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Competitive Electricity Market Requires a Paradigm Shift in System Operation

Last paragraph of introductory chapter of Power Generation and Operation and Control (2nd edition), by Allen J. Wood and Bruce F. Wollenberg

“In the extreme cases mentioned above [industry re-structuring of the form implemented in the United Kingdom], many of the dispatch and scheduling methods we are going to discuss will need to be re-thought and perhaps drastically revised. Current practices in automatic generation control are based on the tacit assumptions that the electricity market is slow moving with only a few, more-or-less fixed, interchange contracts that are arranged between interconnected utilities. Current techniques for establishing optimal economic generation schedules are really based on the assumption of a single utility serving the electric energy needs of its own customers at minimum cost.”
Market Operator not System Operator

- In a competitive market economic concerns drive engineering decision-making
  - Consumers want the small, powerful, low cost cell phones--engineers have financial incentive to meet these demands
  - Consumers want high performance, fuel efficient cars--engineers have financial incentive to meet these demands

Consumers want low-cost, reliable electricity supply
Do power systems engineers/operators have a financial incentive to meet these demands?

Ten Myths about Competitive Electricity Markets

- All myths arise from applying logic of engineering paradigm to competitive market
- All industry participants have fallen victim to some or all of these myths
- Some are much quicker to adapt to new paradigm than others because of incentives they face
  - Merchant producers quickest
  - Incumbent investor-owned utilities next
  - Large consumers
  - Regulators slowest to adapt
Myth #1--Verifiable Forced Outage

- Impossible for outside entity (e.g., regulatory body), no matter how expert, to determine if generating unit declared forced out was actually able to run
  - During summer of Autumn of 2000, California Public Utilities inspected plants throughout California
  - Federal Energy Regulatory Commission Staff prepared January 2001 report on plants outages
- Generating facilities are extremely complex pieces of machinery and have potential to create enormous environmental damage if operated improperly
  - Particularly for old units, on any day there are a large number of reasons why a plant may be unable to operate
  - Considerable amount of operator discretion goes into making decision as to whether plant can run
    - Operator knows plant best and should therefore make this decision

Myth #1--Verifiable Forced Outage

- Analogous problem in labor market--sick days
  - Employee calls in sick
  - Impossible for boss to tell whether or not employee is fact sick
  - Boss can send doctor to employee’s house to verify illness
  - Human bodies are extremely complex machines, so that employee can display symptoms of some previously unheard of disease
  - Boss recognizes this potential response by employee and therefore does not bother to send doctor to verify illness
- Solution to labor market problem
  - Boss allows sick day but requires employee to find another worker in firm to replace him during that day
  - This places risk of sick day on employee
  - Boss does not have to devote any resources to verifying sick days
Myth #1--Verifiable Forced Outage

- Solution to problem for competitive electricity market
  - Risk of all unplanned generation outages borne by generation unit owner
  - Every generation unit owner must have a bid into market for entire capacity of unit during every hour unit is not scheduled out
  - If unit is unable to run in hour, unit owner has three choices
    - Bid higher that expected price in that hour to avoid running
    - Purchase replacement power from other units not likely to win in market during this hour
    - Purchase replacement power for quantity unable to supply from energy market

- This problem has arisen in virtually every competitive electricity market. For an example from the UK, see

Myth #2--Unit Specific Dispatch Instructions

- In all multi-settlement markets generators and load schedule on a day-ahead and hour-ahead basis to supply or demand energy at a specific location in the transmission grid
  - Forward schedules represent firm financial commitments to supply energy or consume energy

- Example from California
  - Generation unit schedules 500 MWh in forward market
  - If unit produces 600 MWh in real-time, it is sells additional 100 MWh at real-time energy price
  - If unit produces 450 MWh in real-time, it is buys 50 MWh that it was scheduled to supply at real-time energy price

- All generators buy or sell deviations from schedule at the real-time price
  - All units can produce more or less than their schedule in real time
  - When real-time price at a given location is increased, all unit owners in this location have the ability
    - To earn this price for sales beyond their final schedule
    - To pay this price for the amount their production is less than their final schedule
Myth #2--Unit Specific Dispatch Instructions

- Implication--No such thing as a unit-specific dispatch instruction
  - All unit owners are free to change their output in response to a price change caused by the system operator accepting bid in the real-time energy market
  - The fact that only the unit whose bid was accepted received a dispatch instruction is irrelevant
  - All units see the real-time price and are free to respond to it and be compensated or make payments for their actions as described above
- Solution--Set prices at location
  - Increase prices at a given location if system state indicates demand increase
  - Decrease prices at a given location if system state indicates demand reduction
  - Unnecessary to have unit owners submit bids
    - System operator posts rate at which it will increase or reduce prices as a function of projected system imbalance during given 5-minute interval
    - Unit owners manage imbalance in real-time throughout grid according this price adjustment scheme

Myth #3--Grid Reliability Problems

- Reliability in monopoly versus competitive regime
  - In monopoly regime, grid reliability is percent of time that consumers actually receive power
  - In market regime, grid reliability is the percent of time that consumers willing to pay any price can receive power
  - Having to pay hourly price of energy in competitive regime may cause dramatic reduction in amount demanded
- This logic suggests revising usual protocols for determining level of generation reserves necessary for reliable grid operation
  - Potential source of efficiency gains from re-structuring
Myth #3--Grid Reliability Problems

• For some hours certain plants are constrained on
  – Given current transmission grid configuration
  – Geographic location of demand

• Generation resource is must-run
  – Only it can satisfy local grid reliability need
  – Regardless of hourly spot price of electricity

• This is not a reliability problem, it is a local market power problem
  – If pay generator what it wants, loads would obtain power
  – This price may violate FERC’s “just and reasonable rates” standard

Myth #3--Grid Reliability Problems

Persistent Reliability Problems Arise Because of Inappropriate Market Incentives Provided to Generators and Loads

• Market participants take actions that harm or benefit system reliability because it is in their financial interest to do so given the market rules for compensating them for their actions

• If an system operator would like market participants to take actions which maintain system reliability, it must design market rules that provide financial incentives for these actions

• Persistent reliability problems do not exist separate from economic incentive or market power problems

• California ISO, much more so than East Coast ISOs, must rely on economic incentives, because generators self-schedule their units and market requires a substantial amount of imports
Myth #4-Good and Bad Imbalances

- Supply for electricity must equal demand at all points in transmission grid in real time
  - All imbalances, regardless of source, increase probability of outages
- System operators issue “unit specific dispatch instructions” (see Myth #2--unit specific dispatch instruction) in real-time to maintain system balance
  - Good imbalances--deviations from schedule that help system operator correct imbalances
  - Bad imbalances--deviations from schedule that system operator must correct by making requests for “good imbalances” from certain units

Myth #4-Good and Bad Imbalances

- Recall Myth #5--Grid reliability problems exist because of poorly designed incentives for generators
- California ISO pays “good imbalances” higher price than “bad imbalances”
  - Implication--two units with exactly the same schedule and same real-time production are be paid different amounts
  - Creates incentives for generators to turn all imbalances into “good imbalances”
- Firms owning a portfolio of generation units can create system conditions that increase the demand for “good imbalances” from some of their units
Myth #5--Generators Bid Their Marginal Costs

- In all markets firms exercise market power
  - Equivalent to serving fiduciary responsibility to shareholders
  - Equivalent to maximizing profits

- Firms in all markets attempt to influence regulatory process and exploit regulator-imposed rules to maximize their profits
  - Example--airline industry safety regulation
  - Regulator must anticipate this use of regulatory process

- Profit-maximizing behavior by generators implies an optimal bid price above marginal cost except in very rare circumstances

Residual Demand Function

\[ DR(p) = Q_D - SO(p) \]
Extreme Case--Pivotal Bidder

- Residual demand faced by Firm A is positive for all prices
  - In this case, Firm A is called a pivotal bidder
  - Mathematically, $\text{DR}(\infty) > 0$
- Given bids of other firms, at least $\text{DR}(\infty)$ from Firm A is required to satisfy market demand
- Extreme case of market power
  - No matter how high a price Firm A bids for $\text{DR}(\infty)$, it will set market-clearing price

Pivotal Bidder

![Graph showing the relationship between price and demand](image)
Elasticity of Residual Demand

- Elasticity of Residual Demand Determines extent to which Firm A’s bids can set $p > MC$
  - Less price-elastic residual demand function allows $p$ to be set further in excess of $MC$
    - Steep residual demand function, smaller loss of sales from higher prices
  - More price-elastic residual demand function forces $p$ to be set closer to $MC$
    - Flat residual demand function, greater loss of sales from higher prices

- Firm’s A optimal market price depends on the price elasticity of its residual demand

![Diagram showing bid to maximize profits subject to residual demand](image-url)
Myth #6--High Electricity Prices Now Encourages New Investment

- One justification given for not correcting current market design flaws
  - High prices now are necessary to provide incentives for new investment
- Electricity generating facilities take at least two years to construct, longer if include siting process
  - Plant cannot earn revenues from market until it is actually able to produce electricity
  - High prices now provide no signal for new investment if they provide no information about value of price more than two years from now
    - Very likely if current high prices are due to market design flaws
Myth #6--High Electricity Prices Now Encourages New Investment

- Consider following thought experiment
  - Suppose all prospective entrants know with certainty that
    - Price for next two years will be very high
    - Prices will be very low after two years
  - No new entry will take place
    - Current high prices do not provide signals for new investment

- What signals do current high prices provide?
  - Current high prices provide very strong economic signals for loads to reduce their current demand
    - Loads must face hourly price and can benefit from reducing their demand in high-priced hours
    - Hourly meters and real-time pricing of loads--No load profiling

Myth #7: Pay-As-Bid Auctions Superior to Uniform Price Auctions

- Many observers argue that high prices in spot electricity markets are due to uniform price auction mechanism
  - All bidders paid highest bid price necessary to meet demand
- Actual bid curves submitted in uniform price auctions have long segments at zero or negative prices
  - These bidders being paid more than their as-bid willingness to supply to market
- This logic ignores fact that rational profit-maximizing bidders would change how they bid in response to being paid-as bid versus uniform price auction
- All bidders would at least raise their bids to an estimate of the bid of highest bidder necessary to serve market demand
Myth #7: Pay-As-Bid Auctions Superior to Uniform Price Auctions

With active forward markets little distinction between two auction formats

Consider airline industry
- Everyday airline operates uniform price auction for seats on flight
- Every prospective traveler receives the same quote for the price of ticket with same characteristics
  - Date and time of travel and return, origin and destination, class of service
- Each day airline runs a different uniform price auction for air travel with these characteristics
- On date of flight virtually every person on flight in same class of service pays a different price for their ticket
  - Huge variability in actual price paid for each seat on flight
- Apparent pay-as-bid market outcome due to active forward market for airline tickets
Myth #8: Optimal Power Flow Models Yield Optimal Outcomes

- Many markets around the world use “optimal power flow” models from vertically integrated regime to schedule and dispatch generation units in a competitive market.
- Optimality properties of dispatch obtained requires that bids submitted by market participants are in fact their actual marginal costs.
- Recall Myth #5--Profit-maximizing generators do not bid their marginal costs into competitive markets.
  - Dispatch obtained from optimal power flow model applied to bids submitted by profit-maximizing firms is not least cost.
  - Unit owners must be provided with financial incentive to reveal their production costs through their bids.
    - Owner knows unit’s minimum operating costs and physical capabilities, system operator does not.

Myth #8: Optimal Power Flow Models Yield Optimal Outcomes

- How generation unit owners are compensated for their actions should lead them to reveal to their minimum costs to system operator.
- Atomistic competition is one way to guarantee truthful reporting is optimal.
  - Many small firms competing in large market.
  - All face horizontal residual demand curve.
    - Optimal for all firms to bid marginal cost.
  - Usually not possible given starting point of restructuring and technology of generation.
- This is fundamental challenge of electricity market design.
**Myth #8: Optimal Power Flow Models Yield Optimal Outcomes**

- **Market Design Problem**
  - Set number and size of market participants
  - Set rules for determining revenues each firm receives
  - So that combined actions of each participant acting in its own best interest
  - Yields market outcomes as close as possible to regulator’s desired outcome
- **Political constraints often imposed on process**
  - Difficult to break-up incumbent monopolist

**Myth #9: FERC Treats All Market the Same**

- **The Federal Energy Regulatory Commission approves market rules for all US ISOs**
  - Internal consistency in policies with respect to all ISOs appears to be a useful goal to pursue
  - If one ISO granted some market rules, others should have right to request similar rules, or told why rules cannot be applied in their market
- **Example--Cost based bid caps on generation resources**
  - California ISO has made several requests to FERC to impose cost-based bid caps on market participants when they have local market power
Myth #9: FERC Treats All Market the Same

- In PJM ISO, FERC allows cost-based bid caps on all units whose construction commenced before July 9, 1996.
- If, on a day ahead basis, a generating unit must be dispatched out of merit order based on its bids because of transmission constraints:
  - There are three ways energy bids will be capped for those hours or entire day at ISO’s discretion:
    - Price bids replaced by $1.1 \times \text{cost curve}$
    - Average prices at node when unit was dispatched in merit order
    - Mutually agreed upon price between ISO and participant
- Dispatch and pricing algorithm re-run with this mitigation measure in place.
- Mitigated generator can set or receive price at node.

Myth #10: Loads Require Different Treatment from Generation

- Many observers argue that loads can only be passive participants in competitive electricity markets.
- The basis for this logic is that electricity is an essential commodity:
  - Consumers will purchase their desired demand regardless of the price
  - High prices will only impose economic harm on consumers with no reduction in demand
- Large loads cannot respond to real-time dispatch instructions like generating facilities:
  - This logic fails to recognize the existence of a wide variety of co-generation and short-term energy storage technologies
  - Pumped storage facilities are profitable if highest price of electricity in the day is more than twice the lowest price in the day.
Need for Price-Responsive End-Users

- End-user that faces an hourly price for actual hourly consumption
  - Can be commercial, industrial or residential
- Time lag of price-response less important than purchasing hourly quantity at an hourly price
  - Forward financial contract holdings reduce generator incentives to exercise market power in spot market
- Ability to shift load across hours in the day due to high prices more important than reducing total daily consumption because of high prices
  - Hourly prices can be used to smooth demand across hours in the day

Load-profile billing does not yield price-responsive end-users

- Can only measure total monthly consumption of electricity
- Representative load shape used to compute weighted-average energy price for month
- Monthly bill = (monthly consumption) x (monthly weighted-average energy price)
- Demand reduction when hourly energy price is $0/MWh leads to same monthly savings as same demand reduction when hourly price is $250/MWh.
How Price-Responsive End-Users Enhance Market Efficiency

- Increase elasticity of residual demand each firm faces for its output
  - Less market power for the firm to exploit for a given industry structure
- Causes generators to bid more aggressively
  - Flatter supply bid curves
  - Lower prices for same bid quantity
- Forward price responsiveness--financial contracting--increases aggressiveness of generator bids
- Reduce market price volatility relative to case of no price-responsive end-users

Benefits of a Price Responsive Demand

\[
\begin{align*}
\text{DR}(p) &= Q_d(p) - SO(p) \\
\text{DR}(p) &= Q_d - SO(p)
\end{align*}
\]
Maximum benefits from restructuring requires price responsive end-users

- A competitive market requires final demand to become more sophisticated than it was under monopoly regime
- Potential for high prices is necessary to give demanders the incentive to invest in price-response technologies
  - Real-time metering for end-user customers
  - Interruptible purchase agreements for end-user customers
  - Within day load-shifting capital equipment for end-user customers
- Positive externalities to all other demanders from more price-responsive end-users
  - Rationale for subsidizing installation real-time metering technology
    - Provides demand with technology to become more sophisticated

The Role of High Prices

- Involving demand in the market requires long-lived, irreversible investments
- Without constant threat of high prices demanders will not make necessary investments
  - May be cheaper to work to continue price caps
- Carrot and stick approach
  - Carrot--subsidies to early adopters of demand response technologies
  - Stick--promise of removal or lifting of safety nets in future
Limited Benefits of Restructuring Without Involving Demand

- US has privately-owned, profit-maximizing firms facing cost-of-service price regulation or incentive regulation plan
  - Detailed prudence review of investment
  - Hard to argue there are large deviations from minimum cost production
  - Vertically integrated ownership and centralized dispatch should be able to improve on bid-based dispatch on true production cost basis

Markets use prices to allocate scarce resources

- Competitive market should be able to get by with lower level of capacity and serve same customers
  - This implies lower capacity costs for market at large
  - If dispatch costs are close to the same, then average price in competitive market should be less than average price in regulated market
- A necessary condition for this to occur is a sufficient number of price-responsive consumers
Example--US Airline Industry

- Load Factors = (Seats Filled)/(Seats Total),
  - In regulated regime highest load factors approximately 55% in 1976
  - Currently Load Factors are close to 73%
- This increased capacity utilization rate allows real average fare per passenger-mile to be significantly less than under regulated regime
- Regime works because of large number of sophisticated price-responsive consumers.
Real-time pricing contracts

- All England and Wales retail customers have option to purchase hourly consumption according to hourly pool price plus transmission charge
- Many large industrial customers purchase according to this pool price contract
  - Estimate half-hourly price responsiveness of a sample of large industrial and commercial customers in England and Wales
  - Significant price response from all classes of industrial customers--water suppliers, industrial process plants, retail stores
  - Even with a small fraction of these customers bidding into demand side of pool, market power can be mitigated.

Concluding Comment

Goal of Re-structuring (AB 1890, Section 1(a))

“It is the intent of the Legislature to ensure that California's transition to a more competitive electricity market structure allows its citizens and businesses to achieve the economic benefits of industry restructuring at the earliest possible date, creates a new market structure that provides competitive, low cost and reliable electric service, provides assurances that electricity customers in the new market will have sufficient information and protection, and preserves California's commitment to developing diverse, environmentally sensitive electricity resources.”

A properly designed competitive electricity market can achieve these goals.