Análisis de los Servicios Complementarios para el Sistema Interconectado Nacional (SIN)

Market Design Lessons from International Ancillary Services Procurement Mechanisms

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Purpose of Talk

- Present economic principles to guide design of ancillary market in Colombia
- Focus primarily on design of operating reserves markets
- Use experience from international markets to draw lessons for Colombia

Outline of Talk

- Determinants of “ancillary services” requirements
- Necessity of coordinating short-term energy and ancillary services market design with system operation
  - Multi-settlement LMP market
- Ancillary services price determination
  - Sequential markets and demand substitution
- Market power mitigation for ancillary services
- Determining scale and scope of ancillary services markets
- Verification of ancillary services
- Paying for ancillary services
- Conclusions

Determinants of Ancillary Services Requirements

Ancillary Services Requirements

- United States Federal Energy Regulatory Commission (FERC) defines ancillary services as
  - “Those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system”

Determinants of Ancillary Services Requirements

- Markets that do not account for configuration of transmission network and other operating constraints require more "ancillary services"
  - Single price for entire region
  - Zonal pricing markets
- Markets that account for all transmission and other relevant operating constraints require "fewer ancillary services"
  - Do not need to purchase "ancillary services" to make generation schedules coming from market physically feasible

Determinants of Ancillary Services Requirements

- Markets that run infrequently require more ancillary services
  - Weekly or Hourly market clearing requires more "ancillary services" to become physically feasible
- Markets that run more frequently require fewer ancillary services
  - 5-minute real-time markets
- Single settlement markets (real-time market only) require more ancillary services
- Multi-settlement markets (day-ahead and real-time market) require fewer ancillary services
  - Day-ahead energy schedules more representative of real-time system operation reduces need for ancillary services

Determinants of Ancillary Services Requirements

Key Point: What *ancillary services* are required to support transmission of energy from seller to purchaser depends on design of short-term energy market

Co-coordinating Energy and Ancillary Services Market Design with System Operation

Physical Realities of Transmission Network Operation

- If suppliers know that model used to set prices is inconsistent with actual reality of how grid operates they will take actions to profit from exploiting this divergence
- Classic example—Mechanism used to set prices assumes no transmission constraints in network for purposes of determining market price
  - Many low-offer price generation units cannot be accepted to supply energy because of configuration of network
    - Ordering offer prices from lowest to highest requires skipping many offers because of transmission constraints

Physical Realities of Transmission Network Operation

- Non-market mechanisms are typically used to
  - Pay needed suppliers above market price to supply more
  - Buy power from constrained suppliers to produce less
  - Example: Positive and negative reconciliations in Colombian market
- Suppliers take advantage of this divergence between financial market and physical realities of system operation for their financial gain
  - Many examples from industrialized and developing country markets

Re-Dispatch Costs in Zonal Markets

- These actions increase cost of supporting transmission of energy between supplier and load
  - These costs are not included in price load pays to supplier for energy
  - These costs are likely to increase substantially as share of intermittent generation resources increases
- Pricing all relevant transmission and operating constraints in energy and ancillary services markets eliminates need for this re-dispatch process
  - Locational Marginal Pricing (LMP) of energy and ancillary services

Locational Marginal Pricing (LMP)

- Prices all relevant network and other operating constraints
  - Minimize as-bid cost to meet demand at all locations in network subject to all relevant network and other operating constraints
    - Ramp rates, minimum run-times, minimum down-times, etc.
  - Limits divergence between financial market that prices and physical realities of grid operation
- All US markets currently operate LMP markets
  - New Zealand and Singapore do as well
- Cost of not pricing all relevant transmission and other operating constraints grows with amount of intermittent renewables control area
  - Many jurisdictions in Europe are exploring LMP market designs for this reason

Locational Marginal Pricing

- A major objection to LMP markets is setting different prices for loads at different locations in transmission network
  - Considered “unfair” because transmission network was not built for an LMP market
- Load-aggregation point (LAP) pricing addresses this challenge
  - Charge all loads quantity-weighted average LMP over all points of withdrawal in retailer’s service territory
  - Generation unit owners receive price at their location in transmission network
- All US markets employ a version of the LAP pricing of loads
- Singapore employs Uniform Singapore Electricity Price (USEP)—Single price paid by all loads in Singapore

LMP and Ancillary Services

- LMP at a location is increase in optimized objective function value associated with a one unit increase in withdrawals at that location
- Ancillary services markets can be incorporated into LMP mechanism as additional constraints
  - Ancillary service price is increase in optimized objective function value (which includes as-offered cost of energy and ancillary services) associated with increasing demand for that ancillary service by one MW

LMP and Ancillary Services

- Straightforward to incorporate new ancillary services into market that are required to manage increasing amount of intermittent renewables, such a flexible ramping product
  - Specify demand for product as additional constraint in LMP market solution
- Straightforward to procure and price ancillary services locationally to manage increasing amount of intermittent renewables such a flexible ramping product
  - Specify locational demand for product as additional constraint in LMP market solution and account for network constraints in meeting locational demands

European versus US Market Designs

- Current European market designs address potential divergence between market model and system operation by building sufficient transmission to ensure that market model used to set prices agrees with physical characteristics of transmission network vast majority of hours of the year
  - A successful zonal market design requires a transmission network within each zone that makes all generation units in the zone “equally effective” at serving load at all locations in the zone vast majority of hours of the year
  - Because congestion across zones is explicitly priced, units located outside the zone need not be as effective at serving load within the zone as those located in the zone
- Little need for locational marginal pricing (LMP) if network owner commits to constructing sufficient capacity within the zone to make all units equally effective at meeting loads throughout the zone
  - If there is sufficient competition among suppliers within each zone then there is less need for local market power mitigation mechanism

Locational Marginal Pricing

- Downfall of the Texas (ERCOT), New England and California zonal models in US was lack of pre-commitment by transmission owner and regulator to building a network within each zone that makes all generation units in the zone equally effective at meeting load in that zone during the vast majority of hours of the year
  - No such commitment is necessary for LMP market
- History of private ownership and state-level regulation left these all US regions with significantly less transmission capacity than European markets which started from state-owned monopolies
- LMP can be used to operate virtually any transmission network if market has an effective local market power mitigation mechanism
  - Note: Market power mitigation is likely to be far from perfect
    - Mitigated bid greater than minimum cost supply, otherwise this would imply the existence of a perfect regulator

Co-coordinating Energy and Ancillary Services Market Design with System Operation

Key Point: Failure to price all relevant transmission and other operating constraints in energy and ancillary services markets creates opportunities for suppliers to increase their profits by increasing costs to consumers and reducing system reliability

Benefits of Advance Planning in Ancillary Services and Energy Market Design

Multi-Settlement Market

- All US wholesale electricity markets operate a day-ahead forward market and real-time imbalance market using LMP mechanism
  - Day-ahead forward market simultaneously solves for output levels and prices *for all 24 hours of following day*
    - Suppliers can obtain least cost schedule of output for their generation units for all hours of the day
- Multi-Settlement--Market clear multiple times before energy is actually delivered)
- Both markets trade "megawatt-hours (MWhs) of energy delivered in hour h of day d“
  - Day-ahead market is a purely financial market
  - Real-time market buys and sells actual energy produced by generation units and consumed by loads

Multi-Settlement Market

- Supplier receives revenue from day-ahead forward market sales *regardless of real-time output of its generation unit*.
  - Sell 40 MWh at a price of $25/MWh receive $1,000 for sales.
  - Any deviation from day-ahead generation schedule is cleared in real-time market.
  - If supplier only produces 30 MWh, it must purchase 10 MWh of day-ahead commitment from real-time market at real-time price
- Buyer pays for day-ahead forward market purchases *regardless of real-time consumption of energy*
  - Buy 40 MWh at a price of $25/MWh and pay $1,000 for energy
  - Any deviation from day-ahead load schedule is cleared in real-time market
  - If buyer only consumes 30 MWh, it sells 10 MWh of day-ahead commitment in real-time market at real-time price

Multi-Settlement Market

- Each time the LMP market is run, the system operator’s best estimate of real-time configuration of grid is used to price transmission congestion and other operating constraints
  - Day-ahead market uses system operator’s best guess of real-time configuration of transmission network
  - Ensures physical feasibility of dispatch and load schedules, which eliminates need for re-dispatch process

Multi-Settlement Market

- In real-time market system operator minimizes the as-offered cost of meeting real-time demand subject to all relevant operating constraints using real-time configuration of grid
  – Most US markets operate real-time LMP market every 5-minutes
  – Sets 5-minute prices and dispatch levels for all dispatchable resources—generation units, loads, batteries, etc.
  – 5-minute real-time markets reduces scope and size of ancillary services markets

Multi-Settlement Market

- Multi-settlement market rewards suppliers for reliability of supply, yet still pays same LMP to all resources at same location in both day-ahead and real-time markets
  - Very important feature of market design for regions with ambitious intermittent renewable energy goals
- Consider a market with significant intermittent resources
  - Hourly supply of intermittent resources in control area typically highly correlated
    - Wolak (2016) “Level versus Variability Trade-offs in Wind and Solar Generation Investments: The Case of California,” The Energy Journal (available at http://www.Stanford.edu/~wolak)

Multi-Settlement Market

- Suppose that a dispatchable thermal unit sells 100 MWh at price of $50/MWh in day-ahead market and intermittent resource sells 80 MWh in day-ahead market at same price
- In real-time, significantly less wind is produced than was scheduled
  – Wind produces 50 MWh, so must purchase 30 MWh from real-time imbalance market at $90/MWh
- Thermal unit supply must maintain supply and demand balance, which explains high real-time price
  – Sells 30 MWh at real-time at $90/MWh
- Average price paid to thermal and intermittent units
  – $59.23 = 100 MWh*$50/MWh + 30 MWh*$90/MWh)/130 MWh)
  – $26 = (80 MWh*$50/MWh – 30 MWh*$90/MWh)/50 MWh
  – Dispatchable unit rewarded with higher average price than intermittent unit

Multi-Settlement Market

- Case of unexpectedly high intermittent resource output yields a similar outcome of rewarding dispatchable resource with higher average price
  - Intermittent resource sells only 50/MWh in day-ahead market and thermal unit sells 130 MWh, both at $50/MWh
  - Intermittent resource produces 80 MWh, which implies that it sells 30 MWh in real-time market at $20/MWh
    - Low real-time price because of unexpectedly large intermittent output
  - Thermal resource buys back 30 MWh in real-time at $20/MWh
- Average prices paid to thermal and intermittent units
  - $59 = (130 MWh*$50.MWh – 30 MWh*$20/MWh)/100/MWh
  - $38.75 = (50 MWh *$50/MWh + $30 MWh*$20/MWh) /80 MWh

Multi-settlement LMP Market

- Wolak (2011) "Measuring the Benefits of Greater Spatial Granularity in Short-Term Pricing in Wholesale Electricity Markets" *American Economic Review*
  - Finds ~3 percent reduction in variable operating cost of operating thermal units from transition to multi-settlement LMP market from multi-settlement zonal market design in California
  - Roughly $110 million in annual operating cost savings associated with introduction of LMP market
- Even larger savings seem possible for Colombian market and markets with significant amounts of intermittent renewables
  - Accounts for configuration of transmission network and other operating constraints in energy and ancillary services procurement
  - Eliminates need for re-dispatch, only need to respond to changes in demand, supply and grid configuration
  - Frequent settlement in real-time limits size and scale of ancillary services markets
  - Colombia uses multi-part bids—Start-up costs and energy offer curves that are ideally suited to operate a day-ahead market

Benefits of Advance Planning in Ancillary Services and Energy Market Design

Key Point: (Multi-settlement) Combination of day-ahead energy and ancillary services market with frequent clearing of real-time energy market limits demand for and cost of ancillary services

Ancillary Services Price Determination and the Role of Co-Optimization

No Direct Variable Cost

- Direct volume variable cost of providing an ancillary service is zero
  - Holding 51 MW unloaded capacity does not impose more costs on generation unit owner than holding 50 MW of unloaded capacity
  - Major volume-variable cost of providing an ancillary service is opportunity cost of using generation capacity
    - A generation unit with a variable cost of producing energy of $50/MWh that sells 1 MWh less (to provide spinning reserve) when the market price of energy is $60/MWh has an opportunity cost of $10/MW for providing 1 MW of spinning reserve
    - Note that if market price is $50/MWh, then the opportunity cost of this unit providing spinning reserve is zero
- There are wear and tear other non-volume variable costs of providing ancillary services

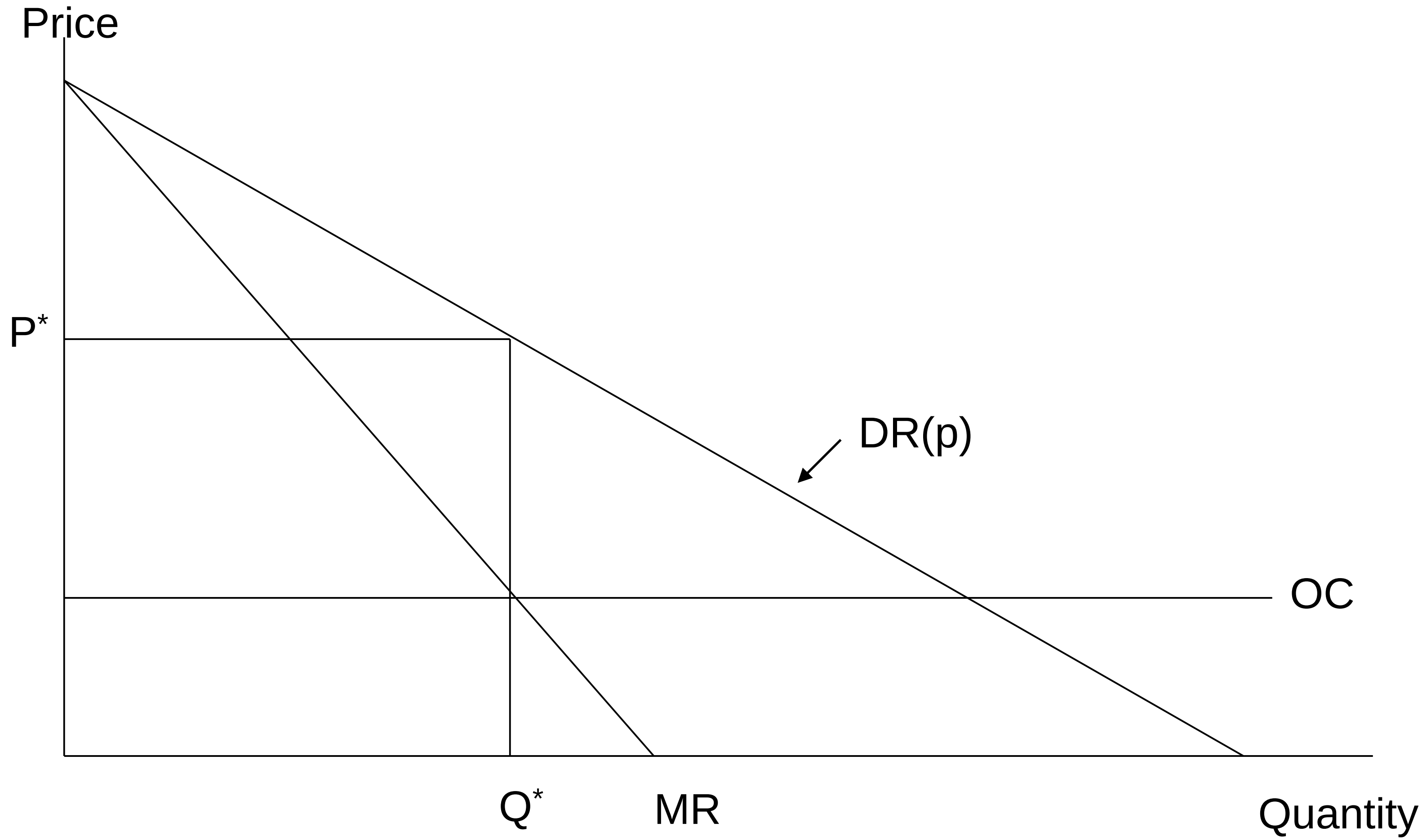
Bidding in A/S Markets

- Optimal bidding--Best-response to strategies pursued by other market participants
- Two factors determining bid into ancillary services market
  - Opportunity Cost of providing energy (OC) = p(energy) - MC(energy) *or other ancillary services*
  - Extent of competition faced from other market participants--*summarized by residual demand function*
    - Market demand less bids submitted by all other market participants besides firm under consideration at a given price
    - A generator wants to bid to maximize expected profits given the distribution of residual demand functions that it faces

Residual Demand Function

- QD: Total market demand in MW
- SO(p): Amount of capacity bid in MW by all other firms besides Firm A at price p
- DR(p) = QD - SO(p): Residual demand in MW faced by Firm A at price p
- SA(p): Amount of energy bid in MW by Firm A at price p
- p: Market-clearing price. Value of p that solves DR(p) = SA(p)

Best Reply-Price and Quantity



Optimal Bidding Strategy

- Best-reply price--P*

  OC = Opportunity Cost of selling Energy Market or other A/S markets = PE - MC(E)

- Market power in one market can be leveraged into other markets through this opportunity cost
- Two necessary conditions for low prices in an A/S market
  - Low opportunity cost of selling in other markets
  - Market participant faces by flat residual demand curve in this market

Sequential A/S Markets

- Sequential ancillary services markets in Europe and many in early US markets
  – Energy market clears and then ancillary services markets
- Early California market operated sequential ancillary services market
  – Extremely costly relative to current market that co-optimizes energy and ancillary services procurement

CA A/S Prices--Oct 99 to June 00

- Regulation Reserve (AGC) separated into RegUp and RegDn
  - Both are price-takers in ISO's real-time energy market for net energy produced during hour
  - RegUp and RegDn used at different times in day and year
- Other reserves--spin, non-spin and replacement-- have associated energy bids that enter real-time energy bid stack
  - Suppliers are dispatched based on these bids

Frequency of Prices above $500/MW(h) in A/S Markets

Different Levels of Total ISO Load--NP15 Prices

(From October 1, 1999 to June 30, 2000)

ISO Load	Reg_UP	Reg_DN	Spin	Non-Spin	Repl	Real-Time Energy
Highest 500 Hours	0.530	0.000	0.350	0.290	0.570	0.132
Next Highest 500 Hours	0.250	0.010	0.040	0.080	0.050	0.002
Remaining Hours	0.0022	0.0002	0.0002	0.0002	0.0002	0.0004

Frequency of Prices above $500/MW(h) in A/S Markets

Different Levels of Total ISO Load--SP15 Prices

(From October 1, 1999 to June 30, 2000)

ISO Load	Reg_UP	Reg_DN	Spin	Non-Spin	Repl	Real-Time Energy
Highest 500 Hours	0.530	0.000	0.350	0.290	0.570	0.132
Next Highest 500 Hours	0.250	0.060	0.040	0.080	0.040	0.012
Remaining Hours	0.0022	0.0009	0.0002	0.0002	0.0002	0.0009

High Prices in A/S versus Real-Time Energy

- Particularly for Regulation, high prices do not occur only in high ISO load periods
  - Regulation providers are paid for any net regulation energy at the real-time price
    - Downside risk of supplying RegDown
- Frequency of high prices significantly higher for other three ancillary services versus real-time energy during next highest 500 hours
- If high prices for an ancillary service are due to market power, it is not just a high load period phenomenon

High Prices in A/S versus Real-Time Energy

- Very similar behavior of ancillary services prices between NP15 and SP15
- Apparent existence of significantly more market power in ancillary services
  - Smaller number of competitors in each market
  - More inelastic demand for reserve versus energy, particularly during high load conditions
- Replacement reserve seems particularly susceptible to infrequent extremely high prices
  - Quiz Question—Why is this the case?

The Trouble With Sequential A/S Markets

- Ancillary services markets in California initially cleared sequentially
  - Regulation → Spinning → Non-Spinning → Replacement Reserve
  - All units that won in previous market excluded from subsequent market
  - All units that lost in previous market were placed into auction for subsequent market if they submitted bid for that product
- Suppliers knew that during certain system conditions few units would be left for replacement reserve auction
  - High bids would be taken with high probability

The Trouble With Sequential A/S Markets

- Suppliers of inferior product—replacement reserve—would often be paid more per MW than suppliers of superior products—spinning and non-spinning reserves
- Ancillary services auction should allows system operator to substitute superior product to meet requirement for inferior product
  - If there is more than enough bids to meet the demand for spinning reserve at $5/MW and at $5/MW non-spinning reserve demand has not been met, purchase additional spinning reserve and reduce demand for non-spinning reserve

Ancillary Services Price Determination and the Role of Co-Optimization

Key Point: Co-optimization of energy and ancillary services allowing system operator to substitute superior product to meet requirement for inferior product limits exercise of market power and rewards units for providing higher quality service with a higher price

Market Power Mitigation in Ancillary Services Markets and Co-Optimization

Market Power in A/S Markets

- Model of bidding behavior in A/S markets identified two major sources of market power in A/S markets
  - Market power in energy market creates large opportunity cost of MW of capacity—price minus marginal cost of selling energy
  - Small number of suppliers that can provide each ancillary service increases slope of residual demand curve each supplier faces for each ancillary service
- Both of these factors imply that market power problems are more likely in ancillary services markets than in energy markets as shown in initial California market
  - Because there is no direct cost of providing ancillary services it more difficult to detect the exercise market power in ancillary services markets
  - This logic further underscores need to limit ability of suppliers to exercise unilateral market power in energy market
- Underscores importance of co-optimizing energy and ancillary services procurement

Substitution in Procurement

- Co-optimization of energy and ancillary services procurement versus sequential energy and ancillary services procurement
  - Co-optimization of energy and ancillary services implies most accurate opportunity cost of energy is used as "cost" of ancillary service
  - Sequential procurement implies stale or inaccurate opportunity cost of energy is used as "variable cost" of ancillary service

Market Power Mitigation for A/S

- Market power mitigation applied to energy market combined with co-optimization of energy and ancillary services procurement
  - Mitigates market power in ancillary services market
- If supplier tries to exercise market power in A/S market by raising offer price, energy offers will be taken instead
  - If supplier raises energy offers high enough for high A/S offer to be taken, energy offer will be mitigated and unit will be accepted to supply energy instead of ancillary services

Market Power Mitigation in Ancillary Services Marketsand Co-Optimization

Key Point: Effective market power mitigation for energy combined with co-optimization of energy and ancillary services procurement largely addresses problem of market power in ancillary services

Market Power Mitigation for Energy (and Ancillary Services)

Origins of Local Market Power

- Transmission network configuration, geographic distribution of wholesale electricity demand, concentration in local generation ownership, and production decisions of other generation units combine to create system conditions when a single firm may be only market participant able to meet a given local energy need
  - Firm is monopolist facing completely inelastic demand
  - No limit to price it can bid to supply this local energy
- Regulator must design local market power mitigation mechanism to deal with these situations
  - Limit ability to supplier to exercise unilateral market power and distort market outcomes

Local Market Power Mitigation

- All US markets have form of ex ante automatic mitigation procedure (AMP) for local market power
  - History of US industry led to transmission network poorly suited to wholesale market regime
- All AMP procedures follow three-step process
  - Determine system conditions when supplier is worthy of mitigation
  - Mitigate offer of supplier to some reference level
  - Determine payment to mitigated and unmitigated suppliers
- Two classes of AMP procedures
  - Conduct and impact
    - NY-ISO, ISO-NE
  - Market Structure-Based
    - CAISO, PJM, ERCOT

Example of Local Market Power Mitigation Mechanism

- Three pivotal supplier market power mitigation mechanism used in PJM market
  - If three suppliers are jointly pivotal to resolve a transmission constraint their offers are deemed worthy of mitigation
  - Their offers are mitigated to variable cost as determined by the system operator based on rules set by regulator
  - Mitigated offers enter LMP pricing process and are used to set all LMPs and ancillary services prices

Market Power Mitigation for Energy (and Ancillary Services)

Key Point: Implicit or explicit market power mitigation mechanism for *energy* is essential for efficient operation of energy and ancillary services markets

Setting Geographic Scope and Number of Ancillary Services

Geographic Scope and Number

- Geographic scope and number of ancillary services differs across markets depending on reliability challenges facing system operator
- Remember definition of ancillary services
  - "Those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system"

Spatial Granularity in Procurement

- As more intermittent renewable resources are added, there is likely to be a need for greater spatial granularity in ancillary services procurement
  - Ancillary services may not be “deliverable” to certain parts of grid, which requires locational procurement
  - Locational marginal pricing market can allow spatial procurement and pricing of ancillary services

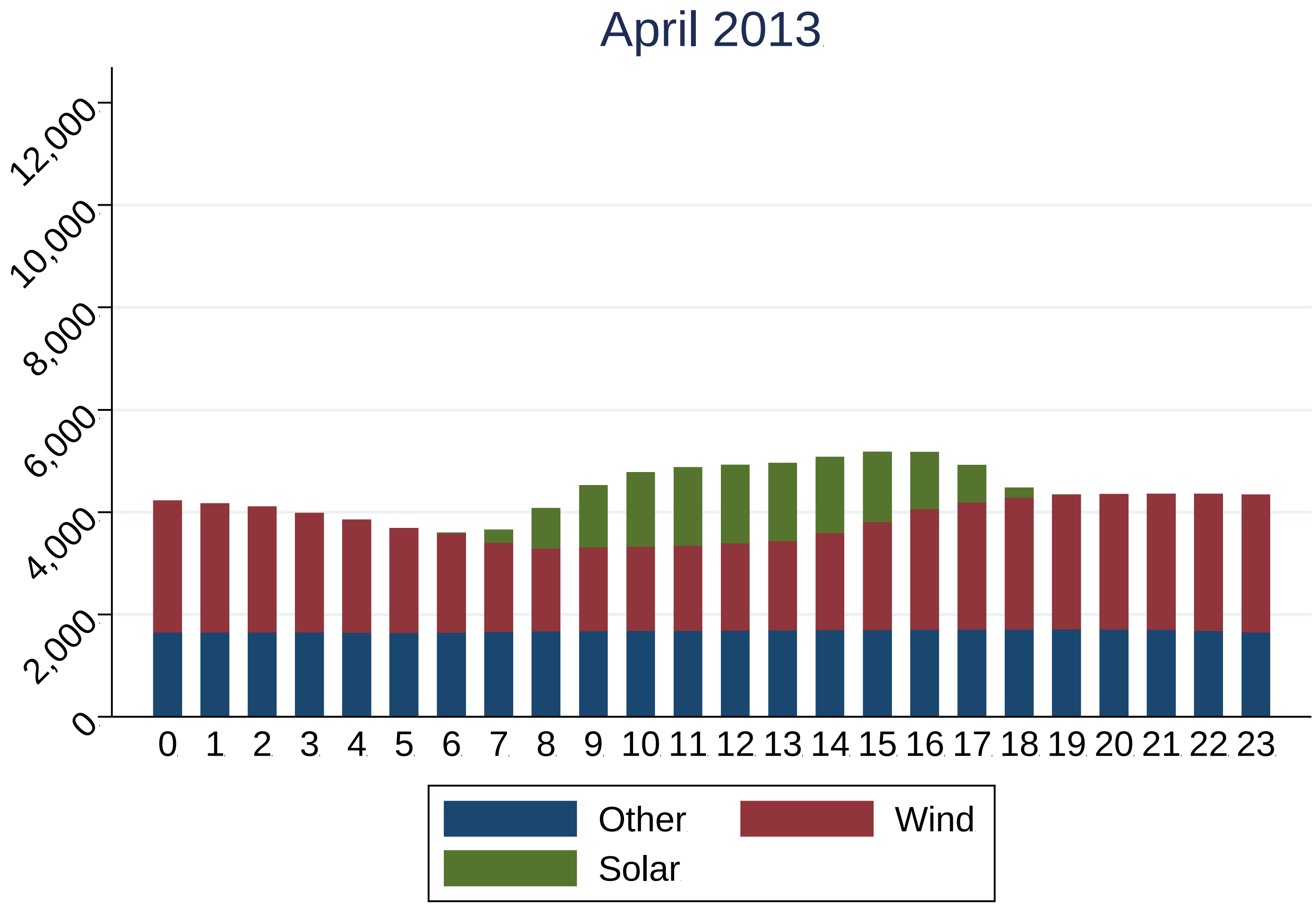
Limiting Number of Ancillary Services

- System Operator defines set of products it requires to operate system reliably
  - Specify technical characteristics of each product and certify which generation and load resources are able to provide each ancillary service
  - For example, regulation reserve, spinning reserve, non-spinning reserve, flexible ramping capacity
- Market design process should focus on determination of ancillary services system operator requires and allow all resources that are able to provide service sell it
  - Avoid tendency to design resource-specific ancillary service which increases likelihood of market power problems
- Increasing amount of intermittent renewables may require creating new ancillary services to deliver energy to loads

Grid Scale Solar and Large Daily Ramps

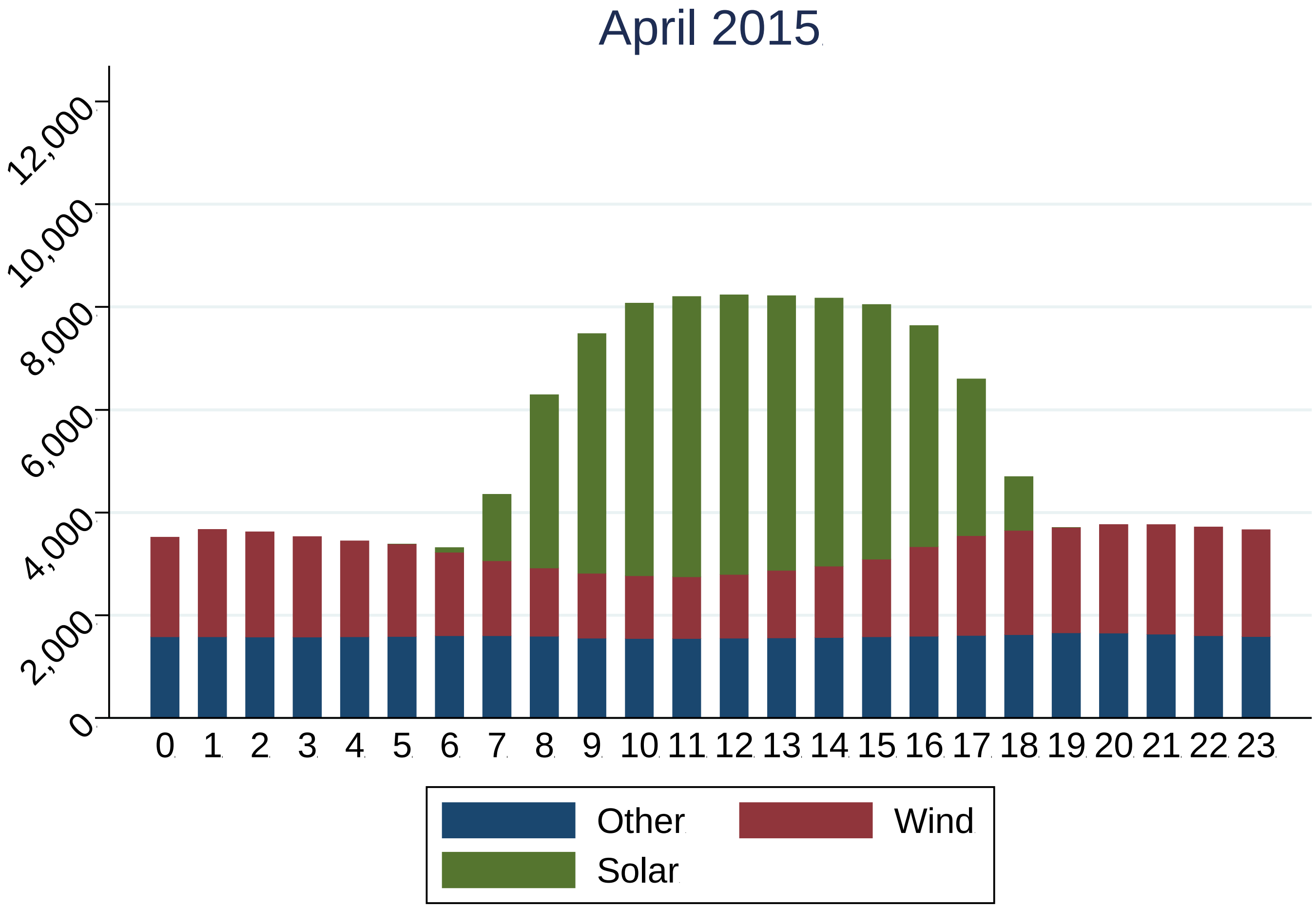
- In California, each day large amounts of solar capacity rapidly begins producing in early morning and stops producing at the end of the daylight hours
  - Roughly 10,000 MW of grid-scale solar and 7,000 MW of distributed solar capacity in California ISO control area
- Thermal and dispatchable generation must produce the difference between total demand and production of renewables
  - Renewables produce at zero marginal cost, whereas thermal resources require purchasing input fuel per MWh
- Difference between system demand and grid-scale renewable production is called the "net load"
  - No available measure of distributed solar production
- The net load involves significantly faster ramps that total system load
  - This has required creating new ancillary services

Hourly Renewable Output on CAISO System



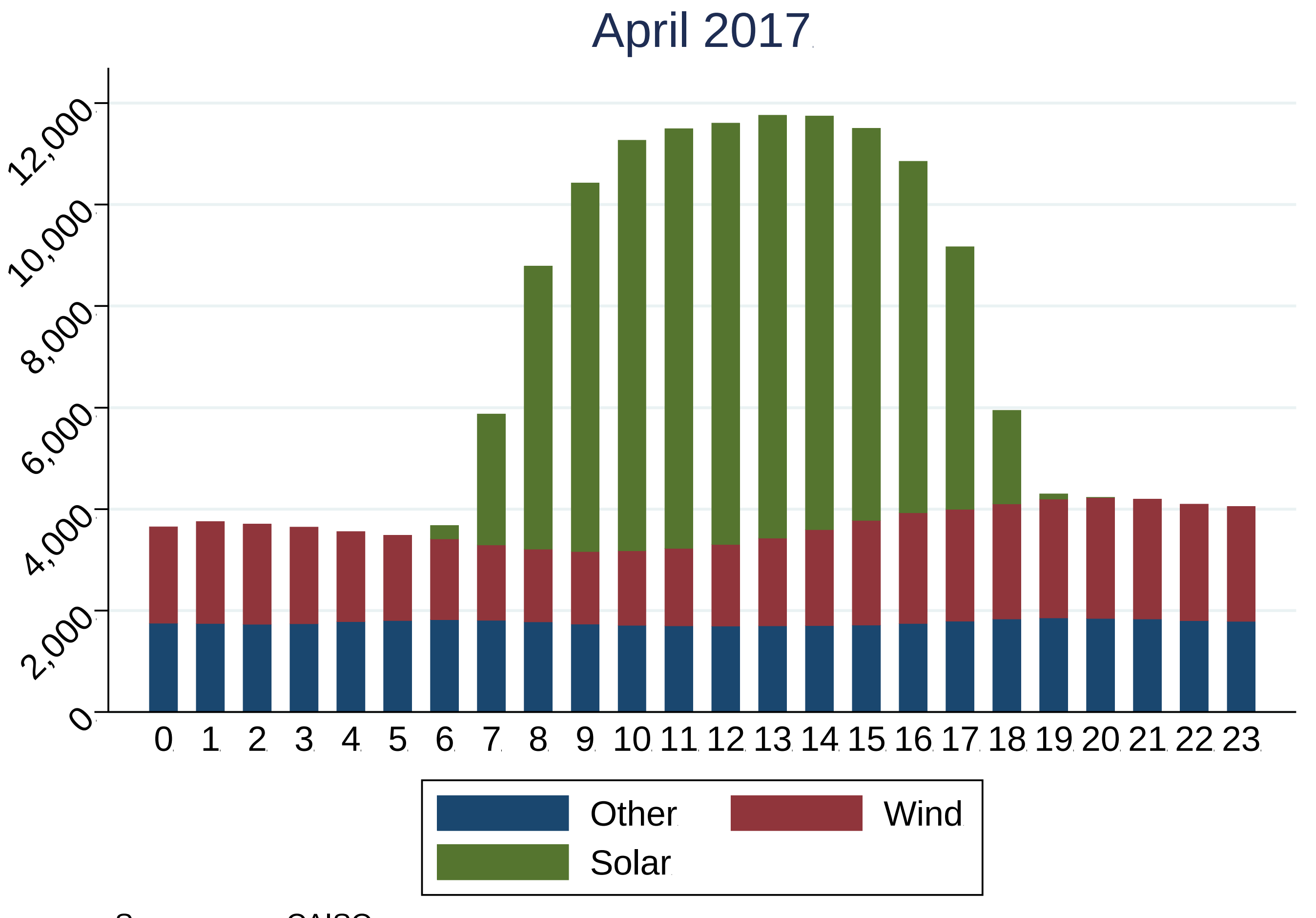
Source: www.CAISO.com

Hourly Renewable Output on CAISO System



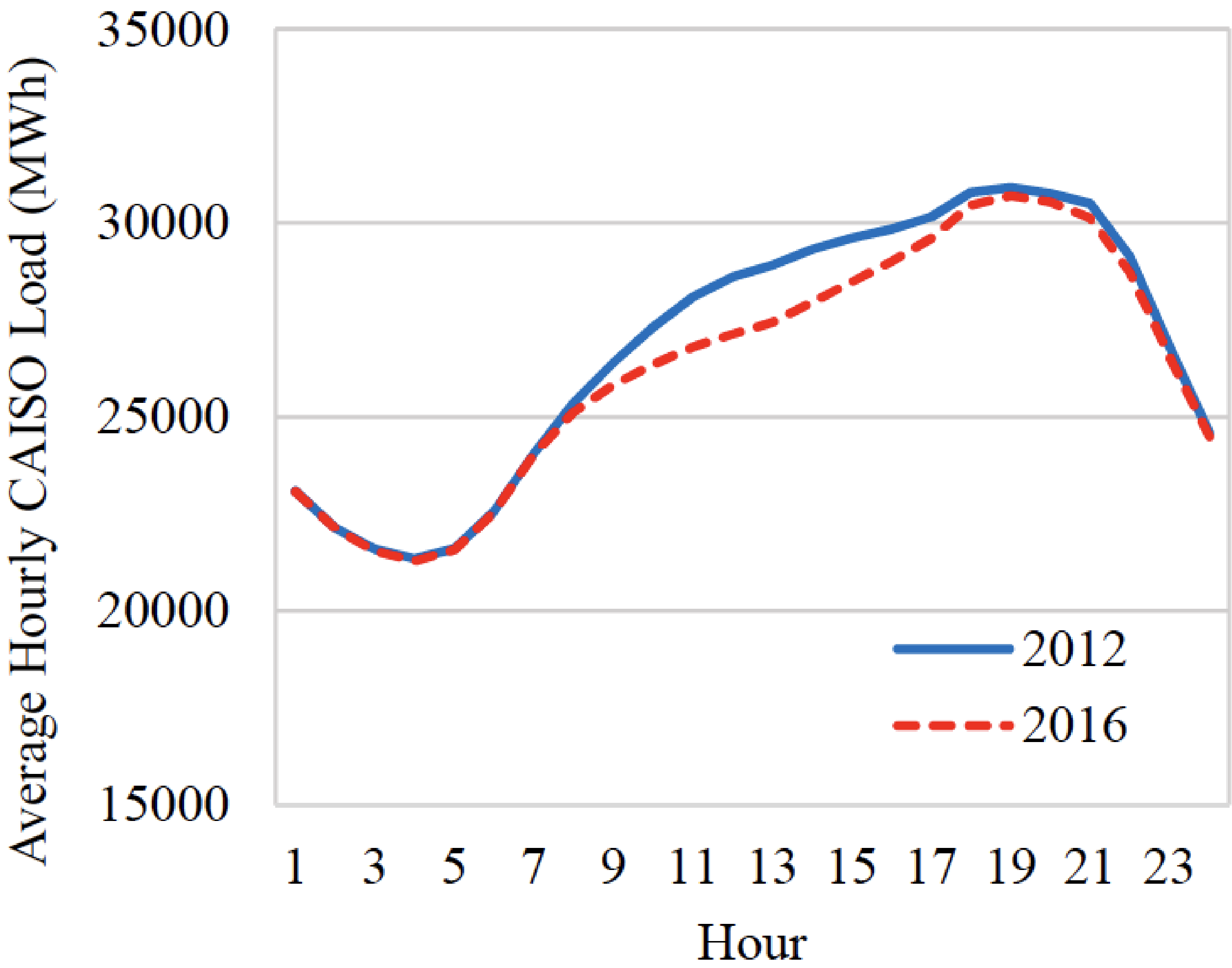
Source: www.CAISO.com

Hourly Renewable Output on CAISO System

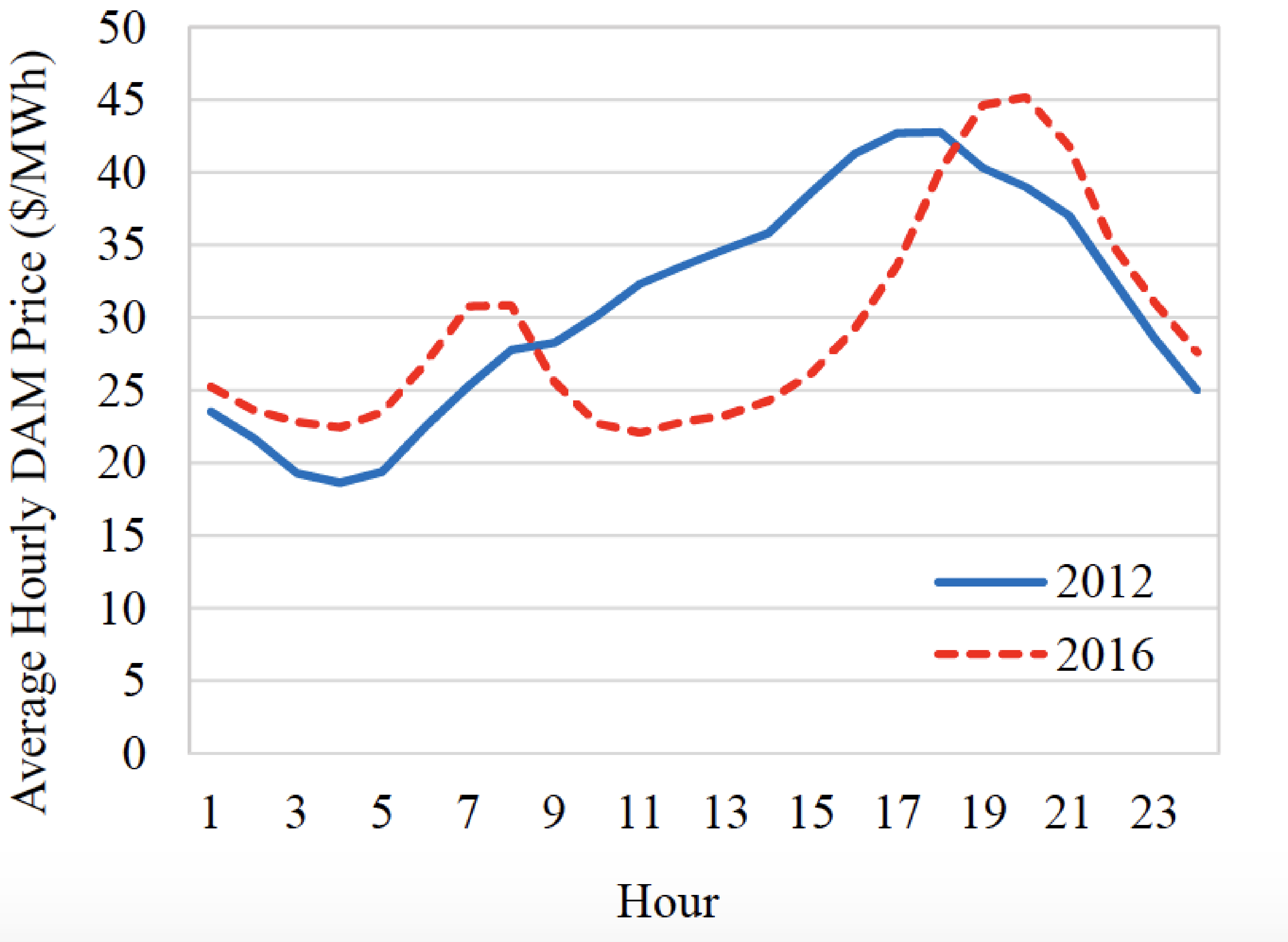


Source: www.CAISO.com

Average Hourly System Load in California ISO Control Area



Average Hourly Day-Ahead Prices California ISO Control Area



Managing Large Daily Ramps

- California and other wholesale markets have designed new products to reward fast-ramping generation capacity
  - California has a "flexible ramping capacity" market that holds out fast-ramping generation capacity to meet evening ramps
- California and other wholesale market have also designed mechanisms to reward fast-ramping products that perform
  - Consistent with Federal Energy Regulatory Commission (FERC) mandate

Setting Geographic Scope and Number of Ancillary Services

Key Point: Design ancillary services market to provide products system operator needs not for technologies or resources

Verifying Provision of Ancillary Services

Verifying Provision of Service

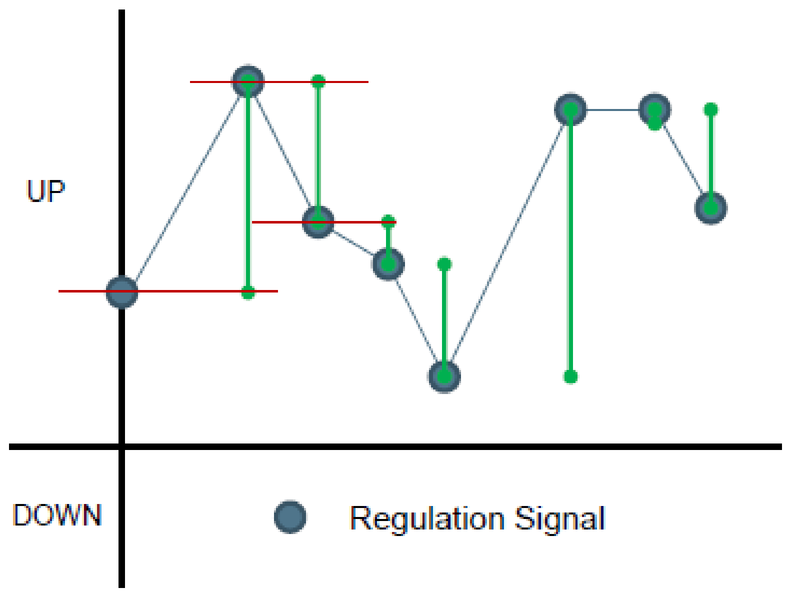
- Except for Regulation reserve, it is impossible to determine if a supplier actually provided an ancillary service
- Spinning reserve is holding unloaded capacity that can respond in 10 minutes
- Non-spinning reserve is off-line capacity that can respond in 10 minutes
- Impossible to tell if reserve not called to respond could have actually responded
- Most markets periodically test provider of these ancillary services and penalize no provision

Verification in the US Markets

- Suppliers providing spinning reserve or non-spinning reserve are randomly tested to see if they can provide required in energy in specified time
- If unit fails to provide energy, owner must refund all ancillary services payments since last time supplier either provided energy from unit under A/S commitment or passed test
  - Called "Ancillary Services No-Pay" in US markets
- There are also penalties for units providing Regulation reserve for failing to meet "set points" for units in required time
  - "Pay for Performance" in US markets

Pay-for-Performance-CA

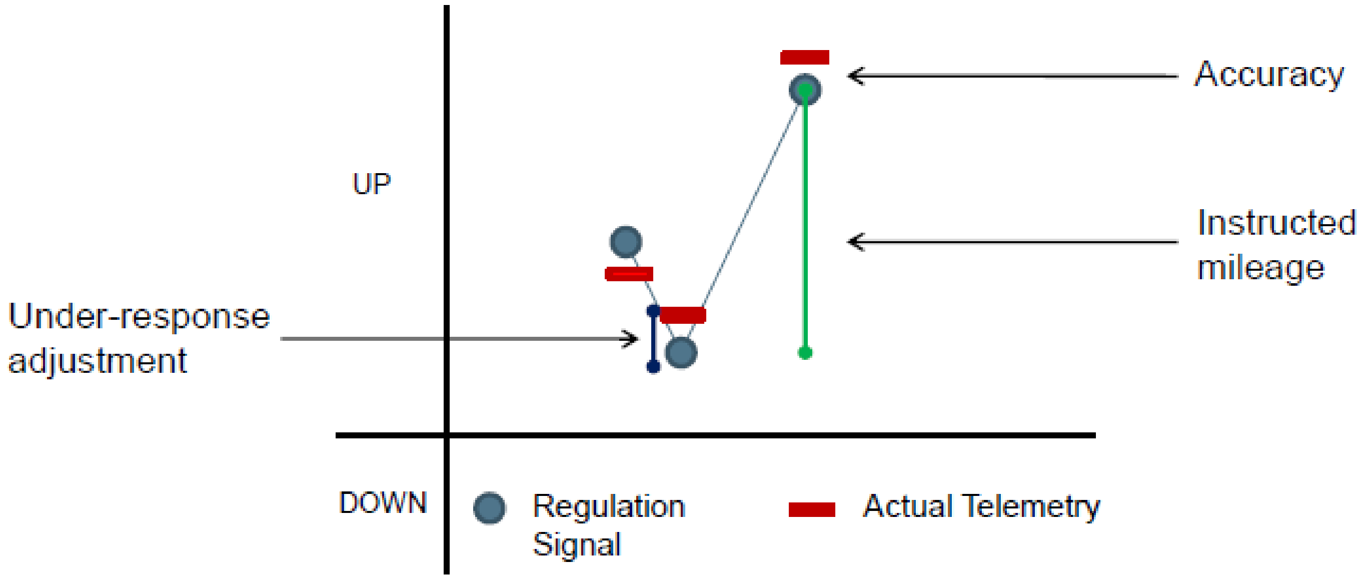
Instructed regulation movement or "mileage" is the sum of all green bars in a 15 minute interval



Resources receive a regulation signal of the MW output needed every four seconds.

Pay-for-Performance-CA

Accuracy adjustments reduce mileage payment based upon performance



1. Under-response adjustment reduces mileage paid when a resource doesn't provide actual movement
2. Accuracy measured by actual telemetry versus regulation signal

Reserve Scarcity Pricing

- When there is insufficient available operating reserves to meet requirements set scarcity price
  - Scarcity price is administratively determined to reward suppliers for providing reserves during scarcity periods
- Provides scarcity rents to generation unit owners for fixed cost recovery
- Provides incentives for demand side participation in managing real-time supply and demand balance
- Reserve scarcity conditions increasingly likely to occur in markets with significant intermittent renewables
- Insert demand bids in LMP market mechanism at reserve scarcity price
  - Automatically sets scarcity price if less than A/S requirement is purchased for any ancillary service

Verifying Provision of Ancillary Services

Key Point: Mechanisms are necessary to verify provision of ancillary services and reward provision under scarcity conditions

Paying for Ancillary Services

Economic Costing Principles

- Charge individual for costs their actions impose on system
  - If load purchases one more unit of energy at a location in the grid, charge them the LMP at that location for energy
  - Provides strong incentive for market participants that impose large costs on system to take actions to reduce those costs
  - Reducing these costs benefits entire system
- Assigning a cost to a market participant implies that market participant will take action to lower this cost
  - Actions taken to avoid this cost could increase costs on all other market participants, unless that market participant "caused" original cost

Economic Costing Principles

- Very difficult, if not impossible, to determine what market participant caused what ancillary service purchase in day-ahead time frame
  - Ancillary services demand typically based size of N-1 contingency for system
  - Specified in terms certain percentage of system load
- In these circumstances, assign ancillary services costs to market participants least able to take actions to avoid these costs
  - Assigning costs to generation unit owners that may not have caused them will likely ultimately increase costs to consumers more than just directly assigning cost to consumers
    - Supplier takes actions to avoid paying cost

A/S Payment Mechanism

- In US markets, ancillary services costs are typically assigned to electricity consumers
  - Can base charge on monthly peak demand and total energy consumed
- By above logic, charging ancillary services to load is less likely to lead to distortions from least-cost system-wide solution to meeting aggregate energy and ancillary services demands

A/S Payment Mechanism

- This logic is much less relevant in markets that do not
  - Run multiple settlements in advance of real-time
  - Run very short-term time interval real-time markets
  - Price all relevant operating constraints in energy and ancillary services markets
  - Co-optimize energy and ancillary service procurement
- In these markets there are likely to be many non-energy costs caused by specific market participants actions
  - These costs should be assigned to specific market participant that caused them

Paying for Ancillary Services

Key Point: Allocate ancillary services costs to entity that caused it and all other costs to entities least likely distort behavior to avoid these costs

Conclusions I

- Ancillary services “requirements” depend on energy market design
- Coordinating energy and ancillary services market designs key to successful market design
  - Prices for energy and ancillary services reflect all relevant transmission and other operating constraints
- Ancillary services price determined by opportunity cost and extent of competition suppliers face
  - Avoid sequential ancillary services markets
  - Allow demand substitution among ancillary services
  - Co-optimization of energy and ancillary services
- Market power mitigation for ancillary services straightforward and more effective with co-optimization of energy and ancillary service procurement

Conclusions II

- Design market to provide services system operator needs, not for technologies or resources
  - When reliability challenges system operator faces change can create new products
- Verification of ancillary services
  - Must have mechanism for verifying provision of ancillary services and rewarding provision in scarcity conditions
- Paying for ancillary services
  - Allocate non-causal costs of ancillary services to loads

Conclusions III

- Increasingly important to get ancillary services market right as attempt to scale up amount intermittent renewable capacity
  - Ancillary services costs in California doubled between 2015 and 2016, $62 million to $119 million
    - $0.27/MWh of load to $0.52/MWh of load
  - Ancillary services costs in California increased by 50% between 2016 and 2017, $119 million to $172 million
    - $0.52/MWh of load to $0.75/MWh of load

Questions/Comments

Análisis de los Servicios Complementarios para el Sistema Interconectado Nacional (SIN)

MUCHAS GRACIAS

Expected increase in regulation and load-following capacity requirements for increased intermittent resources

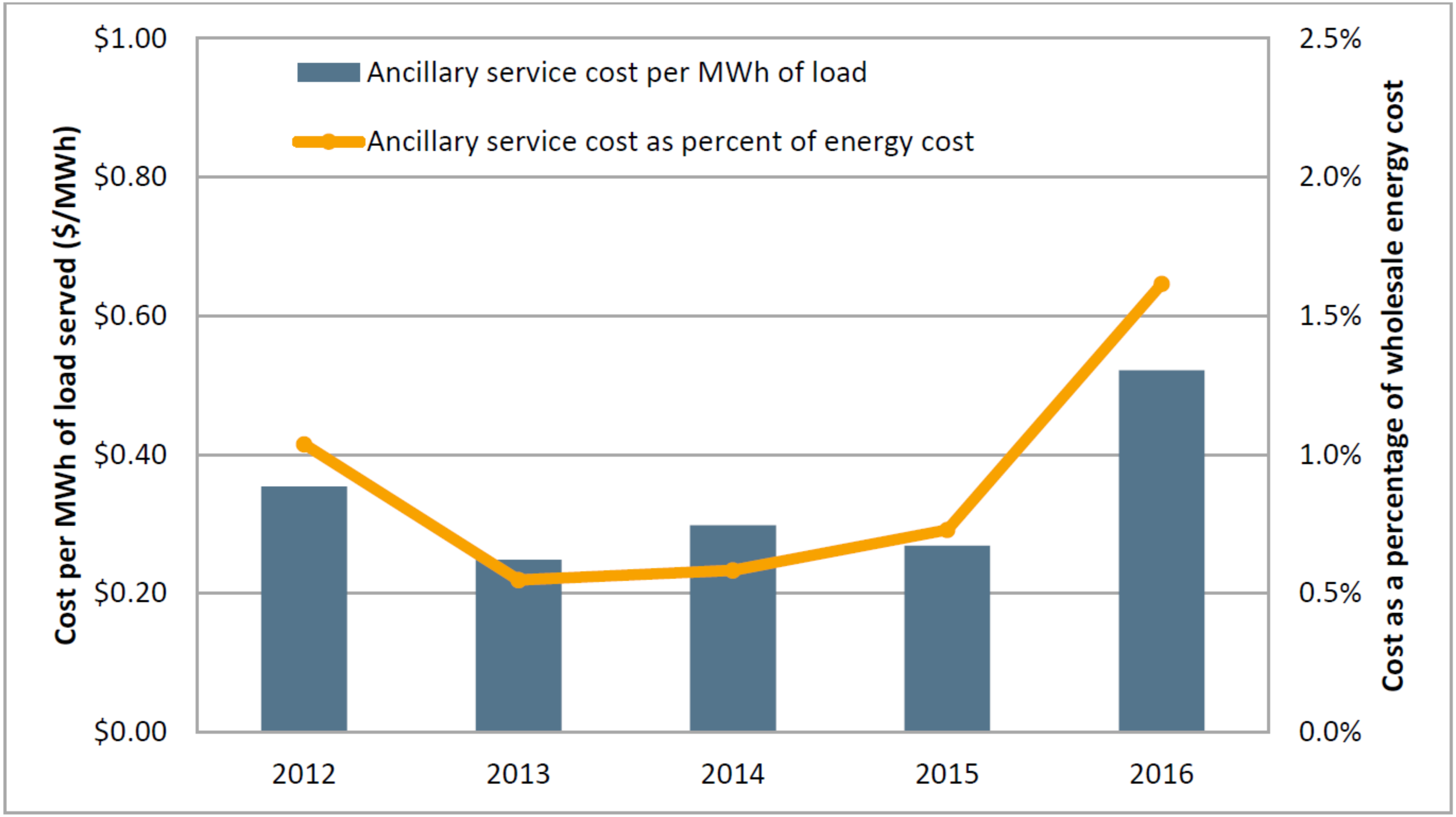
	Spring			Summer			Fall			Winter		
	2006	2012	2020	2006	2012	2020	2006	2012	2020	2006	2012	2020
Maximum Regulation Up Requirement (MW)	277	502	1,150	278	455	1,156	275	428	1,323	274	474	1,310
Maximum Regulation Down Requirement (MW)	-382	-569	-1,112	-434	-763	-1,057	-440	-515	-1,278	-353	-442	-1,099
Maximum Load Following Up Requirement (MW)	2,292	3,207	6,797	3,140	3,737	7,015	2,680	3,326	6,341	2,624	3,063	6,457
Maximum Load Following Down Requirement (MW)	-2,246	-3,275	-6,793	-3,365	-3,962	-6,548	-2,509	-3,247	-7,303	-2,424	-3,094	-6,812

Load, wind and solar forecast errors are the same as experienced today
2012 Case = 20% RPS (2,246 MW of solar and 6,688 MW of wind)
2020 Case = 33% RPS (12,334 MW of solar and 11,291 MW of wind)

Concluding Comments

- Ancillary services facility sales and delivery of electricity in wholesale electricity market
- Many different models for ancillary services markets
- Increasingly important to get ancillary services market right as attempt to scale up amount intermittent renewable capacity
  - Ancillary services costs in California doubled between 2015 and 2016, $62 million to $119 million
    - $0.27/MWh of load to $0.52/MWh of load
  - Ancillary services costs in California increased by 50% between 2016 and 2017, $119 million to $172 million
    - $0.52/MWh of load to $0.75/MWh of load

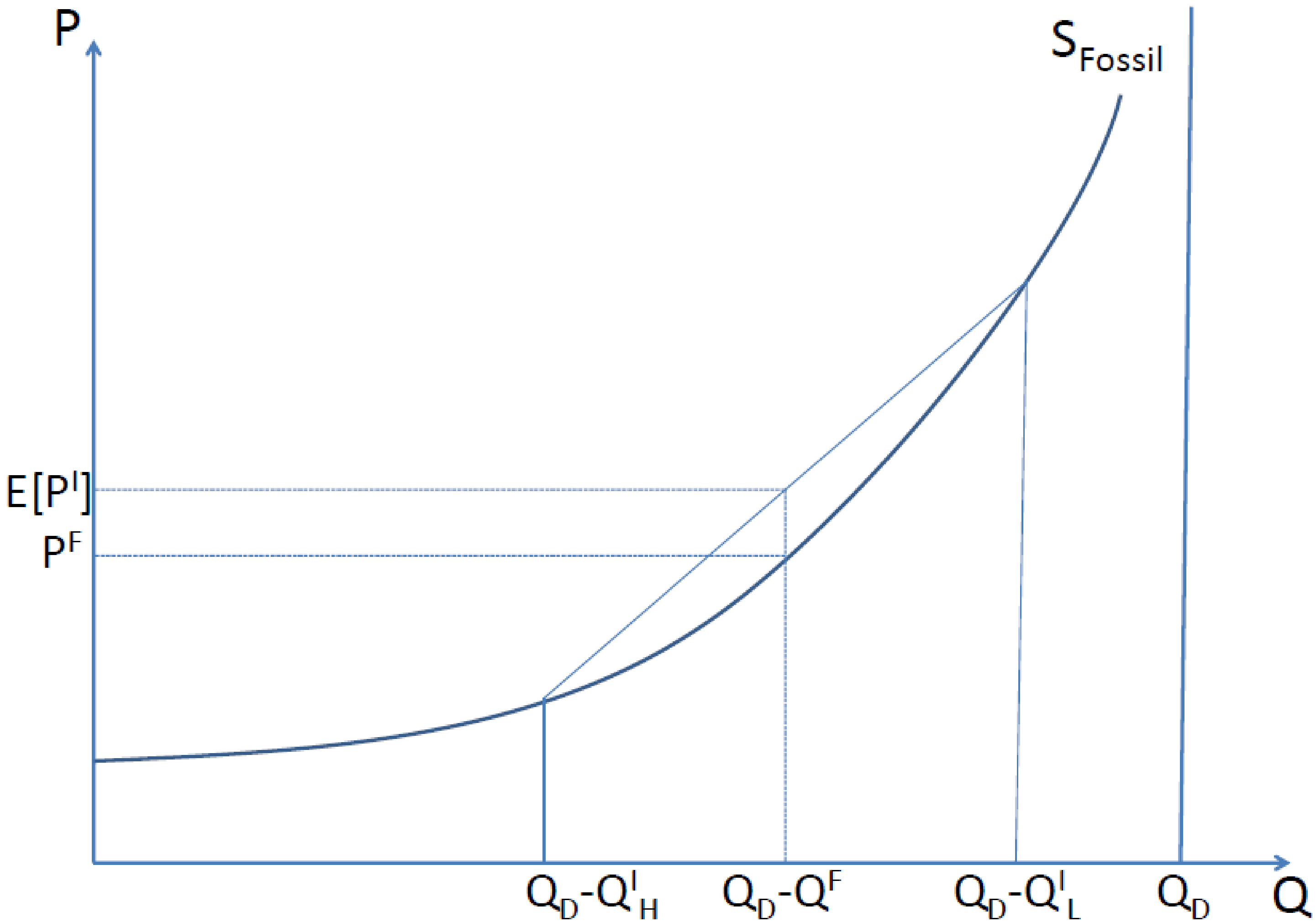
Background on California Market



Multi-Settlement Market

- Greater intermittency of resources increases price volatility, which increases average prices paid to thermal units
- Compare two states of the world
  - Intermittent resources that produces at high level, q(h), with probably p and or low level of output, q(l) with probability (1-p)
  - Dispatchable nuclear resource that produces expected intermittent output, q(n)= p*q(h) + (1-p)*q(l), with probability one
- Average prices are higher for state of the world one versus state of the world two
- Both thermal and intermittent resource owners benefit from higher average prices that result from greater intermittency
  - Forward market with risk neutral traders uses expected price on delivery date as relevant opportunity cost of energy
  - $E_t(P_{t+k}^{s}) = {}_{f}P_{t+k}^{F}$, expected spot price k periods in the future is equal to current forward price for delivery k periods in future

Price and Output Volatility



Intermittency and Price Volatility