Bidding in Electricity Markets

Dana Golden

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Presentation Outline

Types of Markets

- There is not just one electricity market: There are many!

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- There is not just one electricity market: There are many!
- Day-ahead market: Market participants bid to produce generation hourly one day ahead
- Real-time market: Market participants bid to balance grid based on deviations from expectations
- Reserve Capacity Market: Market participants paid to be present to prevent blackouts
- Ancillary Services: market participants provide additional services to market to ensure grid stability
- Renewable energy credits (RECs): Dominant way carbon markets work, separates properties of electricity from physical good

Day-Ahead Market Overview

- **Purpose**: Allows market participants to schedule energy one day in advance based on demand forecasts.
- **Process**:
  - Participants submit bids and offers for the next 24 hours.
  - System Operator (ISO) matches supply and demand at each hour to determine the Market Clearing Price (MCP).
  - Cleared bids become binding for the next day, ensuring reliability.
- **Pricing**:
  - Locational Marginal Pricing (LMP) is used, considering transmission constraints and loss costs.
  - Separate prices for each zone reflect localized demand and generation constraints.
- **Benefits**:
  - Provides transparency and certainty in scheduling.
  - Facilitates better planning and reliability.

Real-Time Market Overview

- **Purpose**: Adjusts generation and demand in near real-time to ensure reliability and address deviations from the day-ahead schedule.
- **Process**:
  - Real-time prices are calculated every 5 to 15 minutes.
  - ISO continuously monitors system balance and adjusts dispatch.
- **Pricing**:
  - Real-time LMPs reflect immediate supply-demand and transmission conditions.
  - Higher volatility in prices due to the immediacy of the market.
- **Benefits**:
  - Addresses unforeseen demand or supply changes.
  - Supports system reliability by balancing actual generation with real-time load.

Real-time and Day-ahead Settlement

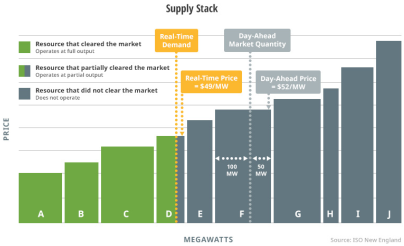

Figure 1: Settlement in Physical Electricity Market

Reserve Capacity Market

- **Purpose of the Reserve Capacity Market:** Ensures that there is enough backup generation available to maintain grid reliability during peak demand or unexpected outages.
- **How it Works:**
  - Generators commit to keeping additional capacity available as a reserve, which can be quickly dispatched in case of demand surges or supply shortfalls.
  - Payments are made to generators for maintaining this reserve capacity, even if it is not ultimately used.

Reserve Capacity Markets

- **Types of Reserve Capacity:**
  - **Spinning Reserve:** Online, ready-to-use capacity that can respond instantly to grid disruptions.
  - **Non-Spinning Reserve:** Offline capacity that can be brought online quickly if needed.
  - **Supplemental Reserve:** Additional reserves that provide support beyond spinning and non-spinning resources.
- **Importance of Reserve Capacity Markets:**
  - Provides financial incentives for generators to ensure grid reliability and avoid blackouts.
  - Supports integration of renewables by providing backup to compensate for their variability.
  - Helps grid operators maintain a stable and balanced system, even during unexpected events.

Demand Response in Electricity Markets

- **Demand Response (DR):** A grid management strategy where consumers adjust or reduce their electricity usage during peak times in response to price signals or incentives.
- **How Demand Response Works:**
  - **Market Signals:** When demand is high or supply is constrained, wholesale prices rise, signaling DR participants to lower consumption.
  - **Incentives:** Consumers receive financial compensation or reduced rates for reducing usage during demand response events.
  - **Aggregator Role:** Aggregators pool reductions from multiple participants, offering a significant decrease in demand to the grid operator.

Demand Response in Markets

- **Types of Demand Response Programs:**
  - **Price-Based DR:** Customers adjust usage in response to dynamic pricing, such as time-of-use rates or real-time pricing.
  - **Incentive-Based DR:** Participants are compensated for agreeing to reduce load during high-demand periods or emergencies.
- **Market Perspective:**
  - Demand response acts as a **flexible resource**, reducing the need for costly, peaking generation.
  - Enhances grid reliability by balancing supply and demand, reducing stress on infrastructure.
  - Supports renewable integration by managing variability, allowing the grid to respond quickly to changes in renewable output.

Overview of Ancillary Services Markets

- **Ancillary Services** support the reliable operation of the electric grid by ensuring balance, stability, and continuity of power.
- **Key Types of Ancillary Services:**
  - **Frequency Regulation:** Maintains grid frequency close to a standard level (e.g., 60 Hz), balancing short-term supply and demand fluctuations.
  - **Spinning Reserves:** Provides immediate backup generation from online resources that can ramp up quickly in case of sudden demand surges or outages.
  - **Non-Spinning Reserves:** Provides additional backup from offline resources that can be brought online within a specified time frame.
  - **Voltage Support:** Controls voltage levels across the grid, ensuring efficient power delivery and system reliability.

Importance of Ancillary Services Markets

- **Importance of Ancillary Markets:**
  - Compensates resources for maintaining grid reliability and stability, which becomes increasingly essential with renewable integration.
  - Provides a mechanism for various generation and storage technologies to participate in maintaining system reliability.
  - Helps prevent blackouts and other disruptions by ensuring the grid can respond to imbalances and unexpected events.
- **Market Structure:** Ancillary services are often structured as separate markets alongside energy markets, with different pricing mechanisms and compensation schemes.

Importance of Maintaining Grid Frequency

- **Grid frequency** is typically set at a standard level (e.g., 50 Hz or 60 Hz) to ensure the reliable operation of the electrical grid.
- Importance of frequency stability:
  - **Equipment Protection**: Electrical equipment is designed to operate at a specific frequency; deviations can lead to overheating or malfunction.
  - **Grid Stability**: Frequency fluctuations signal imbalances between supply and demand, which, if uncorrected, can cause cascading failures.
  - **Consumer Safety and Reliability**: Stable frequency ensures a continuous, reliable power supply, minimizing risks of outages.
- **Challenges with Renewable Integration**:
  - Asynchronous generation from renewables (e.g., wind, solar) contributes little or no inertia, increasing the risk of frequency instability.
  - Ancillary services and fast-responding resources are critical to compensate for these fluctuations.

Inertia in Electricity Markets

- **Inertia** refers to the resistance of synchronous generators (like large turbines) to rapid changes in frequency.
- It is crucial for grid stability, helping to absorb and counteract sudden frequency fluctuations caused by imbalances in supply and demand.
- Sources of inertia include:
  - Synchronous generators (e.g., coal, gas, nuclear, and hydro plants).
  - Rotating mass in generators that naturally resists changes in rotational speed.
- With increasing renewable penetration, there is less natural inertia, as most renewable sources (like solar PV and wind) are asynchronous.

Ancillary Markets for Inertia Services

- **Ancillary markets** exist to maintain grid stability by compensating generators to provide inertia and other reliability services.
- These markets pay for services such as:
  - **Synchronous reserves**: Generators are paid to stay online, ready to respond to frequency changes.
  - **Fast frequency response (FFR)**: Some markets now incentivize faster-responding resources, like batteries, to support grid stability.
- Payment structure:
  - Generators are compensated based on capacity reserved to provide inertia, often on a per-megawatt basis.
  - Payments encourage certain types of generators (usually traditional) to stay online even when energy demand is low.

Synthetic Inertia in Electricity Markets

- **Synthetic Inertia** refers to the ability of non-synchronous generation sources, like wind turbines and batteries, to mimic the stabilizing effect of traditional (synchronous) inertia.
- **How it works:**
  - Uses advanced controls and power electronics to rapidly adjust output in response to frequency changes.
  - Can provide fast frequency response by injecting or absorbing power within milliseconds.
- **Benefits of Synthetic Inertia:**
  - Helps maintain frequency stability as the grid incorporates more renewable energy sources.
  - Enables wind and solar plants to support grid stability in ways previously limited to synchronous generators.
  - Provides grid operators with more flexibility and resilience, especially in areas with high renewable penetration.

Objectives of Optimal Bidding

- Maximize expected profits by strategically setting bid prices.
- Account for uncertainties in demand, competitor behavior, and market prices.
- Balance risks from potential penalties for imbalances with rewards from market-cleared bids.

Mathematical Formulation

- Define variables:
  - q_i: Quantity of electricity bid by generator i.
  - p_i: Bid price per unit of electricity by generator i.
  - D: Forecasted demand in the market.
- Objective: Maximize profit $\pi_i = p_i q_i - C(q_i)$
  - $C(q_i)$: Cost function of generating q_i units of electricity.

Constraints in the Bidding Model

- Supply-demand balance: $\sum_i q_i = D$.
- Capacity constraints: $0 \leq q_i \leq \text{Capacity}_i$.
- Non-negative bid prices: $p_i \geq 0$.

Market clearing price = Marginal cost of the last generator selected

Incorporating Risk and Uncertainty

- Model uncertain demand with probability distribution $D \sim P(D)$.
- Use expected profit: $E[\pi_i] = E[p_i q_i - C(q_i)]$.
- Risk measures: Variance, Value-at-Risk (VaR), and Conditional Value-at-Risk (CVaR).

Solution Approach

- Analytical: Solve for p_i and q_i that maximize expected profit under constraints.
- Simulation-based: Use Monte Carlo methods to simulate different demand and competitor scenarios.
- Optimization tools: Linear programming or stochastic optimization.

Market Clearing

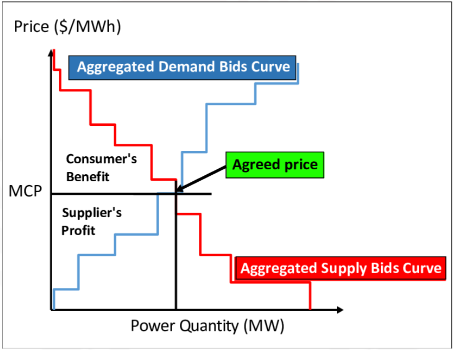

Figure 2: Many bids... One Price

Mathematical Formulation of the ISO Problem

Objective: Minimize Total Cost of Electricity Dispatch

$$\min \sum_{i \in G} C_i(P_i)$$

Where:

- G: Set of all generators.
- $C_i(P_i)$: Cost function for generator i, based on its power output P_i.

Subject to Constraints:

- **Power Balance Constraint:**

$$\sum_{i \in G} P_i = D$$

Where:

- D: Total system demand.

Mathematical Formulation of the ISO Problem

- **Generator Capacity Limits:**

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad \forall i \in G$$

Where:

  - $P_i^{\min}$: Minimum power output for generator i.
  - $P_i^{\max}$: Maximum power output for generator i.

- **Transmission Constraints:**

$$F_l \leq F_l^{\max} \quad \forall l \in L$$

Where:

  - F_l: Power flow on transmission line l.
  - $F_l^{\max}$: Capacity limit of transmission line l.
  - L: Set of all transmission lines.

ISO Problem

- **Locational Marginal Prices (LMPs):**

$$\lambda = \partial \text{Total Cost} / \partial D$$

Where:

- λ: Shadow price of demand, representing LMP.

Goal: Efficiently allocate generation to minimize costs while ensuring system reliability and respecting operational constraints.

Challenges of Real-time and Day-ahead Market

- Day-ahead market must settle before generation and demand known
- Generators must decide bids without knowing state in real-time market
- Getting it wrong can be costly.
- How to solve this?

Typical Supply Stack

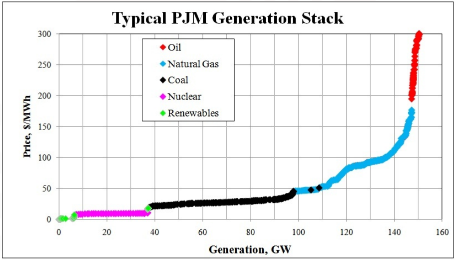

Figure 3: PJM Supply Stack.

Types of Renewable Energy

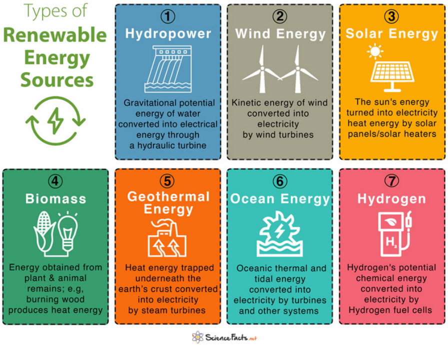

Figure 4: Different Sources of Renewable Energy

Economics of Renewable Energy

- **Cost Trends**
  - Declining capital costs due to technology improvements and economies of scale.
  - Low and predictable operational costs, particularly with wind and solar.
- **Revenue Streams**
  - Power Purchase Agreements (PPAs) ensure steady income.
  - Renewable energy credits (RECs) and carbon credits provide additional revenue.
  - Participation in ancillary service markets (e.g., grid stabilization).
- **Economic Incentives**
  - Tax credits such as the Investment Tax Credit (ITC) and Production Tax Credit (PTC).
  - Government subsidies and grants encourage deployment.
  - Policies like renewable portfolio standards (RPS) drive demand.

Economics of Renewable Energy

- **Risk Mitigation**
  - Long-term predictability of costs due to lack of fuel dependence.
  - Reduced exposure to fossil fuel price volatility.
- **Local Economic Benefits**
  - Job creation in installation, maintenance, and manufacturing.
  - Land lease payments provide income for property owners.

Technical Aspects of Solar Panels

- **Photovoltaic (PV) Effect**
  - Solar panels convert sunlight into electricity through the PV effect.
  - Photons strike the semiconductor material (e.g., silicon), generating electron flow.
- **Panel Efficiency**
  - Defined as the ratio of electricity generated to sunlight energy absorbed.
  - Typical efficiency ranges:
    - Monocrystalline: 15–22%
    - Polycrystalline: 13–18%
    - Thin-film: 7–13%
- **System Components**
  - **Solar Panels:** Capture sunlight and generate DC electricity.
  - **Inverters:** Convert DC to AC electricity for grid use.
  - **Mounting Systems:** Optimize panel orientation for sunlight.
  - **Energy Storage (Optional):** Batteries store excess energy for later use.

Solar Panel Performance Factors

- **Performance Factors**
  - **Irradiance:** Solar power depends on the intensity of sunlight.
  - **Temperature:** Higher temperatures can reduce panel efficiency.
  - **Orientation and Tilt:** Affects how much sunlight is captured.
  - **Shading:** Obstructions can significantly decrease output.

Types of Solar Panels

- **Monocrystalline Solar Panels**
  - Made from a single crystal structure.
  - High efficiency and longevity.
  - Sleek black appearance.
- **Polycrystalline Solar Panels**
  - Made from multiple silicon fragments melted together.
  - Lower cost compared to monocrystalline panels.
  - Slightly less efficient and has a bluish hue.
- **Thin-Film Solar Panels**
  - Made from a variety of materials like amorphous silicon or cadmium telluride.
  - Flexible, lightweight, and less expensive.
  - Lower efficiency and shorter lifespan.

Anatomy of Solar Panel

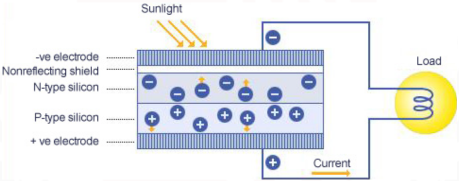

Figure 5: Solar Panel Makeup

Wind Farm

- **Components of a Wind Turbine**
  - Rotor Blades: Capture wind energy and rotate.
  - Nacelle: Houses the generator, gearbox, and other components.
  - Tower: Supports the nacelle and rotor, optimized for height to capture stronger winds.
  - Foundation: Provides structural stability.
- **Energy Conversion Process**
  - Kinetic energy of wind is converted into mechanical energy via rotor blades.
  - Mechanical energy is converted into electricity through the generator.
  - Power output is proportional to the cube of wind speed: $P = \frac{1}{2}\rho A v^3$.
- **Types of Wind Farms**
  - Onshore: Located on land, easier to maintain, lower costs.
  - Offshore: Located in water, benefits from stronger and consistent winds, higher costs.
- **Grid Integration**
  - Requires voltage regulation, frequency control, and storage solutions.
  - Impact on transmission infrastructure and load balancing.

Components of Offshore Wind Farm

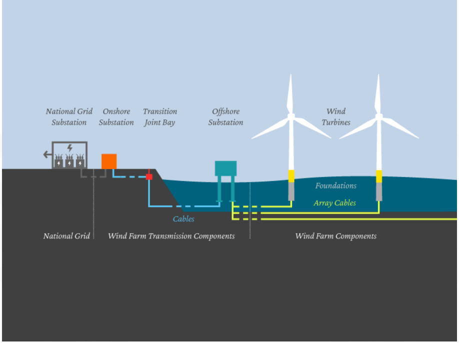

Figure 6: Offshore Wind Farm Diagram

Cost Comparison: Wind Farms vs. Solar Farms

- **Capital Costs**
  - **Wind Farms:**
    - High upfront costs due to turbine manufacturing and installation.
    - Offshore wind farms are significantly more expensive than onshore.
  - **Solar Farms:**
    - Moderate initial costs, with panel prices decreasing over time.
    - Less variation in costs compared to wind farms.
- **Operational and Maintenance Costs**
  - **Wind Farms:**
    - Higher maintenance costs due to moving parts and turbine height.
    - Offshore farms face additional logistical challenges and costs.
  - **Solar Farms:**
    - Lower maintenance costs with no moving parts.
    - Cleaning of panels and occasional inverter replacement required.
- **Energy Cost per MWh**
  - **Wind Farms:**
    - Competitive levelized cost of energy (LCOE), particularly in areas with consistent wind.
    - Offshore wind has higher LCOE due to installation and maintenance

Modeling Supply Uncertainty for Renewable Generators

- **Supply Forecasts:** Day-ahead bids rely on weather forecasts to predict renewable generation levels.
- **Uncertainty in Generation:**
  - Wind and solar output are highly variable and depend on factors like wind speed, solar irradiance, and cloud cover.
  - Forecast errors increase the risk of not meeting committed day-ahead bids.
- **Probabilistic Modeling:** Use probability distributions (e.g., Gaussian, Poisson) to model expected generation and uncertainty.

Day-Ahead Bidding Strategy

- **Objective:** Maximize expected profits while accounting for supply uncertainty.
- **Bid Quantity and Price:**
  - Bid based on forecasted generation with adjustments for forecast uncertainty.
  - Price bids should consider the risk of penalties for under-delivery if actual output falls short.
- **Risk Management:** Incorporate risk measures like Conditional Value at Risk (CVaR) to limit exposure to extreme outcomes.

Real-Time Market Adjustments

- **Real-Time Corrections:** Renewables can adjust output bids in the real-time market to better match actual generation.
- **Adjustment Costs:** Deviation from day-ahead commitments can incur costs or penalties, influencing real-time bidding decisions.
- **Balancing Benefits:** Selling excess generation or buying shortfall in the RTM provides flexibility but adds complexity in decision-making.

Model Formulation

- Define variables:
  - Q_{DA}: Quantity bid in day-ahead market.
  - Q_{RT}: Real-time adjustment quantity.
  - P_{DA} and P_{RT}: Prices in day-ahead and real-time markets.
- **Objective Function:** Maximize expected profit $\pi = P_{DA}Q_{DA} + P_{RT}Q_{RT} - C(Q_{DA}, Q_{RT})$, where C is cost of penalties and adjustments.
- **Constraints:**
  - Supply constraint: $Q_{DA} + Q_{RT} \leq$ Expected Generation.
  - Risk constraint: Minimize risk metrics like CVaR to account for variability in actual generation.

Benefits of a Two-Stage Bidding Model

- **Flexibility:** Allows renewable generators to optimize both day-ahead and real-time decisions based on updated information.
- **Risk Mitigation:** Reduces exposure to forecast errors and potential penalties by enabling real-time adjustments.
- **Enhanced Profitability:** By dynamically adjusting to market conditions, renewable generators can better capture high prices or minimize losses.

Contracts for Differences

- Renewable energy is extremely capital intensive
- Electricity market prices are volatile, for renewables supply is also volatile
- Banks need guarantees that they can be paid back
- Contracts for differences lock in prices by transferring risk from generator to buyer
- Bank now can feel comfortable lending

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- Contracts for differences lock in prices by transferring risk from generator to buyer
- Bank now can feel comfortable lending
- Contracts for differences also distort market pricing signals. How?

Impacts of Renewable Energy on Prices

- Renewable energy tends to have extremely low marginal costs and is non-dispatchable
- Generally pushes prices down and increases volatility
- This presents reliability challenges and challenges for markets with high renewable penetration

Types of Energy Storage Systems

- Electro-chemical
  - Thermo-chemical
  - Battery
  - Fuel Cell
- Mechanical
  - Potential: Compressed air energy storage, Pumped Hydroelectric Storage
  - Kinetic: Flywheel
- Electromagnetic
  - Magnetic: superconducting magnetic energy storage
  - Electrostatic: Capacitor, super-capacitor
- Thermal: Low Temperature, high temperature

Pumped Hydroelectric Storage (PHS)

- **Overview:** Pumped hydroelectric storage (PHS) is a large-scale energy storage technology that uses gravitational potential energy.
- **How it Works:**
  - During times of low electricity demand, water is pumped from a lower reservoir to an upper reservoir.
  - During peak demand, water flows back down through turbines to generate electricity.
- **Advantages:**
  - Provides grid stability and flexibility with quick response to demand changes.
  - Highly efficient with a round-trip efficiency of around 70-80
- **Challenges:**
  - Requires specific geographic conditions (elevation difference).
  - High upfront costs and long construction times.

Anatomy of a Battery

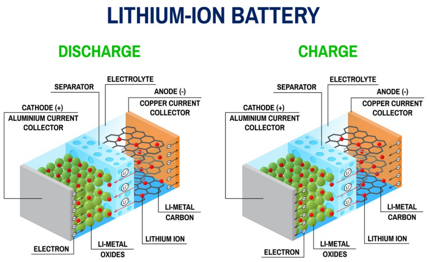

Figure 7: Battery Makeup

Types of Batteries

- Lithium-Ion
- Sodium Sulfer
- Nickel-cadmium
- Vandium Redox
- Zinc-Bromine

Types of Batteries for Energy Storage

- **Lithium-Ion Batteries**
  - Widely used in grid-scale and portable applications.
  - High energy density and efficiency.
- **Sodium-Sulfur (NaS) Batteries**
  - Operate at high temperatures.
  - Suitable for long-duration energy storage.
- **Nickel-Cadmium (NiCd) Batteries**
  - Robust and reliable with a long lifespan.
  - Can tolerate extreme temperature variations.
- **Vanadium Redox Flow Batteries**
  - Store energy in liquid electrolytes.
  - Scalable for large grid-scale applications.
- **Zinc-Bromine Flow Batteries**
  - Use zinc and bromine as active materials.
  - Low cost and long cycle life.

Advantages of Different Battery Types

- **Lithium-Ion Batteries**
  - High energy density: Ideal for space-constrained installations.
  - Fast charge/discharge cycles.
  - Low self-discharge rate.
- **Sodium-Sulfur (NaS) Batteries**
  - High energy capacity for large-scale applications.
  - Long-duration energy storage (6–8 hours or more).
- **Nickel-Cadmium (NiCd) Batteries**
  - Durable and reliable under harsh conditions.
  - Long cycle life, ideal for remote applications.
- **Vanadium Redox Flow Batteries**
  - Independent scaling of power and energy capacity.
  - Excellent cycle life with minimal degradation.
- **Zinc-Bromine Flow Batteries**
  - Cost-effective for large-scale deployments.
  - High safety due to non-flammable materials.

BESS

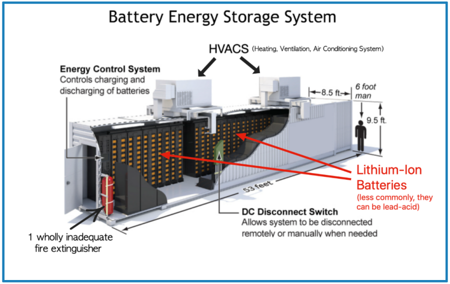

Figure 8: What do You Imagine when You think of BESS?

Hydrogen Fuel Cells

- **Overview:** Hydrogen fuel cells convert hydrogen and oxygen into electricity, heat, and water, offering an emissions-free source of power.
- **How it Works:**
  - Hydrogen reacts with oxygen in the fuel cell, producing electricity through an electrochemical process.
  - Outputs include electricity, heat, and water, with no direct emissions except water vapor.
- **Advantages:**
  - High energy density, suitable for long-duration storage and various applications (e.g., backup power, transportation).
  - Scalability and modularity for distributed energy systems.
- **Challenges:**
  - Hydrogen production is energy-intensive and can have emissions unless produced from renewable sources.
  - Storage and transport of hydrogen require careful handling and infrastructure.

Colocation

- Almost all new renewable energy projects involve colocation
- In colocation, ESS is situated by renewable energy
- Why would they do this?

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- In colocation, ESS is situated by renewable energy
- Why would they do this?

1. Smoothing: Energy storage systems prevent penalties in day-ahead markets
2. Arbitrage: Colocation allows renewable energy to become dispatchable and take advantage of price fluctuations, may even buy energy through ESS
3. Stability: Colocation can help prevent curtailment and make quick start-up and shut-down less likely

Things to Consider in ESS Modelling

- Energy storage is about reliability but it is also about arbitrage
  - Renewable energy dislikes price variability, energy storage loves it
- Upcycles and downcyles depreciate a battery
- Energy storage is fundementally a dynamic problem, in a lot of ways much like option or bond pricing
- Energy storage is capital intensive, tradeoff between capacity and
- Energy storage systems are major participants in reserve capacity and ancillary services markets

Modeling Dynamic Storage Choices

- **Objective:** Maximize profits by choosing optimal charge/discharge cycles in response to market prices.
- **State Variables:**
  - S_t: State of charge at time t, constrained by capacity.
  - P_t^{charge} and $P_t^{discharge}$: Charging and discharging power bids at time t.
- **Dynamic Constraints:**
  - $S_{t+1} = S_t + \eta P_t^{charge} - P_t^{discharge}/\eta$, where η is the efficiency factor.
  - Capacity constraint: $0 \leq S_t \leq \text{Max Capacity}$.
- **Intertemporal Choice:** Optimize P_t^{charge} and $P_t^{discharge}$ across time periods to respond to price forecasts and state of charge.

Electricity Market Futures

- Electricity markets are also a commodity.
- Does that mean they also have futures?

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- Yes!
- Electricity markets have both physical and financial markets

Electricity Market Futures

- Electricity markets are also a commodity.
- Does that mean they also have futures?
- Yes!
- Electricity markets have both physical and financial markets
- Not only do electricity markets have futures, but they have some of the most sophisticated financial contracts in all of commodities markets!
- Financial contracts allow generators and demanders to hedge against remarkably complex outcomes at high frequencies

Incs, Decs, UTCs, and FTRs

- Incs: offer to sell electricity in the Day-Ahead market at a stated price at a particular location
- Decs: offer to buy electricity in the Day-Ahead market at a stated price, at a particular location
- UTCs: bid to purchase transmission congestion and losses in the Day-Ahead market at a stated price spread, between two particular points
- FTRs: Long-term hedge against transmission congestion over time

Incremental Offers (INCs)

- **Definition**
  - A financial offer submitted by market participants to sell additional electricity into the market if the price is favorable.
- **Purpose**
  - Capitalize on higher locational marginal prices (LMPs) at specific nodes.
  - Provide additional supply to balance the grid during congestion or high demand.
- **Mechanism**
  - Participants specify:
    - Quantity of energy offered.
    - Minimum price at which the energy is willing to be sold.
  - Accepted INCs are settled at the market-clearing price.
- **Key Characteristics**
  - Tied to price arbitrage opportunities in the day-ahead and real-time markets.
  - Does not involve physical delivery of electricity.

Decremental Bids (DECs)

- **Definition**
  - A financial bid submitted by market participants to buy electricity from the market if the price is favorable.
- **Purpose**
  - Arbitrage lower locational marginal prices (LMPs) at specific nodes.
  - Help reduce excess supply during periods of low demand or congestion.
- **Mechanism**
  - Participants specify:
    - Quantity of energy desired.
    - Maximum price willing to pay.
  - Accepted DECs are settled at the market-clearing price.
- **Key Characteristics**
  - Tied to price arbitrage opportunities in the day-ahead and real-time markets.
  - Does not involve physical receipt of electricity.

Comparison: INCs vs. DECs

Aspect	Incremental Offers (INCs)	Decremental Bids (DECs)
Definition	Offers to sell electricity at favorable prices	Bids to buy electricity at favorable prices
Purpose	Arbitrage high LMPs and provide additional supply	Arbitrage low LMPs and reduce excess supply
Market Role	Increase supply during periods of high demand	Decrease supply during periods of low demand
Price Threshold	Minimum price specified by seller	Maximum price specified by buyer
Delivery	No physical delivery of electricity	No physical receipt of electricity
Timeframe	Day-ahead or real-time market	Day-ahead or real-time market

Incs and Decs Graphically

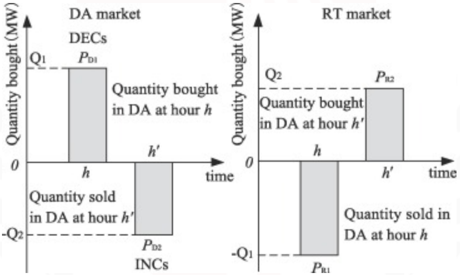

Figure 9: DA and Real-time Financial Market.

UTCs vs. Paired INC/DEC Transactions

Aspect	Up-To-Congestion Transactions (UTCs)	Paired INC/DEC Transactions
Definition	Financial transaction to arbitrage congestion costs	Separate INC and DEC transactions paired to mimic congestion trades
Structure	Single transaction specifying source, sink, and congestion cost limit	Two independent bids: one to sell (INC) and one to buy (DEC)
Purpose	Profit from arbitrage of congestion cost differences	Mimic the financial effects of UTCs for arbitrage opportunities
Cost Control	Limits maximum congestion cost exposure	No explicit congestion cost limit, profit depends on LMP spread
Implementation	Simple, requires only one financial position	Requires coordination of two bids (INC and DEC)
Market Impact	Typically simpler and more transparent	Can increase market complexity and risk of gaming
Risk Management	Directly tied to congestion cost	Subject to separate market risks at INC and DEC nodes

Key Takeaway: UTCs are designed explicitly to arbitrage congestion costs with a built-in cost limit, while paired INC/DEC transactions require separate bids and are more flexible but riskier and complex.

Up To Congestion (UTC) Transactions

- **Definition:**
  - A type of financial transaction in electricity markets involving two locations on the grid.
  - Participants bid on the price difference between a source and sink node.
- **Key Features:**
  - Allows market participants to profit from price differentials caused by grid congestion.
  - Bids are submitted with an upper and lower price limit, setting the desired range for congestion costs.
- **Purpose:**
  - Enables speculative trading or hedging against price volatility due to transmission constraints.
- **Settlement:**
  - Profits are realized when the actual congestion cost falls within the bid limits.
  - Losses occur if the congestion cost exceeds the bid range.

Financial Transmission Rights (FTRs)

- **Definition:**
  - A financial instrument used to hedge against congestion costs in electricity markets.
  - Provides rights to receive (or pay) congestion revenues between specified source and sink nodes.
- **Key Features:**
  - Allocated or auctioned by grid operators.
  - Typically sold in monthly, seasonal, or yearly blocks.
- **Purpose:**
  - Helps market participants manage congestion risk and stabilize revenues.
- **Settlement:**
  - Based on the difference in locational marginal prices (LMPs) between the source and sink.
  - Participants earn congestion revenue if their FTR matches the grid's actual power flow.

Comparison: UTC Transactions vs. FTRs

Aspect	Up-To-Congestion Transactions (UTC)	Financial Transmission Rights (FTRs)
Type	Short-term financial transactions	Long-term financial instruments
Purpose	Arbitrage price differences due to congestion	Hedge against congestion cost
Path Dependency	Flexible between two locations	Fixed source and sink
Delivery	No physical delivery	No physical delivery
Timeframe	Typically day-ahead or real-time markets	Auctioned for longer periods (e.g., months, years)
Cost Limit	Participant specifies max congestion cost	Entitled to congestion revenue differences
Market Role	Increases liquidity and arbitrage opportunities	Provides risk management for congestion exposure

Gaming Example: Financial and Physical Electricity Transactions

Scenario: Exploiting Congestion and Price Differences

- **Setup:**
  - Market participant submits a physical transaction to create artificial congestion.
  - Simultaneously, the participant places financial transactions (e.g., FTRs, UTCs, or INC/DEC pairs) to profit from the resulting price differences.
- **Steps:**
  1. Submit a low-cost physical transaction at Node A to Node B to artificially increase congestion.
  2. Congestion causes a price spread between Node A (source) and Node B (sink).
  3. Use financial instruments (e.g., FTRs or UTCs) to profit from the artificially induced price difference.

Gaming Example Outcome

- **Outcome:**
  - Market participant profits financially from the manipulated price spreads.
  - Grid operations are disrupted, and market efficiency is reduced.
  - Increased costs for other market participants and end-users.

Example Impact:

- Congestion artificially drives the Locational Marginal Price (LMP) at Node B higher than at Node A.
- The participant's FTR positions pay out based on the exaggerated price spread.

Key Concern: Gaming undermines market integrity, leading to inefficiency, higher consumer costs, and regulatory intervention.

Thank You So Much!

List of References