

Power System Economics and Market Modeling



M1: Electricity Market Concepts and Industry Trends



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Overall Course Objectives



- Review electricity market concepts and trends
- Introduce power system optimization methods
- Describe how both system security and system economics are modeled in Simulator.
- Use Simulator optimization tools to study electricity markets:
 - Optimal Power Flow (OPF)
 - Security-Constrained Optimal Power Flow (SCOPF)
 - OPF Reserves
- Present large-scale and simulation automation examples.

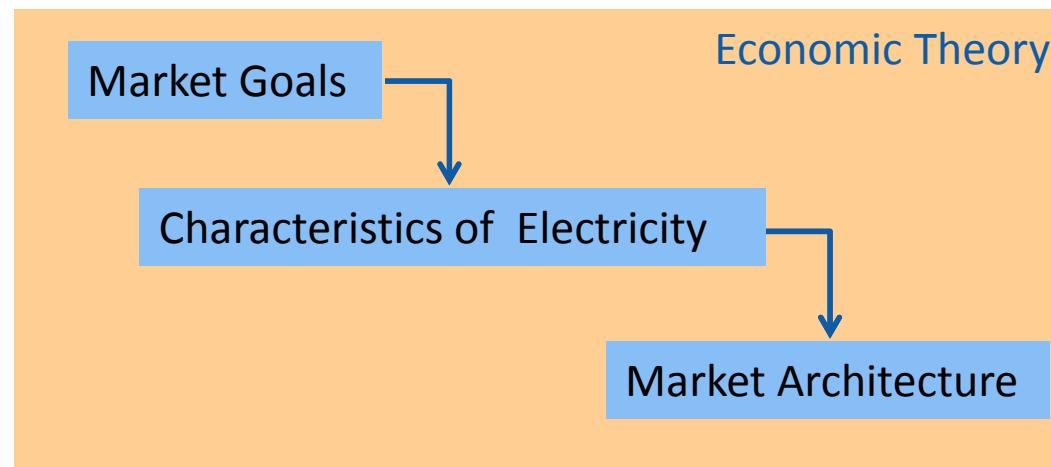


Electricity Market Concepts and Industry Trends

Section Overview



- Review key electricity markets concepts



- Present current trends in market design and implementation.

Electricity Market Goals



- Can the electricity sector function better if it is subject to *competition* and market discipline?
- Main objectives of markets:
 - Reduce overall production cost
 - Discover actual costs
 - Promote fair prices to consumers
 - Promote efficiency and transparency
 - Promote technological development

Electricity Markets



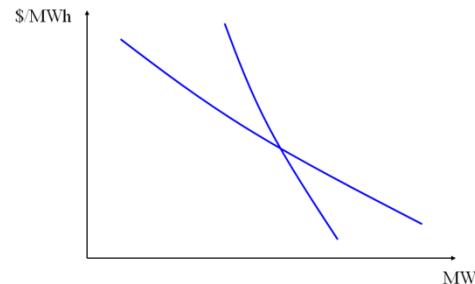
- A *market* is a place where producers and consumers of a product meet to make deals.
 - Quantity of the product
 - Price of the product
 - Quality of product
 - Electricity is assumed to be identical across the system



Consumer Demand



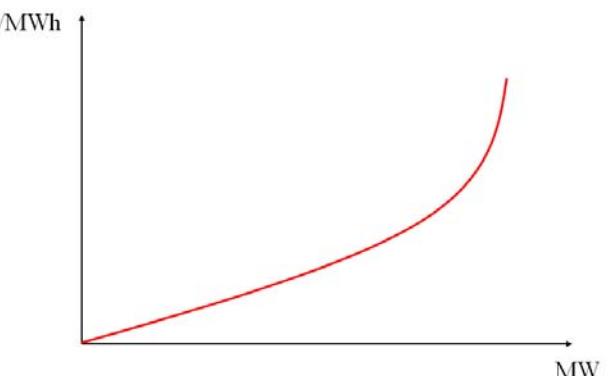
- Consider the incremental value a consumer assigns to electricity:
 - The first kW is given a high value.
 - A low value is given to electricity available in excess of what is needed.
- Electricity price-elasticity:
 - Inelastic in the short-term
 - Exhibits some elasticity in the longer term



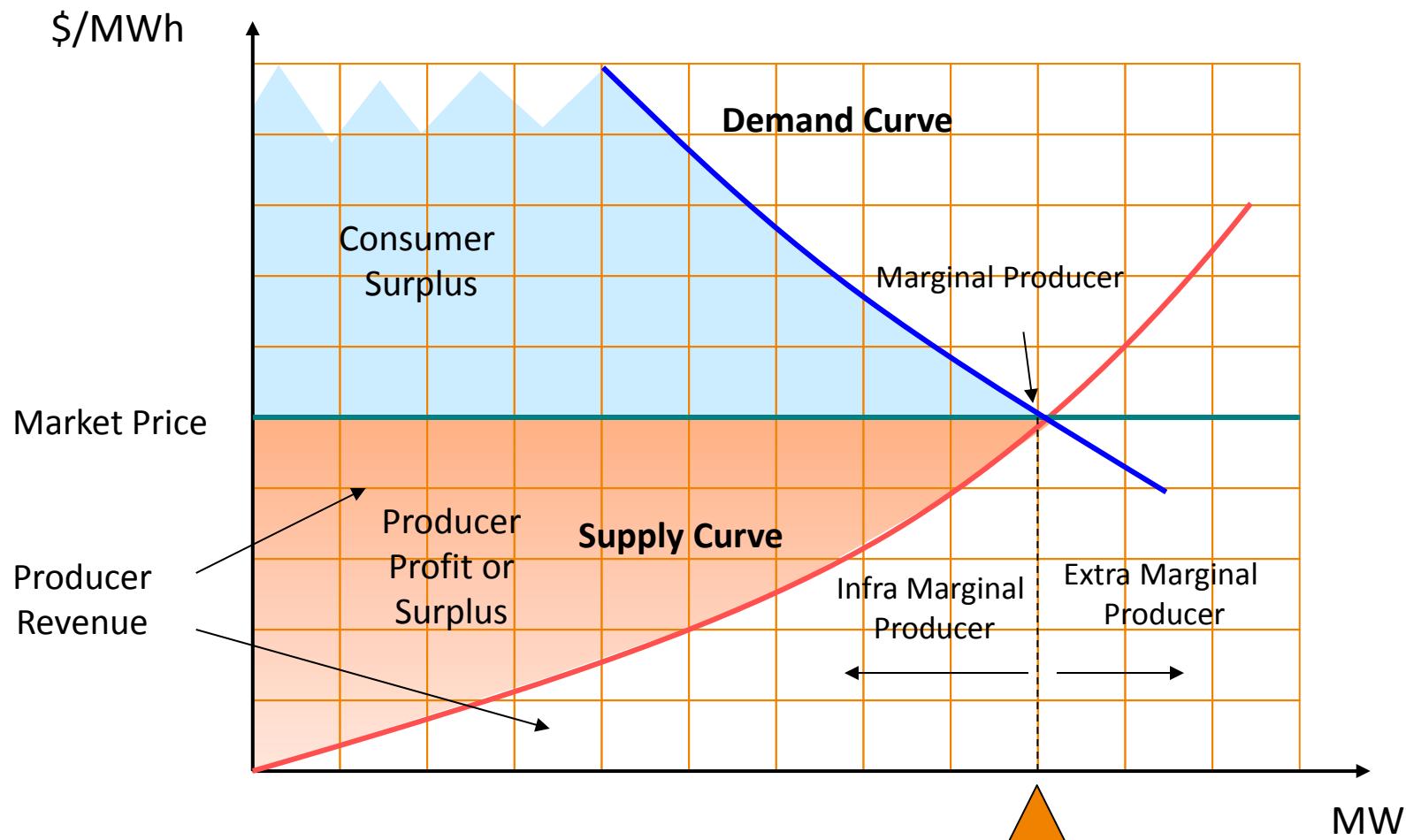
Producer Supply



- Incremental cost of production varies with technology.
 - Less expensive units are used as base, while more expensive units are used only during hours of high demand.
 - System incremental cost increases with quantity. This is typical of supply curves.



Electricity Market Equilibrium



Electricity Market Equilibrium



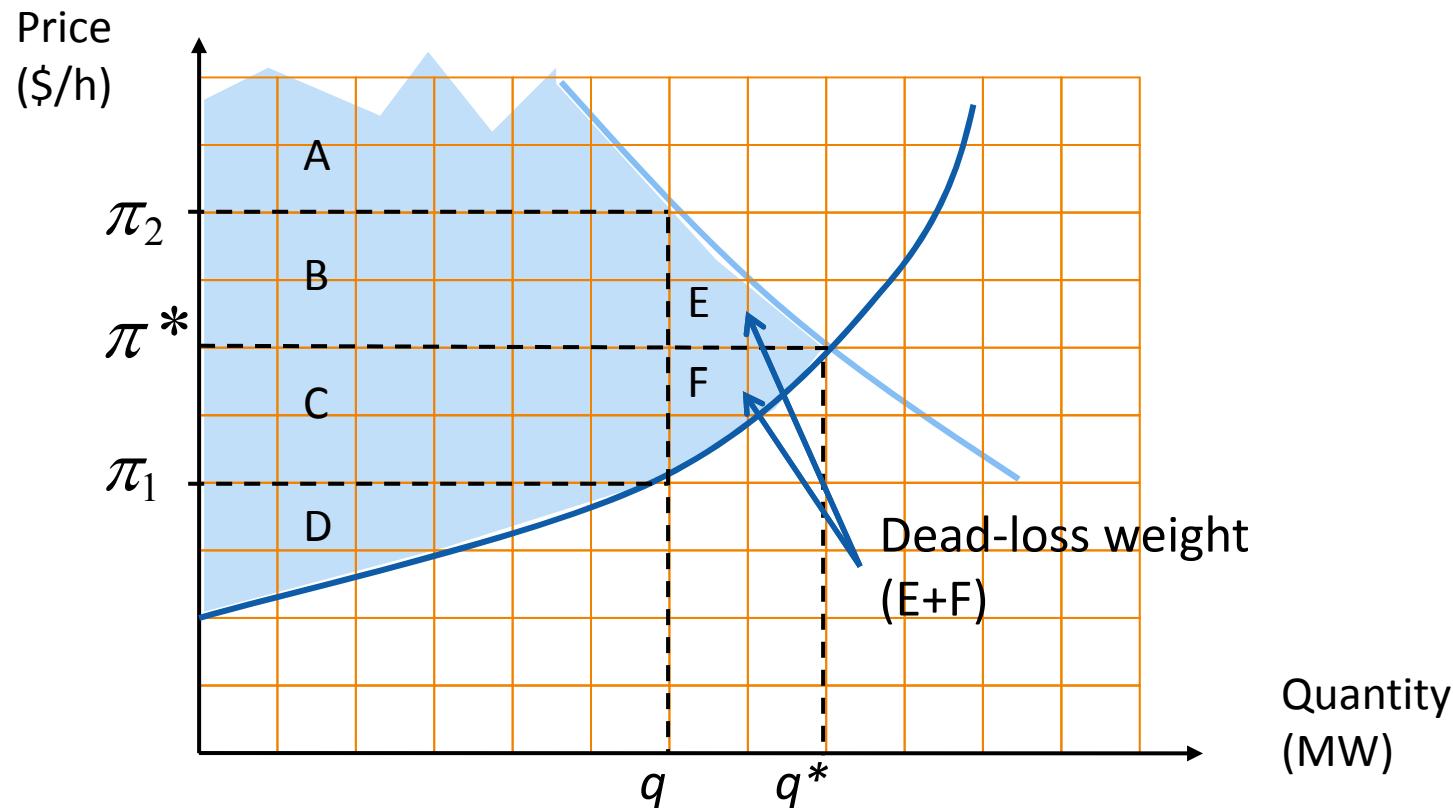
- Characterized by an equilibrium price and quantity, where supply equals demand.
- The equilibrium is stable
 - There are incentives not to deviate from it.
- If electricity is traded at the equilibrium price the market is *Pareto efficient*
 - This means that the benefit derived by any of the parties can be increased only by reducing the benefit of the other parties.

Electricity Market Equilibrium



- *Global Welfare* is the sum of the consumer surplus and the producer profit.
 - It quantifies the benefit that arises from trading.
- External intervention redistributes the global welfare in favor of the producers, the consumers, or the government.
 - Intervention examples are: fixing a minimum or a maximum price (cap), taxes, and subventions.

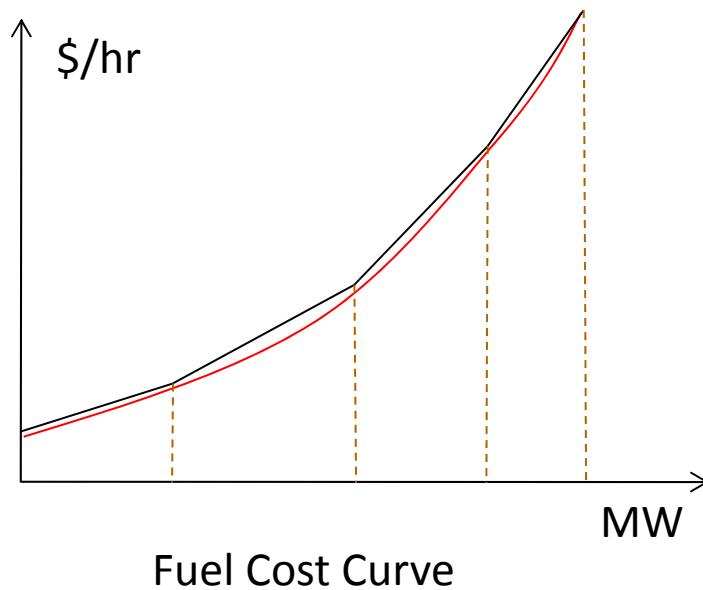
Electricity Market Equilibrium



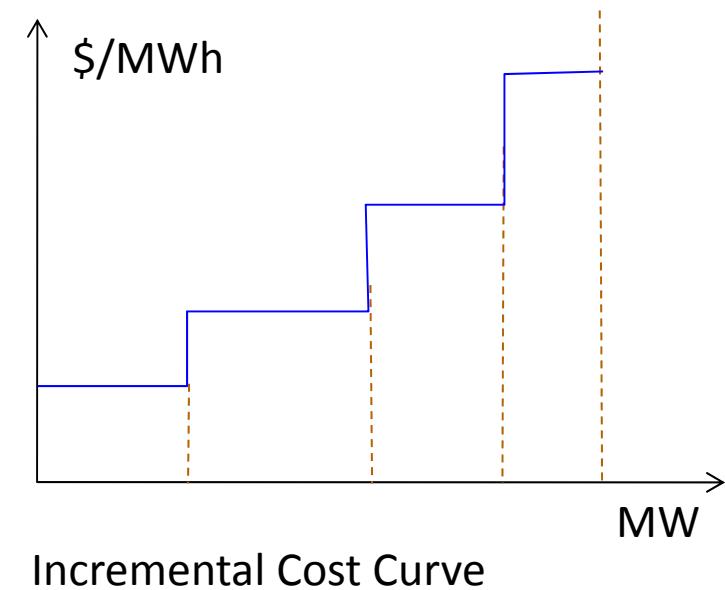
Electricity Market Equilibrium



- Recall generator (fuel) cost curves
 - Represented by a quadratic or cubic functions
 - Can be approximated by a piece-wise linear function
 - Derivative is the Incremental cost curve.



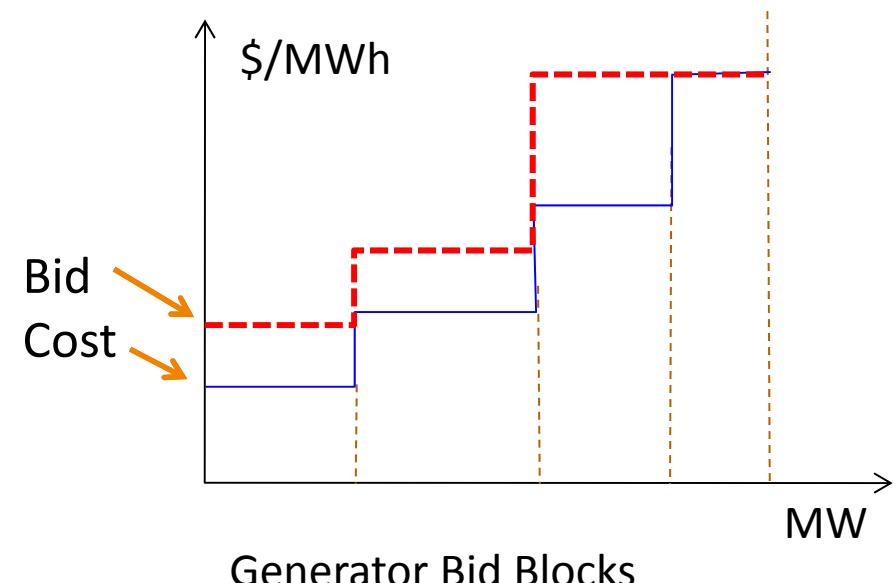
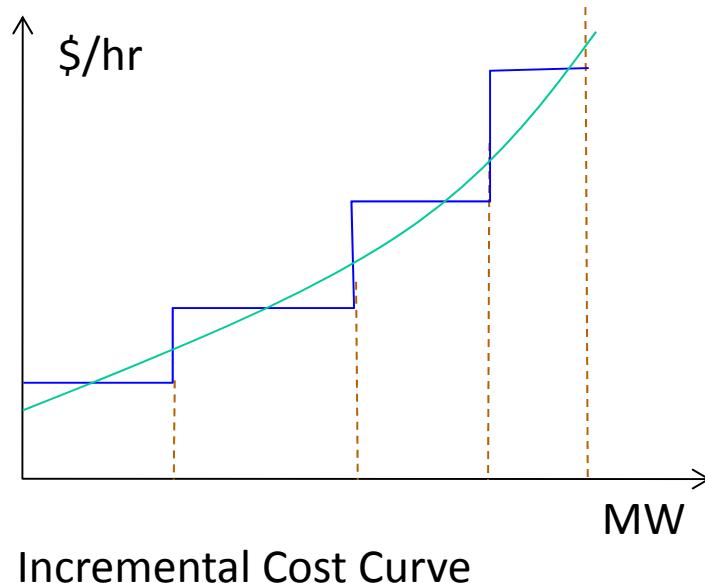
$$\frac{d}{dx}$$



Electricity Market Equilibrium



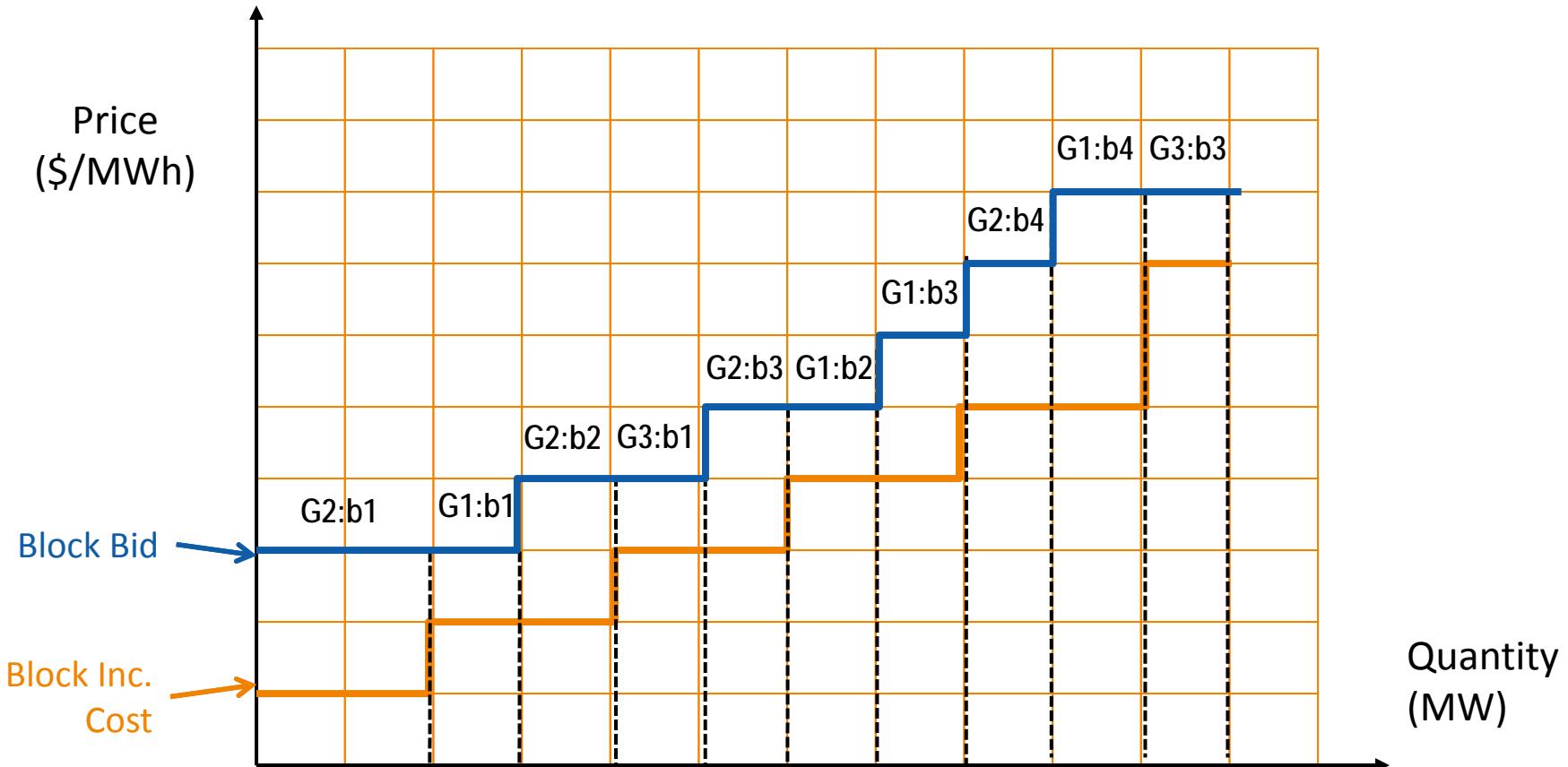
- Actual incremental cost curve is a continuous function.
- Stair function approximation allows bidding by blocks to take place naturally, e.g. 10 MW @ 20 \$/MWh



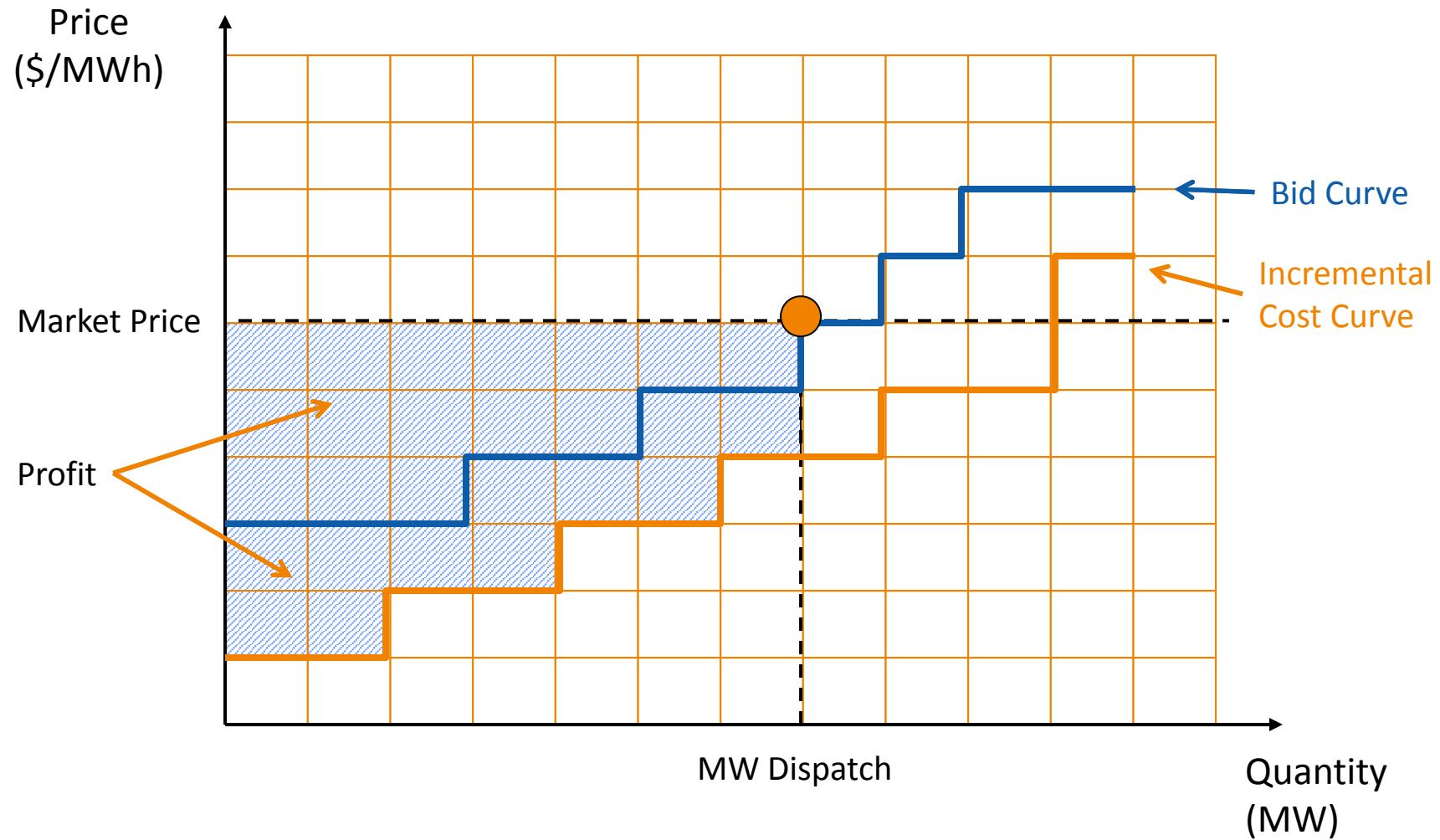
Electricity Market Equilibrium



- For a given hour, generator bids can be stacked in ascending order to form the system supply curve.



Electricity Market Equilibrium

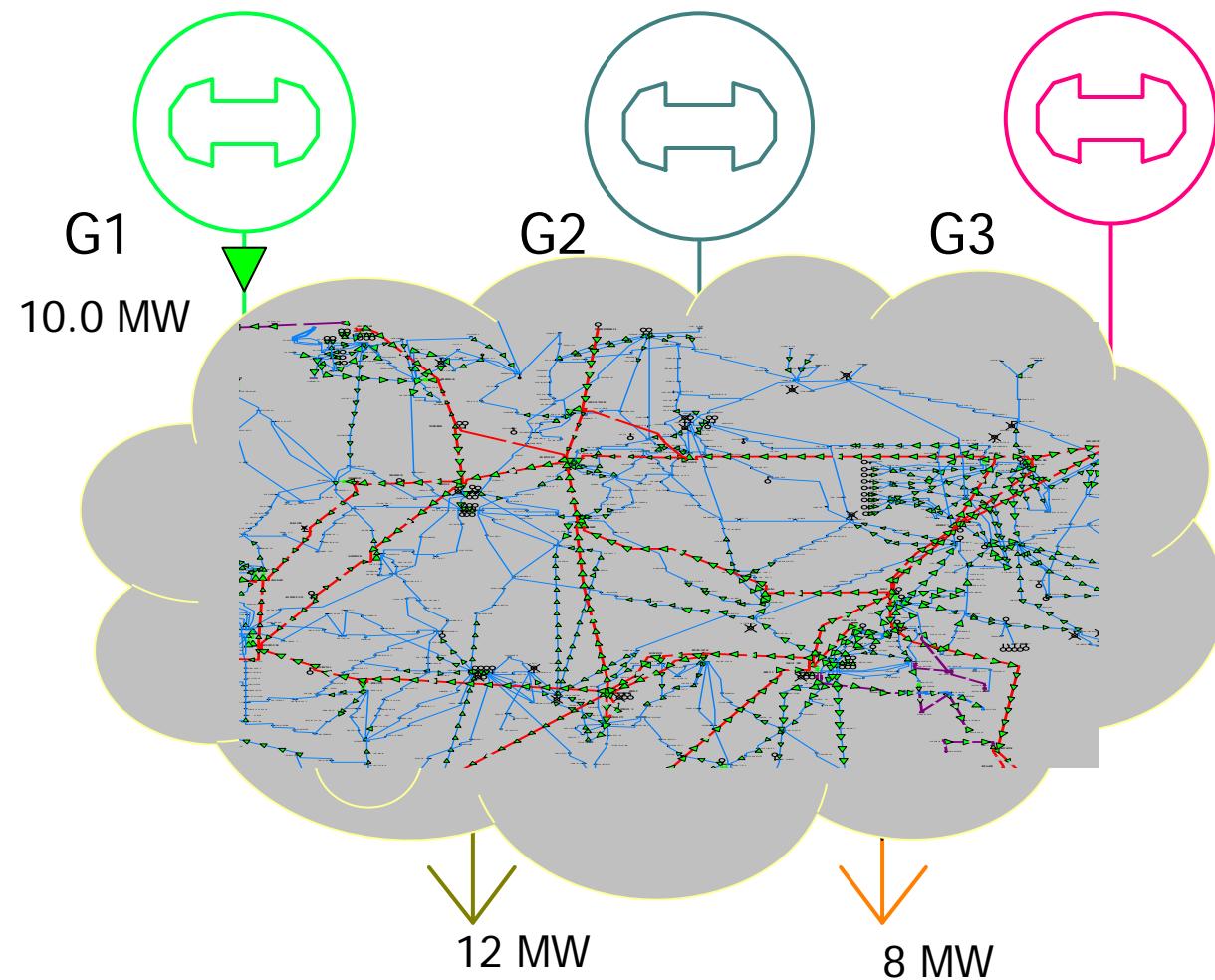


Characteristics of Electricity

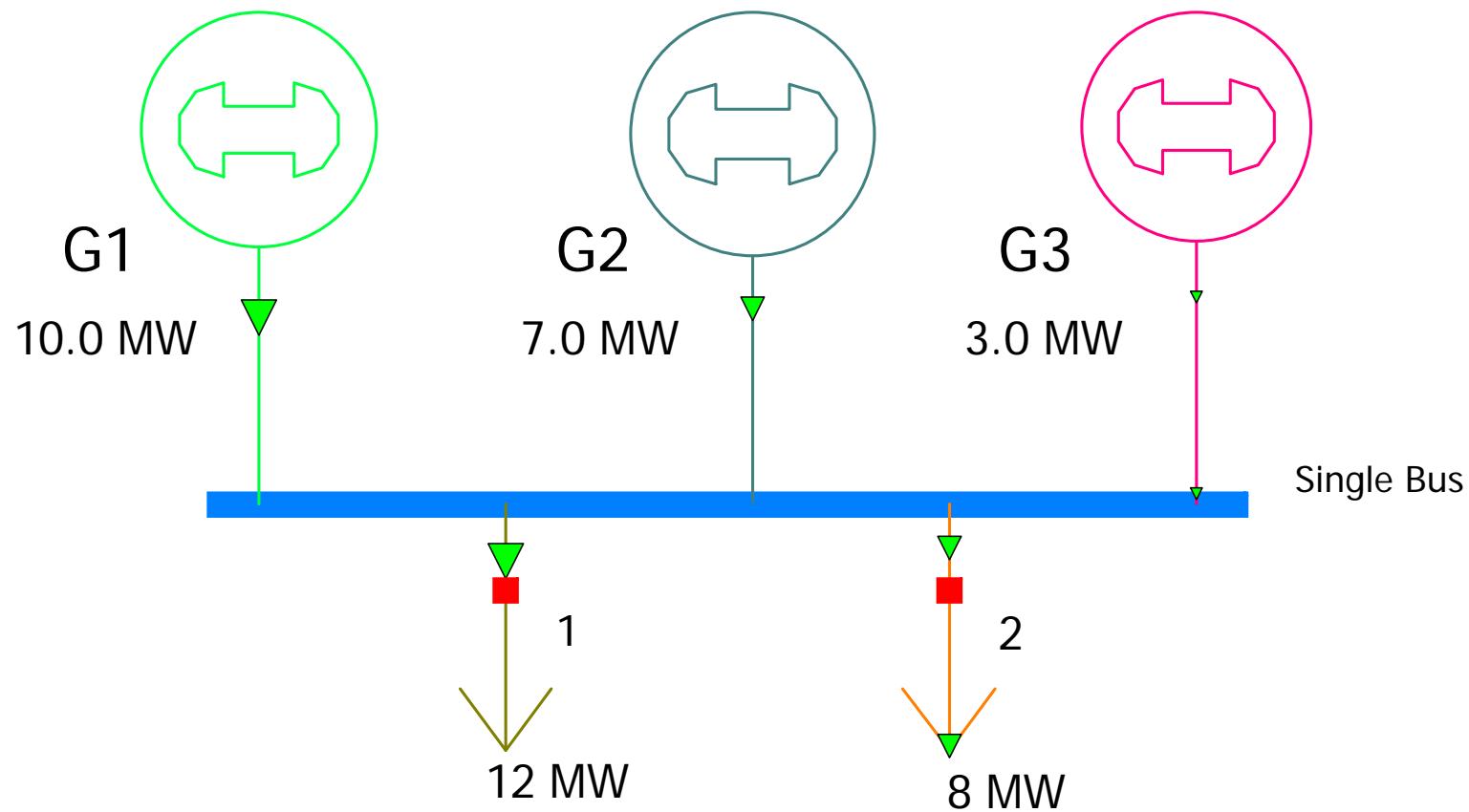


- Describing how electricity is different from other goods is key to understanding operation of electricity markets.
- Complexity of electricity markets is increased by the effect of the transmission system.
- Let us assume first that all generators and loads are connected to a single bus. This means that:
 - The grid is lossless
 - The grid has unlimited capacity.

Characteristics of Electricity



Characteristics of Electricity



Characteristics of Electricity



1. Just-In-Time

- Electrical energy is produced and consumed at the same time.
 - Production must be adjusted to balance demand.

2. Physical System is Faster than any Market

- Electricity is linked with a physical system that functions much faster than any market.
 - In real-time load balance must be maintained at almost any cost through a mechanism that does not rely on a slow (human) market.

Characteristics of Electricity



3. Fast Changing, Cyclic Marginal Prices

- Since the marginal producer and its cost changes as the load increases or decreases, the marginal cost of producing electricity (hence the spot price) varies over the course of the day.
- These cyclical and rapid variations in the cost and price are not very unusual in markets.

Characteristics of Electricity



Comparison with gas (and fuel markets)

- Trading in gas also takes place over a physical network.
- Gas is pooled and its demand is cyclic.
- However, the amount of energy stored in gas pipelines and tanks is much larger than the kinetic energy stored in generating units.
- Thus, an imbalance in gas needs to be really large and long to cause a pipeline network to collapse.
- This imbalance could be corrected through a market mechanism. In the power system that is not possible.

Characteristics of Electricity



The Grid Effects:

4. Pooled Physical Delivery

- Electricity in the power grid cannot be routed.
- The energy is *pooled* on its way to the consumer. In other words, producers inject power to the grid and consumers take power from it.
 - This is possible because the electricity produced by different producers is identical.
- Markets work well when producers and consumers are allowed to interact. Thus trading must resemble interaction as much as possible.

Characteristics of Electricity



5. Congestion

- Since electricity is not routable, one must change the source of electricity in order to alleviate congestion,
 - This is different from other types of network industries such as transportation or communications.

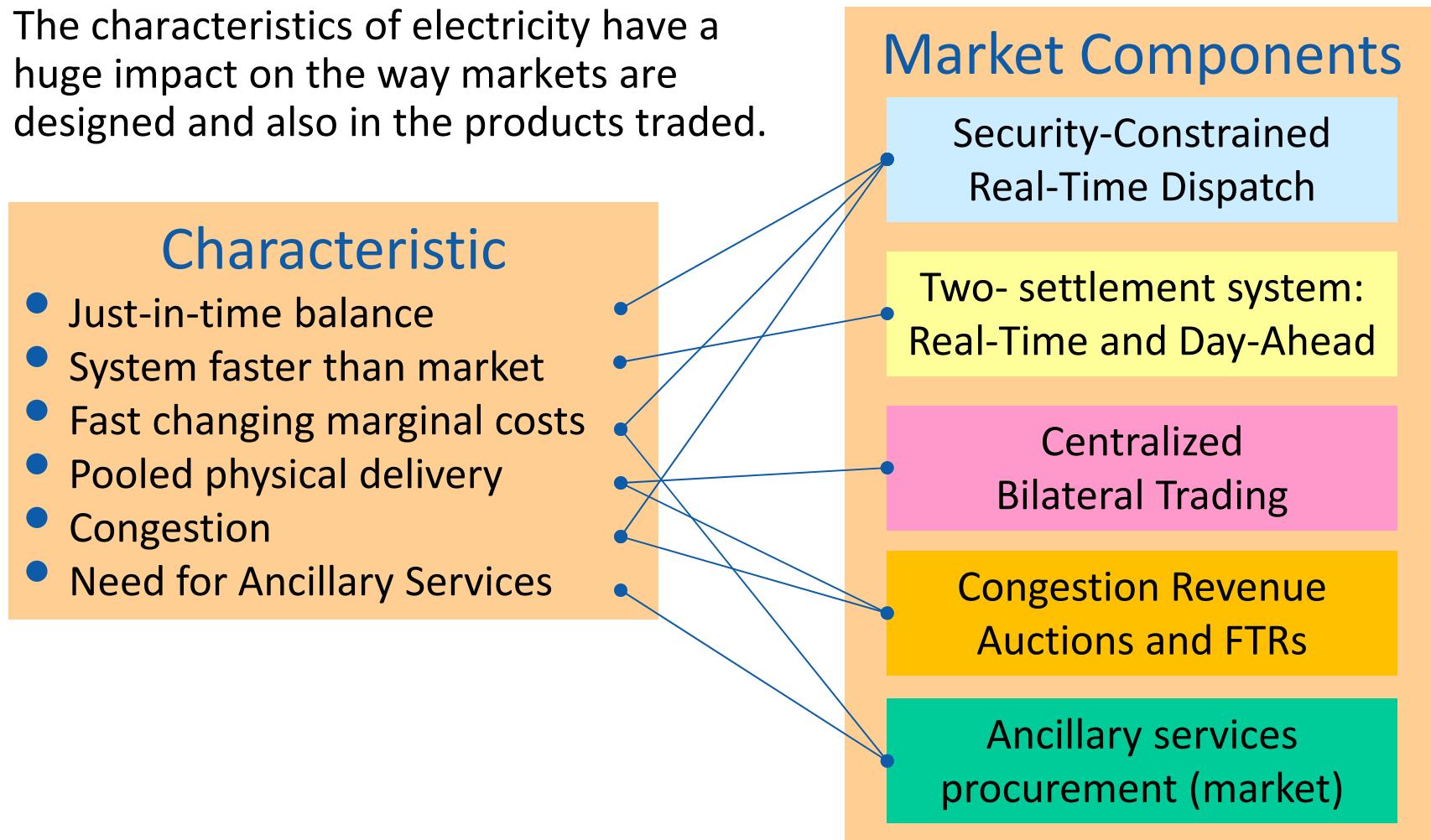
6. Need for Ancillary Services

- In order to function securely, the power system requires a set of ancillary services:
 - Reserve
 - Frequency regulation
 - Voltage regulation
 - Black-start capability

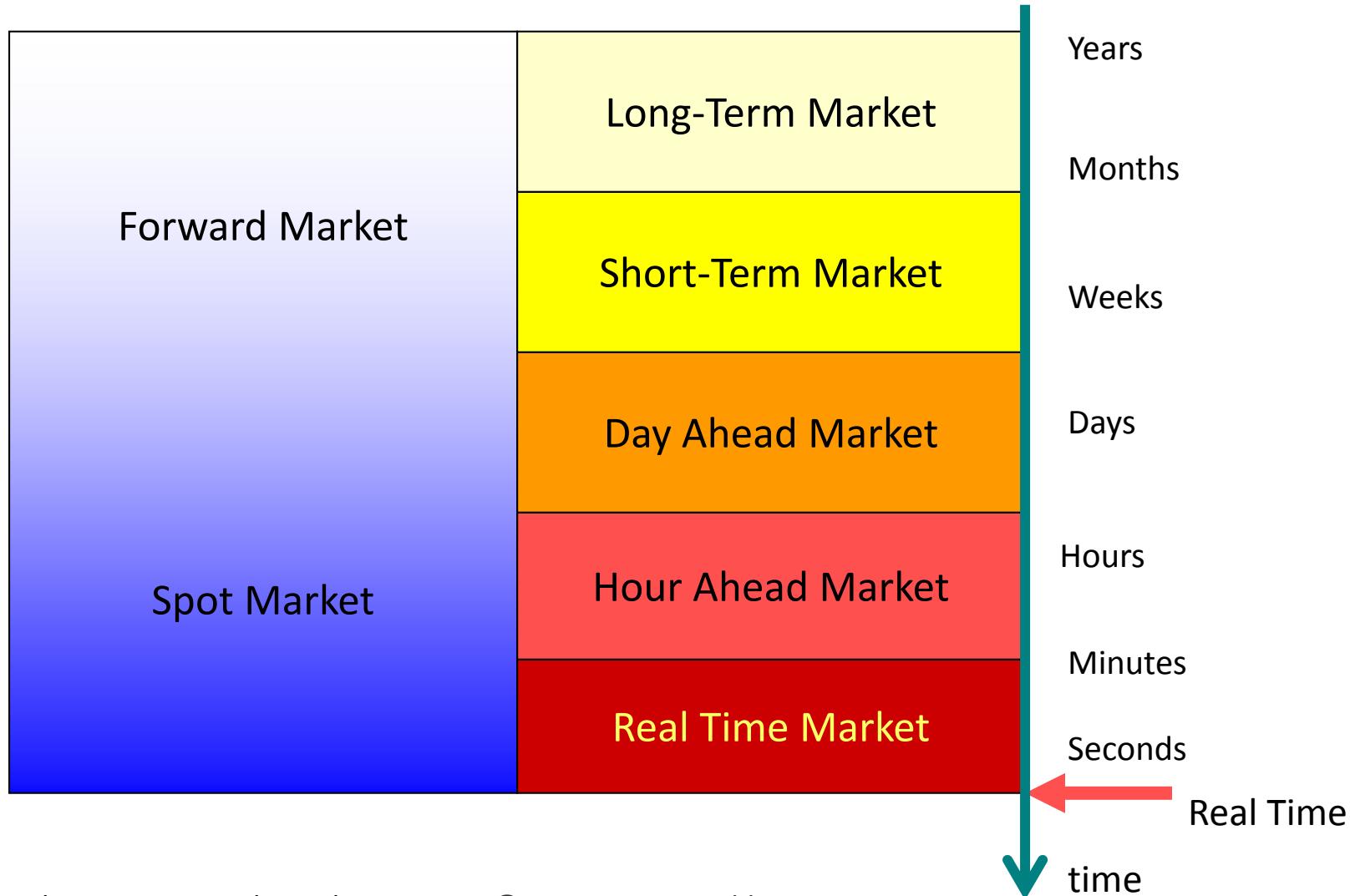
Market Architecture



The characteristics of electricity have a huge impact on the way markets are designed and also in the products traded.



Market Architecture

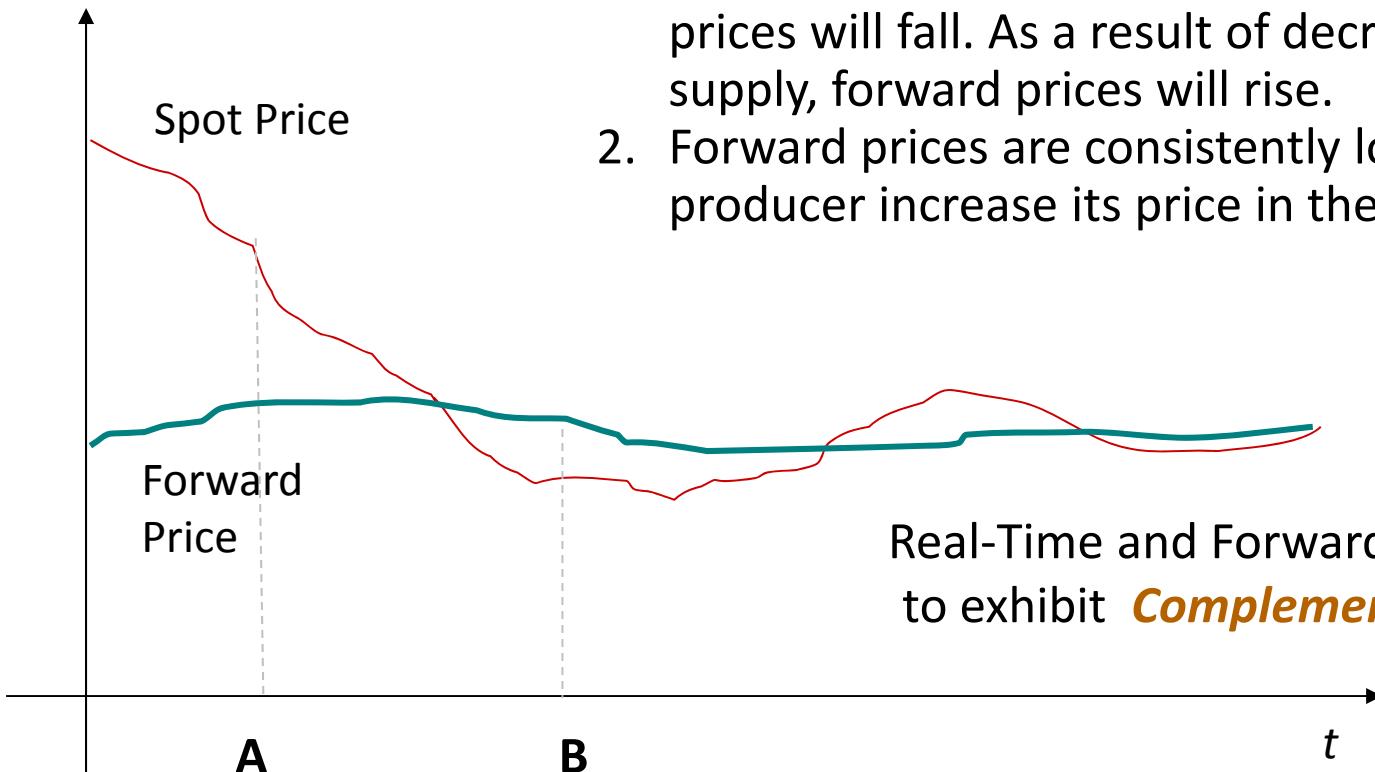


Market Architecture



Producer Strategy at time-point A

1. Real-time price is consistently high, thus increase quantity in real-time market.
As a result of increased real-time supply, real-time prices will fall. As a result of decreased forward supply, forward prices will rise.
2. Forward prices are consistently low. Should the producer increase its price in the forward market?



Market Architecture



- If market is well designed and operated, spot and forward prices together form a system that reaches equilibrium.
- The spot prices are still the ultimate signals that drive the whole market.
 - FTR and CRR valuation are derived from forecasted LMP prices.
 - Generators are paid the LMP price at their nodes and LSEs pay the LMP at their nodes.
- Thus the determination of LMPs is central to the overall operation of the electricity market.

Market Trends: Zonal to Nodal



- Zonal markets are changing to nodal model.
- Zonal market issues:
 - Insufficient price transparency
 - Resources grouped by portfolio
 - Indirect assignment of local congestion.
- Benefits of Nodal Markets
 - Improved price signals
 - Improved dispatch efficiencies
 - Direct assignment of local congestion

Market Trends: Reserves

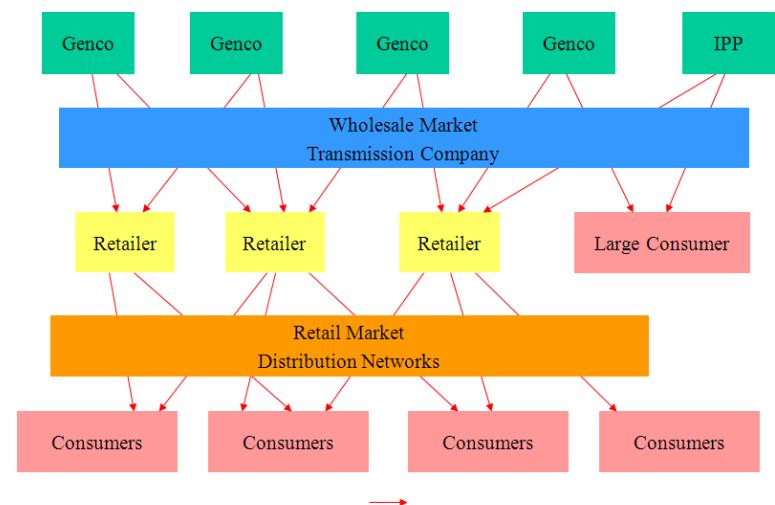


- Energy alone is not able to capture reliability aspects of power system resources, which causes:
 - Price volatility
 - Need of mandatory procurement
 - Insufficient or too much reserve
- Markets are moving towards Ancillary Reserve Markets where Simultaneous Co-optimization of Energy and Reserve takes place.

Market Trends: Retail



- Goal is to incorporate retail markets and consumer choice.
- There are significant ongoing efforts on demand response programs.
- Retail competition will result in more stable market and more transparent prices to customers.



Market Trends: All Markets (2008)



| Service | ISO-NE | NYISO | PJM | MISO | SPP | ERCOT | CAISO |
|----------------------------------|--------|-------|-----|------|-----|-------|-------|
| Bilateral Transactions | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Online Physical Trading | ■ | | ■ | ■ | | ■ | ■ |
| Online Financial Trading | ■ | ■ | ■ | ■ | | ■ | ■ |
| Real-Time Energy Market | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Locational Energy Price | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Day Ahead Energy Markets | ■ | ■ | ■ | ■ | | 09 | 08 |
| Locational Energy Price | ■ | ■ | ■ | ■ | | 09 | 08 |
| Ancillary Services Markets | ■ | ■ | ■ | 08 | C | ■ | ■ |
| Regulation Services Markets | ■ | ■ | C | C | C | ■ | ■ |
| Operating Reserves Markets | ■ | ■ | ■ | C | C | ■ | ■ |
| Reactive Power Market | | | C | C | C | | C |
| Black Start Market | | C | C | C | C | C | C |
| Financial Transmission Rights | ■ | ■ | ■ | ■ | | ■ | ■ |
| Capacity Market | | ■ | ■ | | | | C |
| Regional Transmission Scheduling | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Regional Economic Dispatch | ■ | ■ | ■ | ■ | ■ | | |
| Regional Transmission Planning | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Regional Interconnection Process | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Independent Market Monitor | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Mitigation | ■ | ■ | ■ | ■ | ■ | ■ | ■ |

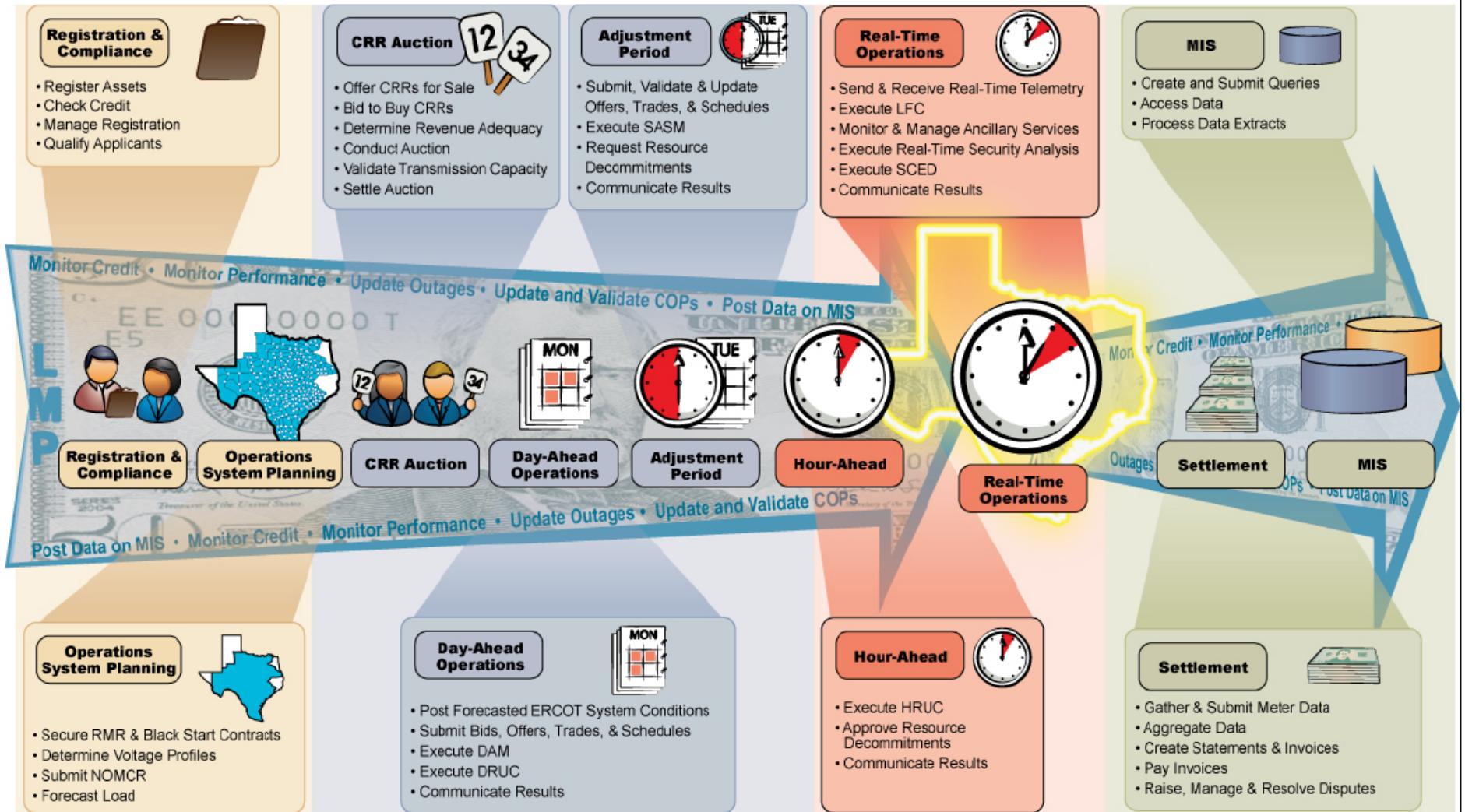
C: Cost Based

M1: Market Concepts and Trends

Source: FERC 2008 State of Markets + PowerWorld analysis of current and announced RTO Rules

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Market Trends: ERCOT (2009)



Source: Electric Reliability Council of Texas (ERCOT)

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