
  Wide integration & *seamless* operation of (volatile) renewables in electrical grids

- How do I make what I care about possible?

  Control, system modeling, optimization, heuristic methods (AI & ML), standards

- Who am I working with?

  X, Dept. of Energy, NYISO, Depsys, IEEE, IET, NASPI



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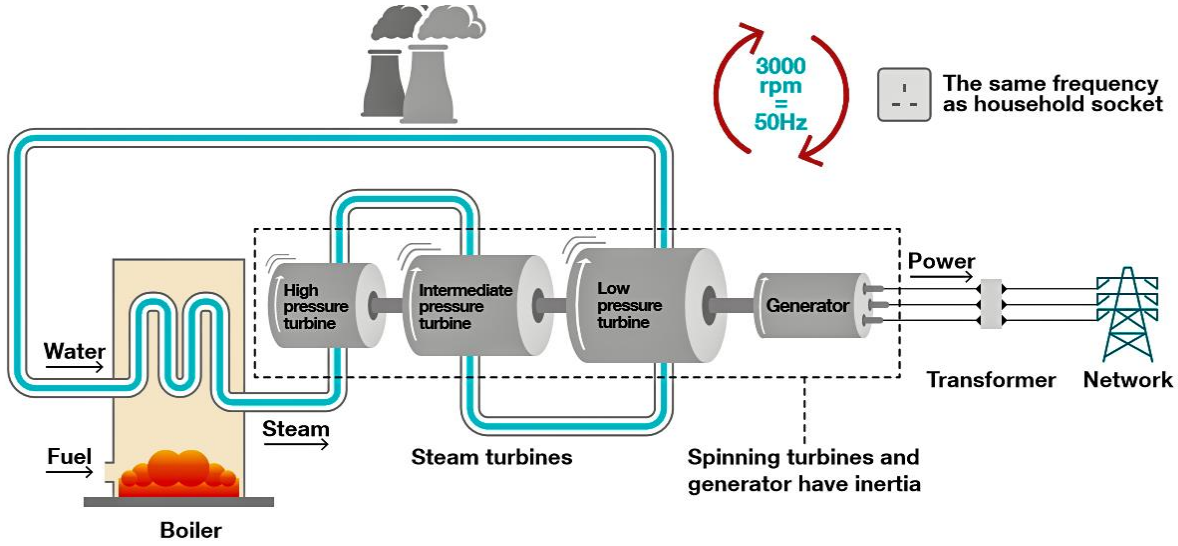
Electric Power System Fundamentals (1/2)

- Flip a switch and you have *commanded* for power
- Let's 'freeze' for one instant the power system
- All engines, generators rotating to one direction



Source: National Grid

- Flipping a switch 'tries' to change the rotation
- The generators respond to your switch flip by increasing fuel intake
- Energy NOT stored (atm… and for a while…)

Electric Power System Fundamentals (2/2)

- Electricity dispatching could be controlled *fully* online => too risky
  - Availability of resources and Coordination
  - Complexity of power system itself (non-linear, non-convex ***model***)
- Various stages of scheduling longer and shorter terms (days, months, etc)
- Various "products" (balancing, security, reserves, reactive power, bi-lateral contracts)
- Equipment management, additions, upgrades
- And all this in de-regulated framework…

Electric Power System Fundamentals – Is that all?

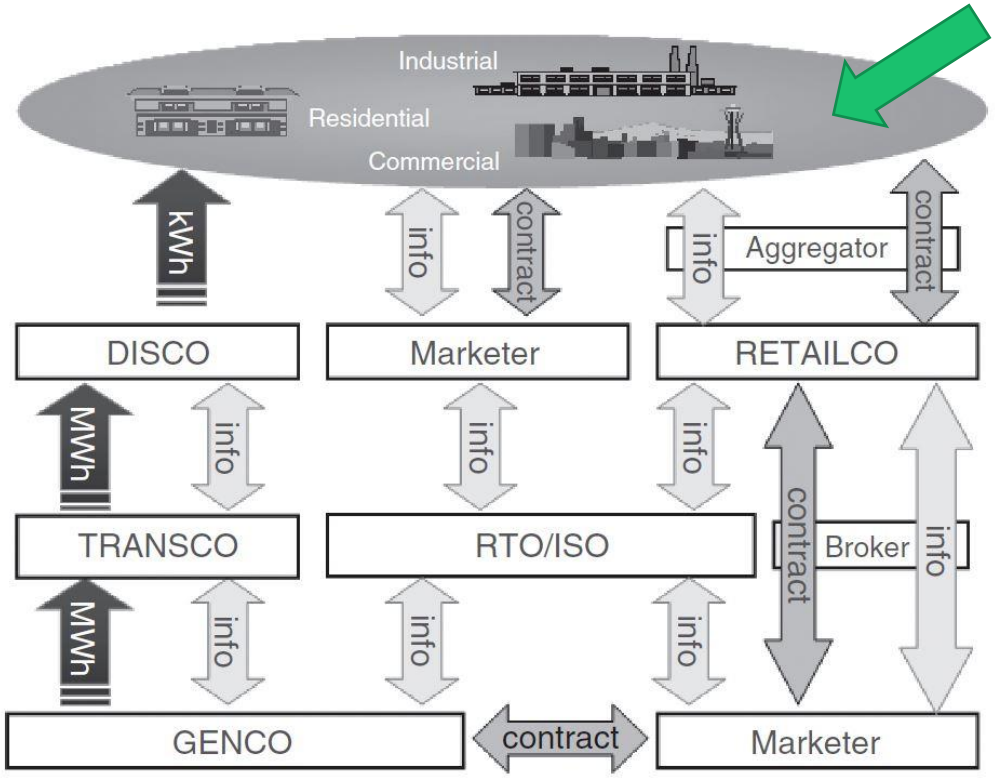
- PG&E (main utility in California) 2 times 'bankrupt' (1st causing fire, 2nd – almost bankruptcy – service disruptions to avoid fire)
- Texas 2021 freeze blackouts with some blame on gas pipes/supply
- NIMBY
- Climate change

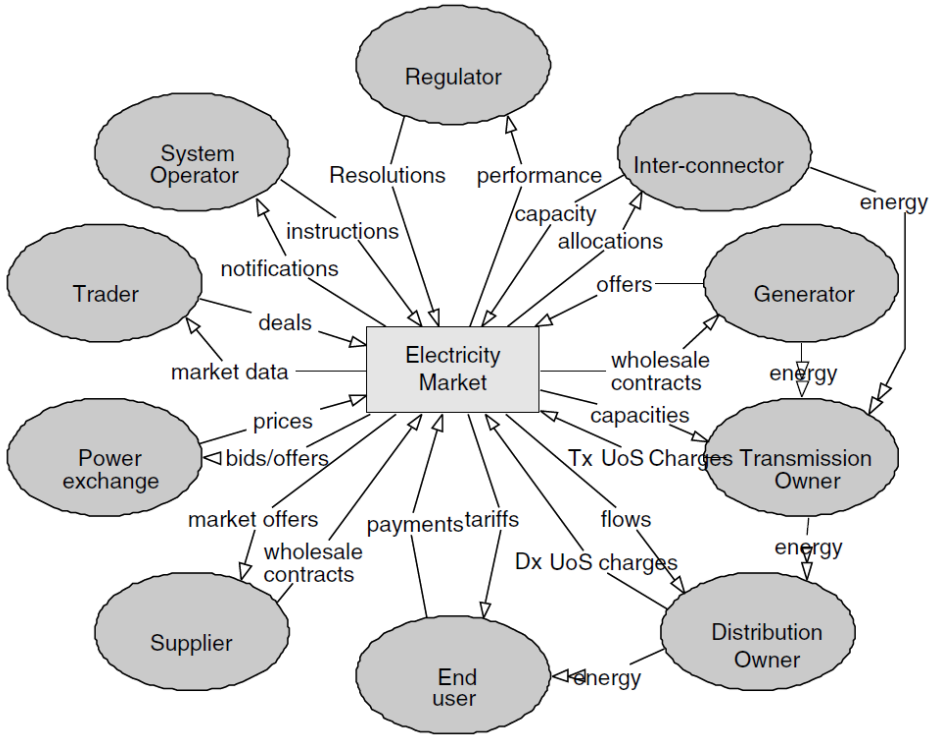
The case for Deregulation/Liberalization

- Why traditionally one single utility?
  - Load volatility and real-time coordination for service and reliability
- However this is a monopoly… Need for disruption – controlled though ! ! !
- The method was vertical de-integration => horizontal liberalization
  - Generation one business to be distributed among investors
  - Transmission another business…
- Objective change from security of supply to profit – tricky, right?
  - Regulators enforce strong operating protocols & procedures

Electricity Industry Landscape

Customer on top? I like it…





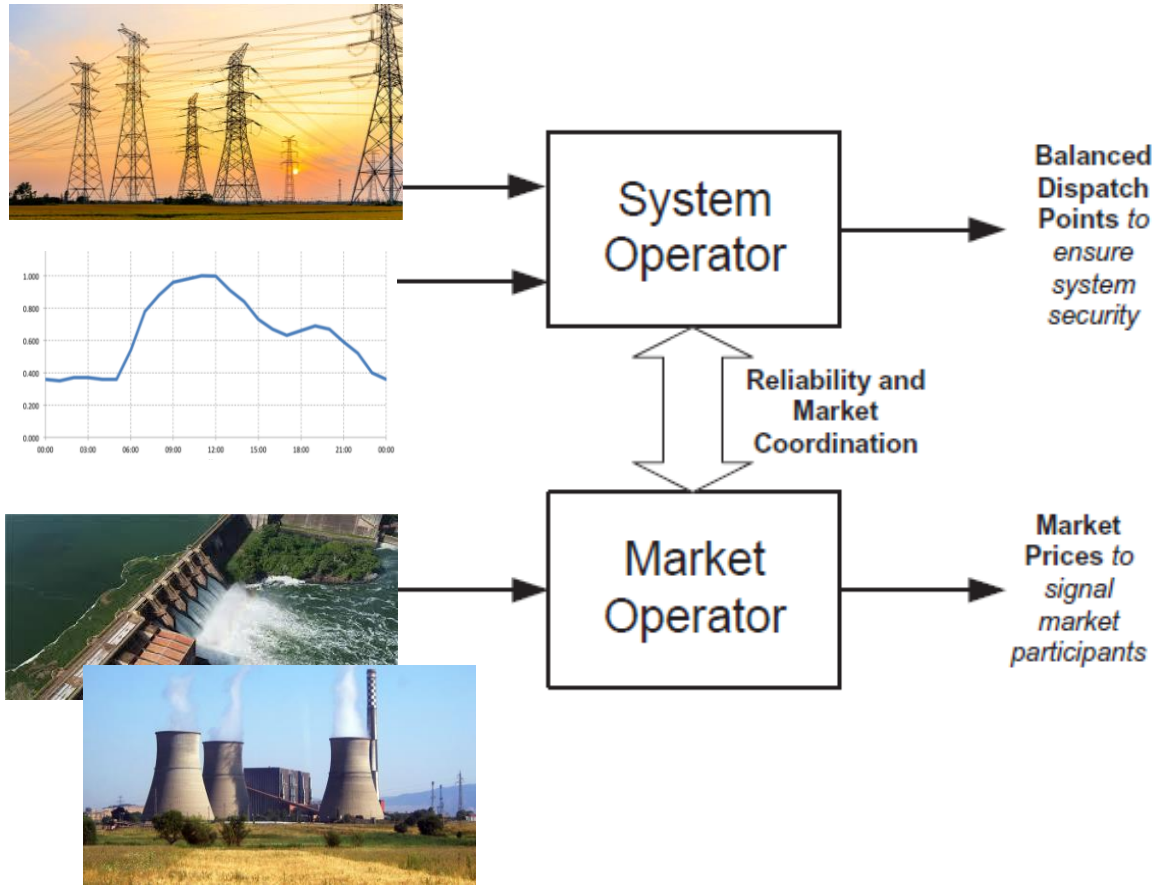
Data-base format

Major Stakeholders – Definitions

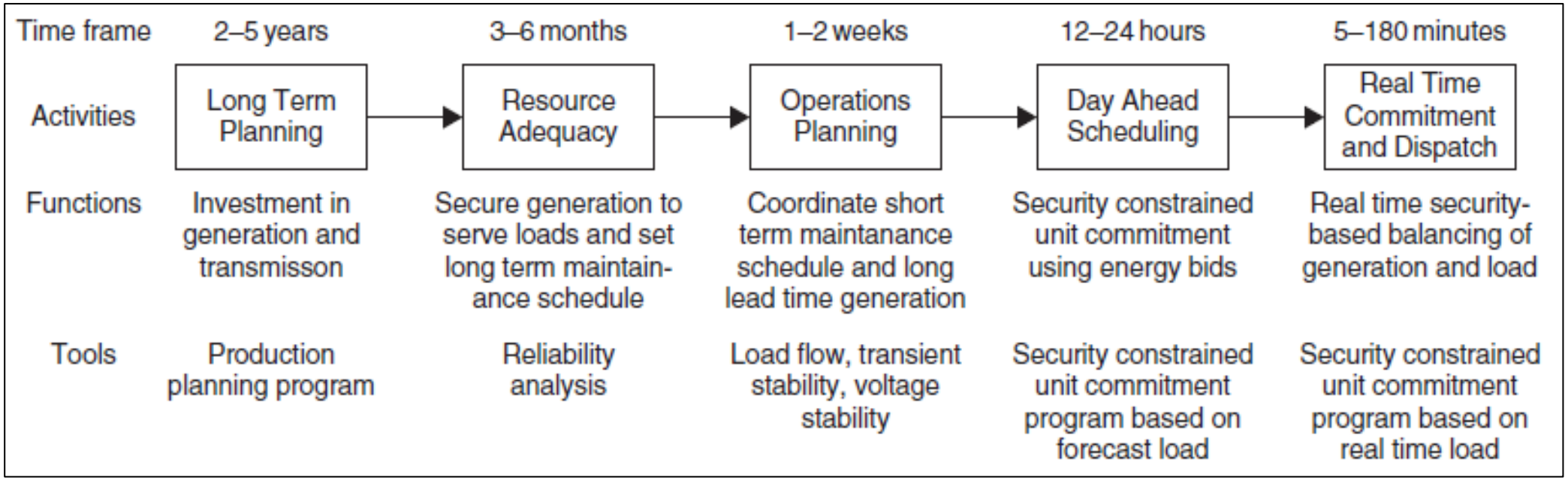
- GENCOs: GENerator COmpanies, sell generated energy (contracts or offer volume+price in pools, not price regulated – mostly (Greek aluminum case)
- TRANSCO: TRANsmission COmpanies, build+maintain+operate transmission lines and substations but NOT control them
- DISCO: DIStribution system COmpanies, ensure customers' load service from energy received from the transmission system
- ISO/RTO: Independent System Operator/Regional Transmission Organization, controls transmission lines and substation, runs market pools
- Regulators: There **are** regulated parts in the industry, also government…

What does an electricity market do?

- Online, reliably, fairly, openly ensure that generation meets all demand
- Online, reliably => System Operator
- Online, fairly, openly => Market Operator
- Usually System+Market Operators = = ISO/RTO



Typical timelines of an electricity market



DAM: Day-Ahead Market
RTM: Real-Time Market

Standard Marked Design basic functions

- Energy from generators (Gs) to loads (Ls)
  - Payments for the use of the Transmission (trX) system = Financial trX Rights
- Plan (DAM) and manage (DAM & RTM) energy from Gs to Ls
  - DAM: sufficiency for system & certain revenue for GENCOs
  - RTM: handling deviations & imbalances from expected with Ancillary Services
- Ancillary Services: ensuring energy can be delivered consistently
- Market monitoring

Standard Marked Design basic characteristics

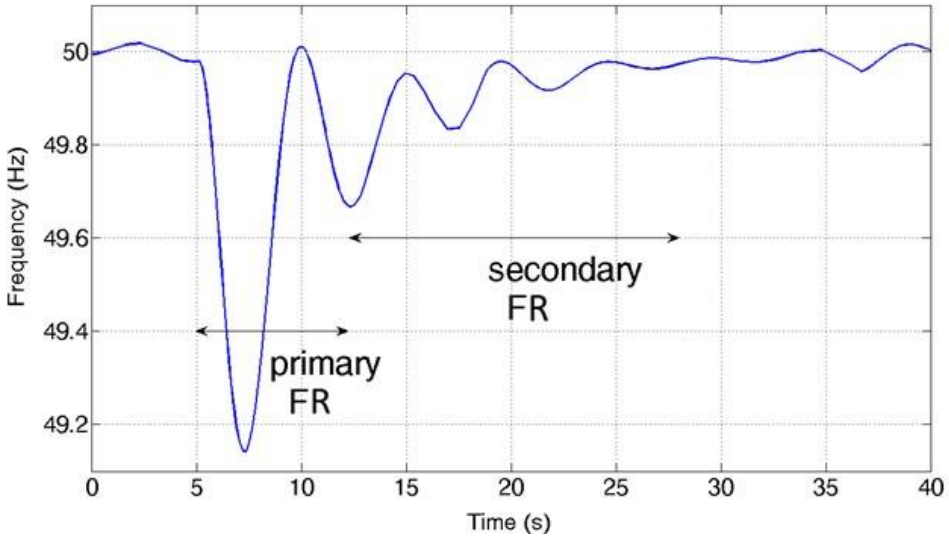
- Clear energy trading mechanisms based on physical deliverability
  - Real-time markets ensure that "forward" markets work!
- Ancillary services markets supporting all energy trading
  - Products complementary and/or supplementary to energy trading
- OASIS markets
- Frequent market clearing & dispatch of set-points to Gs (every 5')
- As realistic as possible modeling of power system and trades

Ancillary Services – Active & Reactive Power

- In the past reactive power (definition here) was not paid
  - Not absolutely true – Volumes speak volumes for large generators
- Primary & Secondary reserves: active power activated automatically
- Emergency/contingency reserves: active power activated "manually"

1ary, 2ary Reserves and Frequency Response (FR)

- Any flip-of-switch changes electric frequency
- Generators capture the change and respond automatically in two stages 1ary & 2ary
- To respond => procurement of some available (unused) power/energy (+/-)



Is Perfect Market Operation Feasible? NO!

Minimize $f(x)=P \cdot c_2 \cdot P^T + c_1 \cdot P + c_0$ (o)

s.t. $P_{k,g,min} \le P_{k,g,} \le P_{k,g,max}$ (I) $Q_{k,g,min} \le Q_{k,g,} \le Q_{k,g,max}$ (II)

$P_{km,min} \le P_{km} \le P_{km,max}$ (III) $Q_{km,min} \le Q_{km} \le Q_{km,max}$ (IV)

$$P_{km} = V_k^2(g_{skm} + g_{km}) - V_k V_m [g_{km}\cos(\delta_k - \delta_m) + b_{km}\sin(\delta_k - \delta_m)]$$
$$Q_{km} = -V_k^2(b_{skm} + b_{km}) - V_k V_m [g_{km}\sin(\delta_k - \delta_m) - b_{km}\cos(\delta_k - \delta_m)]$$ (V)

$$\sum_k P_{km} = P_k = P_{k,g} - P_{k,d}$$ (VI)

$$\sum_k Q_{km} = Q_k = Q_{k,g} - Q_{k,d}$$ (VII)

$V_{k,min} \le V_k \le V_{k,max}$ (VIII)

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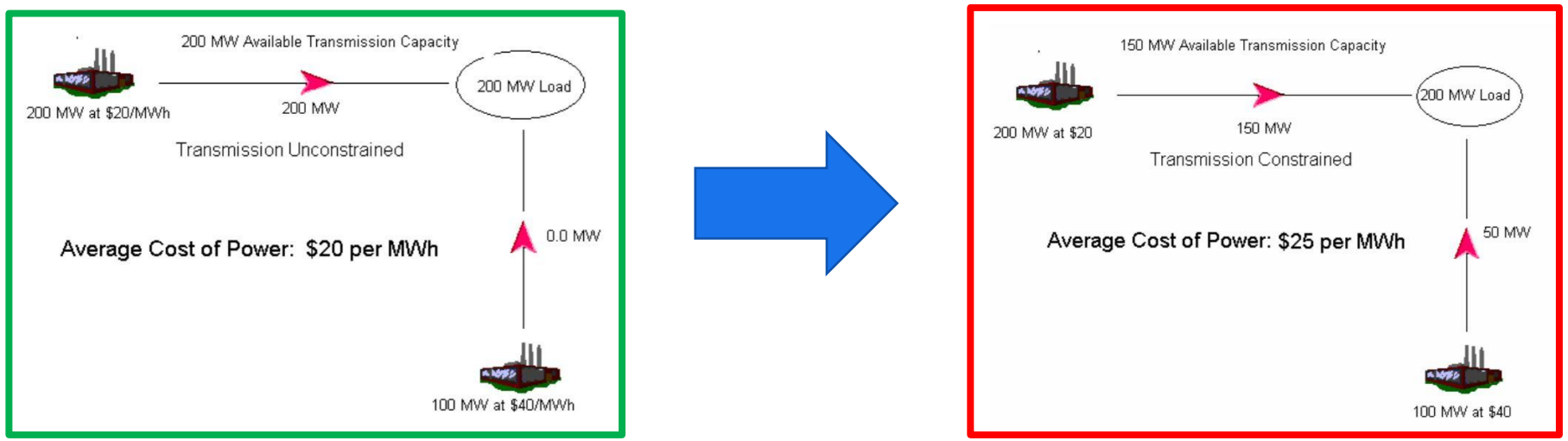
Network Constraints & Zonal pricing – Definitions

- Transmission system cannot be easily liberalized, but affects markets
- Transmission lines have a finite capacity – thermal limits =>
- Ls may not be served by the 'electrically closest & cheapest' Gs



Have electricity markets not worked? (1/2)

- California 2000-2001
  - Extreme weather conditions
  - Low adequacy of resources
  - Poor market structure
  - Market power at the absence of proper regulating response
- Ancillary services and spot markets not well developed
  - Long-term contracting problematic
  - Small players disadvantaged
  - Bundled/contracted demand response from end-customers

Have electricity markets not worked? (2/2)

- Congestion and Locational Marginal Prices
  - Essentially create “electric market islands” =>
  - Limit exports from competitive units-suppliers
  - Limit imports of cheaper energy for load customers
  - May not guarantee share of assets/resources procuring reliability
- Network investments scarce & implementation almost impossible
- Reliability+Resilience needs clears value proposition (quantification)
- The Texas 2021 case: not enough incentive/enforcement for resilience ***

Electricity requires a policy/politics framework

In other words, electricity cannot be definitively deregulated…

1. Market operators required for fairness
2. Network investments jointly and definitely decided, assisted by incentives
3. LMPs and Financial Transmission Rights (FRTs) need to be clear, transparent and linked to transmission use and congestion causes
4. Spot and Ancillary Services markets facilitate the market and system operation
5. Fuel diversity must be incentivized and linked to local availabilities

Thanks for your attention!

Questions, please?

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