The Emerging Hierarchical Multi-Tier Energy Market Architecture Suitable for the Energy Transition: Challenges and Potential Solutions

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Outline

- The Evolution of the Energy Market Design
- The New Energy Market Design Principles
- The New Hierarchical Multi-Tier Energy Market Structure
- Wholesale energy ISO/TSO Energy Markets
- Challenges to Energy Markets due to Energy Transition
- Optimal Energy Market Design Architecture
- DSO Nodal DLMP & Local Energy DER Markets
- Distributed Energy Resources (DERs) & Market Behind The Meter
- Transactive Energy Architecture & Blockchain
- Key Messages

Evolution of Energy Market Design

- The first two waves of energy market design were driven by:
  - Increased efficiency in investment and operation through wholesale energy markets
  - Unbundling and privatization of the electricity infrastructure
- The emerging third wave of energy market design is driven by:
  - **An environmental agenda for decarbonization** of electricity generation to reduce global warming
  - **Rapid technological innovations in edge grid technologies** like IoT smart devices and other Distributed Energy Resources (DERs)
  - **A social movement towards more consumer choice** and “democratization” of the energy supply through DER growth

The New Role & Principles of Energy Market Design

- **Decarbonization** of the energy system with DERs
- **Reliability** of the system with **affordable market prices** to avoid major geopolitical shifts (deal with the gap of operational realities and aspirational policies)
- **Consumer choice** and free participation of edge grid DER assets in all markets
- **Avoidance of subsidies** (Subsidies are counter to the fundamental principles of energy market design)
- **Decentralization** of markets
- **Maximum utilization** of existing assets
- **Design for complementary resources** to maximize efficiency gains

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Distributed Energy Resources

- Distributed Energy Resources (DERs) are supply and demand-side resources connected to the distribution system BTM and IFOM
- They are growing in volume and diversity in response to multiple forces of change (decarbonization policies, costs, customer choice) required for the energy transition
- Local resilience is an increasing concern driving micro-grid formation
- Most DERs are ZERO marginal costs resources
    - Solar Photovoltaic (PV) and wind Resources
    - Small, gas-fueled generators
    - Energy storage resources (BESS)
    - Combined Heat & Power
    - Microgrid systems
    - Demand Response Resources
    - Electric Vehicles

Energy System Transformation

	Old	New
Load	Almost flat	Explosive growth AI, EV
Paradigm	Centralized	Decentralized
Generation	Dispatchable	Intermittent
Energy mix	Thermal/Coal	Gas/DER/DR/Storage
Renewables	Expensive	Grid Parity
Grid Power flow	One-way	Bi-directional
Customers	*“Consumers”*	*“Prosumers”*
Tariffs	Volumetric	Transactive
Demand	Inflexible	Price-responsive
Data	Manageable	Explosive Growth
Electric Vehicles	Rare	Massive Penetration

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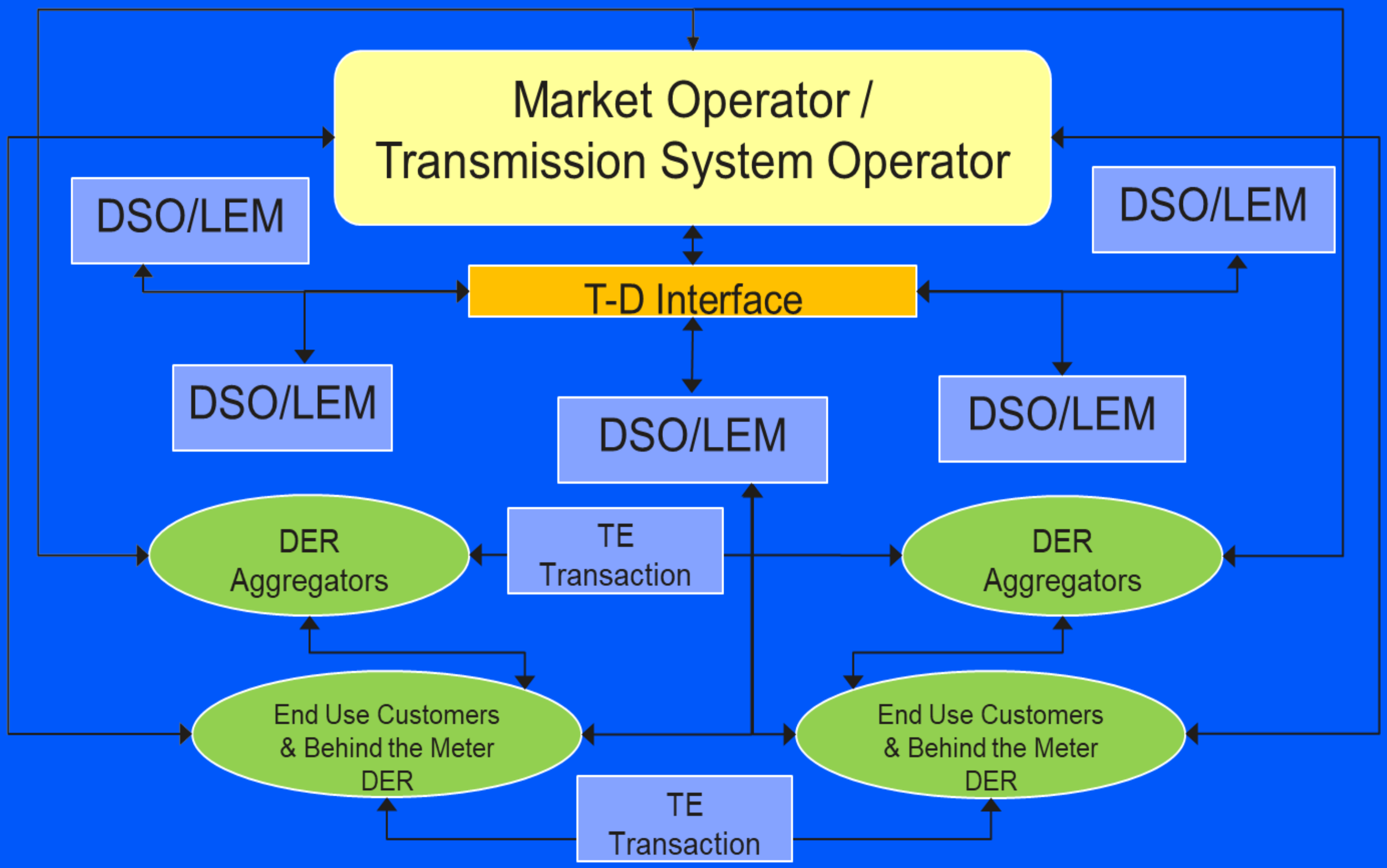
Major Energy Transition Challenges

- Massive penetration of a very large number of small assets at edge grid – DERs, EVs, Storage, Demand Response, RES to enhance the energy transition
- Transition to a zero marginal cost energy mix
- Get the prices right (non-convexities)
- Balancing the system (reliability) & RES curtailments
- Missing money problem through capacity markets or effective scarcity pricing or a combination of both
- Long Term markets & hedging
- Need for a resilient energy infrastructure
- Emergence of hierarchical multi-tier energy markets

Hierarchical Multi-Tier Energy Markets

- Wholesale Energy Markets (MOs/TSOs/ISOs)
- Distribution Energy Markets (DSOs)
- Local Energy Markets (LEMs)
- Markets Behind The Meter (BTM)
- Transactive Energy Markets

The Hierarchical Energy Market Architecture



ISOs/TSOs: Basic Market Design Elements

- Forward/DAM Market, Mitigation & Reliability Process
- Transmission & Ancillary Services Markets
- Real-Time Markets
- Financial Transmission Rights (FTRs)
- Capacity Markets
- Virtual Trading Markets

EU Energy Crisis: Politicians' Comments

"We still have an electricity market that is designed in a way like it was necessary twenty years ago before we started to bring in the renewables. Today, the market is completely different and the system does not work any more." Ursula von der Leyen, 8 June, 2023

"People are being charged for their electricity prices on the basis of the top marginal gas price, and that is frankly ludicrous. We need to get rid of that system." Boris Johnson, 25 June 2022

"You have skyrocketing electricity prices that no longer have anything to do with electricity production costs, it follows gas, it's absurd" Emmanuel Macron, 28 June 2022

Energy Reforms of the Target Model Architecture

Zonal vs Nodal Market Architecture

- Facts from Fiction and the Misplaced Fear for Transition to Nodal
- **Fact:** A single transmission constraint in an electric network can produce different prices at every node
- **Fiction:** We can avoid the complications of dealing directly with nodal pricing by aggregating nodes with similar prices into a few zones; this will provide a foundation for a simpler competitive market structure
- The real impact of zonal pricing is to create more administrative rules, poorer incentives for investment, arbitrary decisions on behalf of the TSOs to manage security constraints, demands to pay generators not to generate power (the famous "DEC" game in the US before the transition to nodal), and proposals to "socialize" the re-dispatch costs by using the taxing power of the TSO

Rebuttal of EU's False Arguments

- **Market Power** (The INC-DEC game is rampant in zonal markets)
- **REBUTTAL:** In nodal market we have the ex-ante market power mitigation)
- **Barriers to unlock flexibility** (No continuous intraday trading, No Demand Response and Storage Under Central Dispatch, No topology changes)
- **REBUTTAL:** continuous trading is possible even though auctions are preferrable, DR/Storage has been implemented in nodal markets and topology changes are possible even though are less useful in nodal markets)

Rebuttal of EU's False Arguments

- **Market Liquidity:** Nodal markets are not liquid
- **REBUTTAL:** Trading in nodal markets occurs in hubs (not nodes); the PJM West Hub is the most liquid market in the world
- **Complexity:** Nodal markets are very complex
- **REBUTTAL:** Euphemia is severely challenged in terms of computational complexity with 40 bidding zones; in contrast, PJM clears a wholesale market consisting of 11,000 nodes
- **CONCLUSION:**
- The switch to a nodal design should be one of the highest priorities in EU energy markets to foster the energy transition

Unified Market vs Bifurcation of Markets

- **<u>Bifurcation of the DAM into two markets</u>**
- one for RES, hydro and nuclear and
- the other for coal and gas
- <u>A terrible idea</u>
  - It kills the market signal and the inframarginal rents
  - It kills the maximization of social welfare and creates huge regulatory and investment uncertainty
  - Increases the cost of capital
  - Provides disincentives for long-term PPAs and Forward Markets

Self-Scheduling vs. Central Dispatch Architectures

- The **central dispatch design** based on a Unit Commitment formulation (like in Greece, Italy, Poland, etc.) finds the least-cost commitment and dispatch of a set of generating units to meet expected load
- Commitment costs are not part of the market pricing and it is possible that the market revenues of generators may not be sufficient to recover their costs
- This issue is resolved by all TSOs by means of 'make whole' payments (incentive compatibility problem)
- The **self-scheduling market design** on the other hand due to generator nonconvexities, network externalities, and other complexities of power systems, can suffer from both **efficiency losses and higher settlement costs**
- In summary, **self-scheduling results in suboptimal market solutions and higher costs**

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Long Term Market and CfDs

- We strongly support long term contracts with CfDs
- Our analysis show that the current design of CfDs in EU markets impacts negatively the optimal dispatch because generators get paid based on physical volume produced (even when prices are below their marginal costs) and may significantly reduce the liquidity of forward markets
- We analyzed various structures (CfDs with increased price exposure, CfDs with revenue caps and floors, capability-based CfDs, etc.)
- **We recommend the adoption of CfD variants with increased price exposure and the Capability-based CfDs**

Capacity Market Design

- Capacity markets are more important than ever
- We analyzed various design architectures, including bilateral markets, capacity optimized auctions, centralized reliability options and targeted tenders
- We strongly support capacity auctions with centralized reliability options

$$\text{Payoff function: } (\lambda - C) \cdot p - \max(\lambda - K, 0) \cdot x$$

- Strike price, K, should be set at high levels to ensure generators can cover their costs during scarcity conditions
- In EU markets the strike prices is set administratively
- We do not support price floors because it imposes costs to buyers (ISONE)

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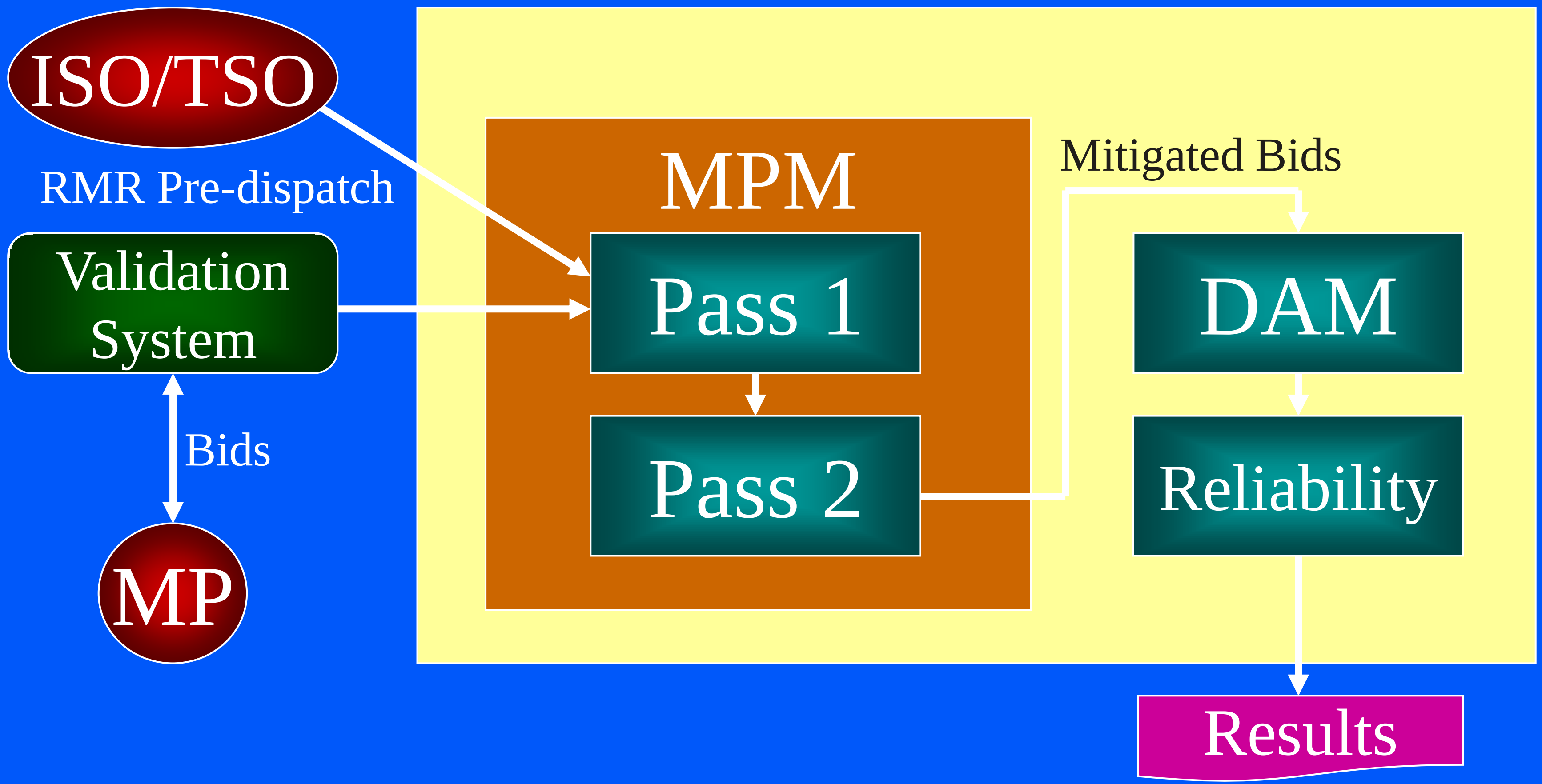
Market Competition & Market Power Mitigation



Optimal Energy Market Design Architecture

- Nodal LMP energy market option
- Unified energy market auctions (no technology based bifurcation)
- Unit based central scheduling/dispatch with bid-based Security Constrained Unit Commitment (SCUC)
- Marginal Pricing
- Co-optimization of energy and ancillary services
- Long term contracts with increased price exposure CfDs and capability based CfDs
- Centralized capacity auctions with reliability call options
- Ex-ante market power mitigation mechanisms
- Price shock absorbers for emergency conditions and market failures

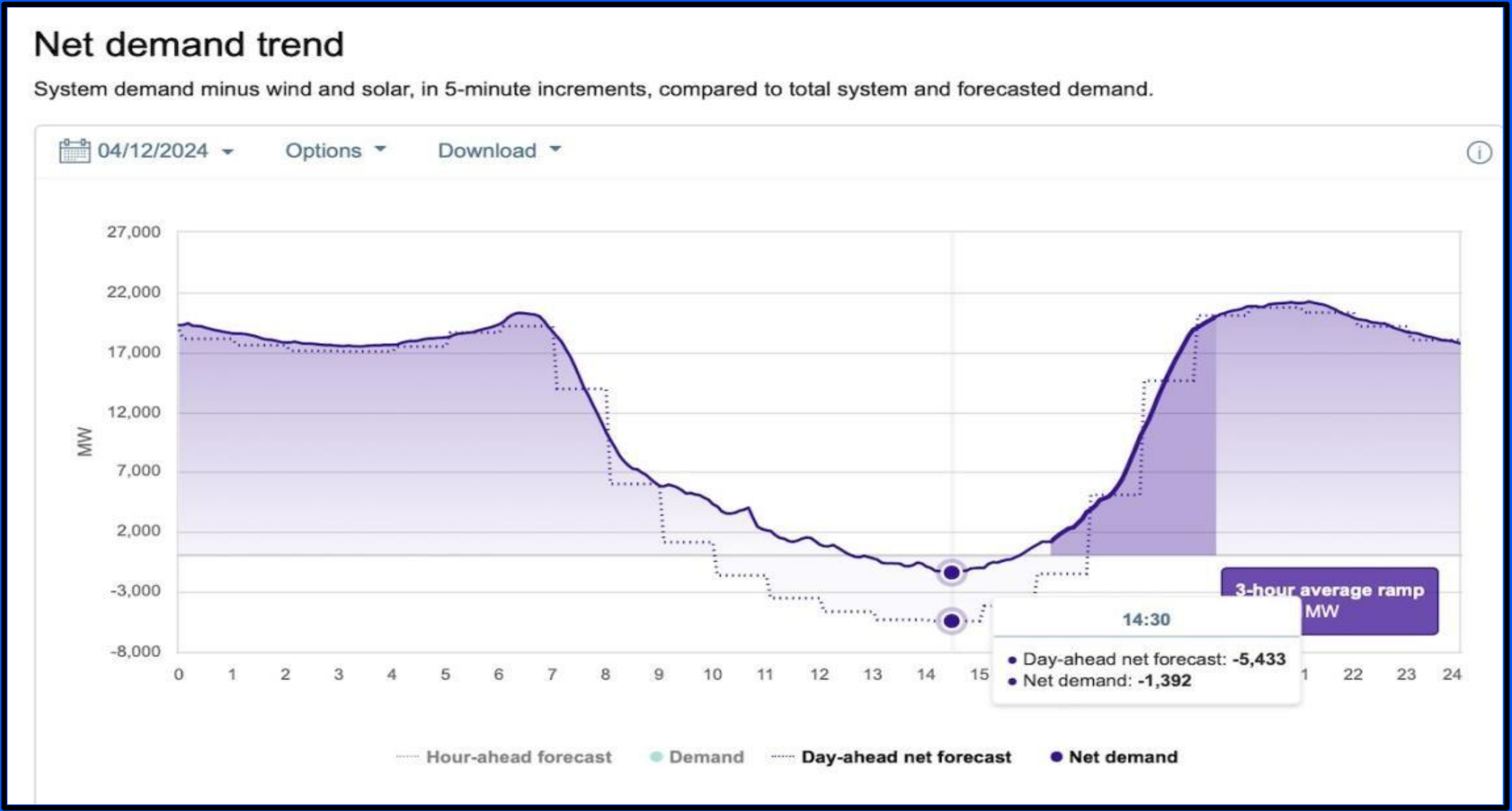
Problem Size

- Time Horizon: 1 day, 24 increments
- Network model: 6,000 buses, 10,000 lines
- Number of Generators: 1,500
- Number of Constraints: 1,500,000
- Number of Controls: 150,000
- Performance: 7 minutes!!

Renewable Energy based Systems with Zero Marginal Cost Generation

- Challenges in Renewable Energy based systems include increased:
  - Congestion (will increase) – nodal market architecture is a must
  - Uncertainty (will increase) – revisit AS design; include ramping and address reliability externality cost-causation issues (the "polluter" pays)
  - Reliability challenges – balancing – RES curtailments
  - Non-convexities (will increase) – this is a long-standing issue that will be aggravated (frequent switching of units, more hours in technical minimum generation)

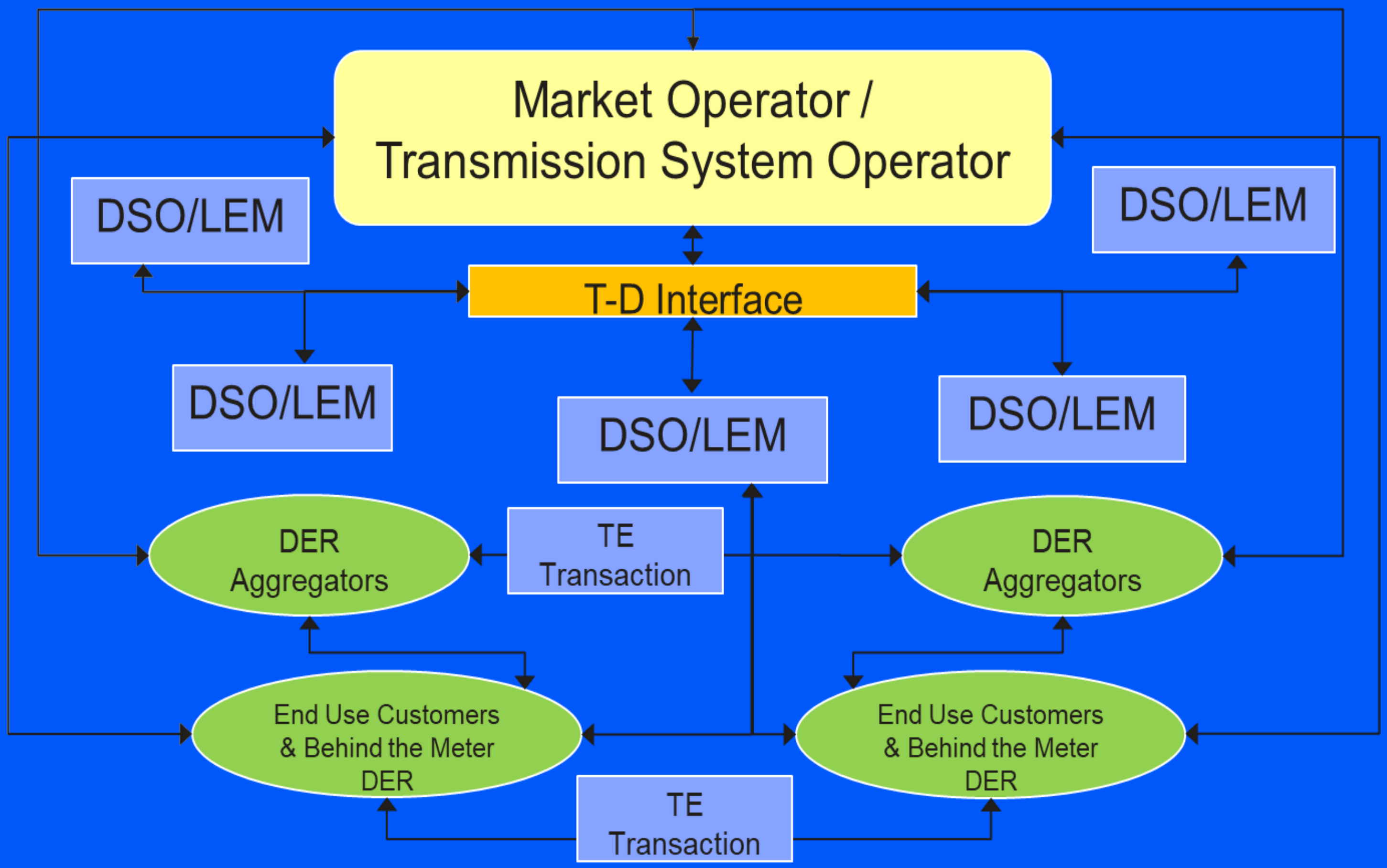
CAISO: Negative Net Peak Demand April 12, 2024: 12:45 p.m. to 3:40 p.m



Renewable Energy based Systems with Zero Marginal Cost Generation

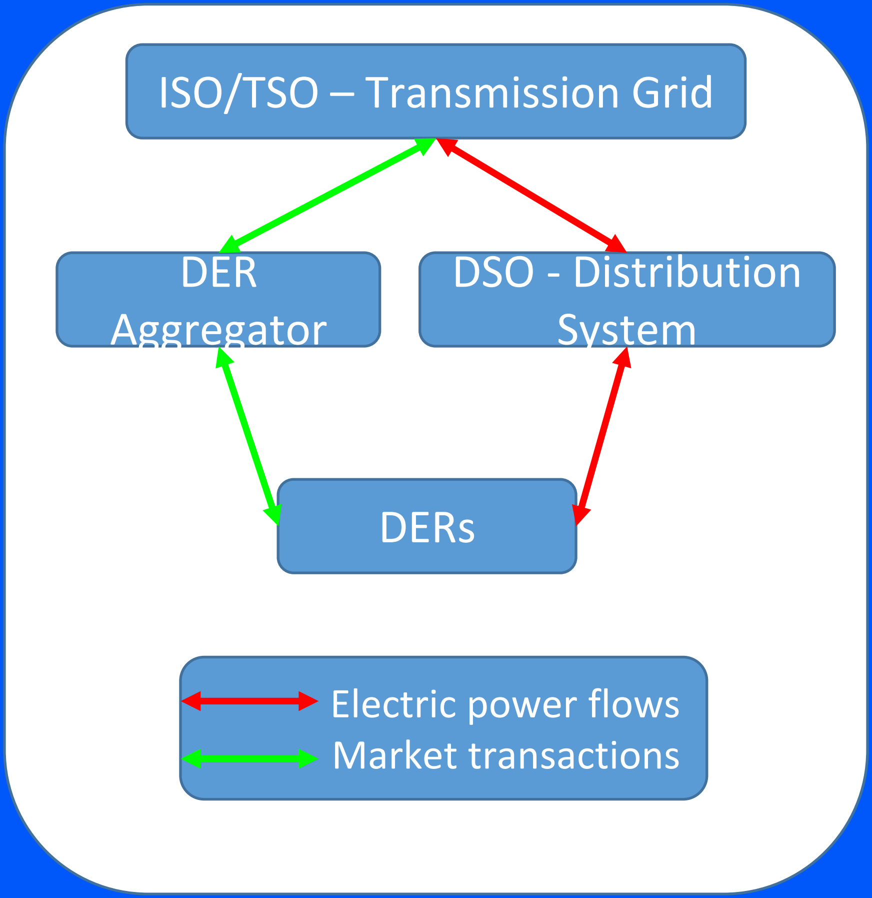
- Approaches such as **Integer Relaxation**, **Average Incremental Cost**, **Convex Hull pricing** are all compatible with marginal pricing to deal with non-convexities
- **Integer Relaxation** is a "proxy" Convex Hull pricing
- **Average Incremental Cost** adds on the LMP component to eliminate make-whole payments
- **Convex Hull pricing** derives the marginal cost in a "convexified economy" (obtained from a convex combination of feasible schedules) and supports the market solution with minimum uplift

The Hierarchical Energy Market Architecture



Tier Bypassing & TSO/DSO Coordination (FERC Order 2222)

- DER Aggregator is the single point of contact responsible for managing, dispatching, metering and settling the individual DERs in an aggregation
- ISO apply non-performance penalties to DERA due to DSO/DNO override
- Allow DERA as geographically broad as technically feasible -- to allow multi- node DERAs
- Under FERC Order 2222 market transactions bypass the distribution system, where electric power must flow to move between DERs and the transmission grid
- This tier bypassing creates a coordination gap between TSOs & DSOs



ISO/DSO Coordination Framework

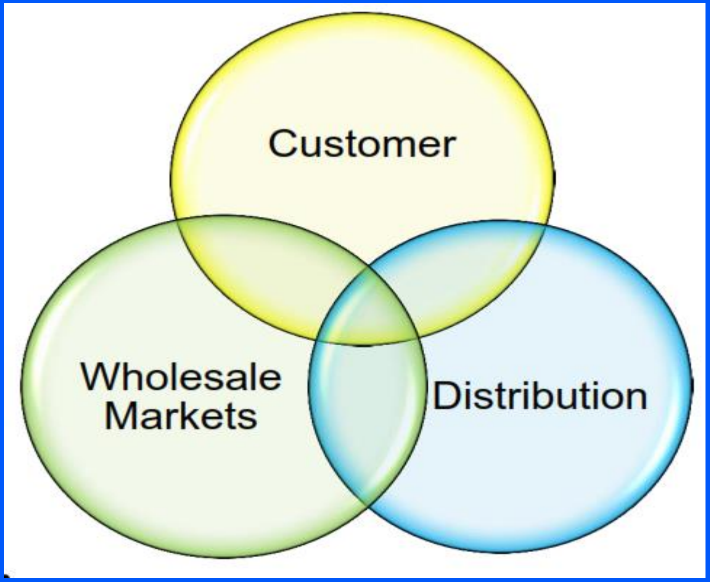
- Coordination protocols between the ISO/TSO and the DSO in all timeframes from technical and market perspective is required
- The coordination should take into account at the minimum a) congestion and other market data at the TSO level, b) voltage support, c) grid balancing, d) black start, e) protection, f) islanding, etc .
- The coordination protocols should take into account the business model of the DSO (minimum vs. maximum role)
- Wholesale market prices should be incorporated in the computation of the Distribution LMPs

Nodal DER Market Development Process

- We follow the same general approach we adopted in implementing wholesale markets – with some major differences
- We overlay the economic model (MILP where offers and bids are housed) on a distribution power flow
- Offers and bids are submitted by DER aggregators and the market clears through an iteration process between the economic model and the distribution power flow (asymmetric, meshed or radial)
- Distribution LMPs are produced along the feeder (3 DLMPs for each phase of each node– these reference prices will be deployed to allow trading for transactive energy, Nodal DLMP DER and ISO/TSO markets
- ISO LMP prices are used as an input to the market clearing of the Nodal DER market

Multi-Tier Market Participation

Time of Use Bill Management
Demand Charge Reduction
Back-up Power
Increased solar self-consumption
Located Behind the Retail Meter (BTM)



Energy
Capacity markets
FCR/aFRR/mFRR
Reserve Resource
Ramping
Located IFOM or BTM

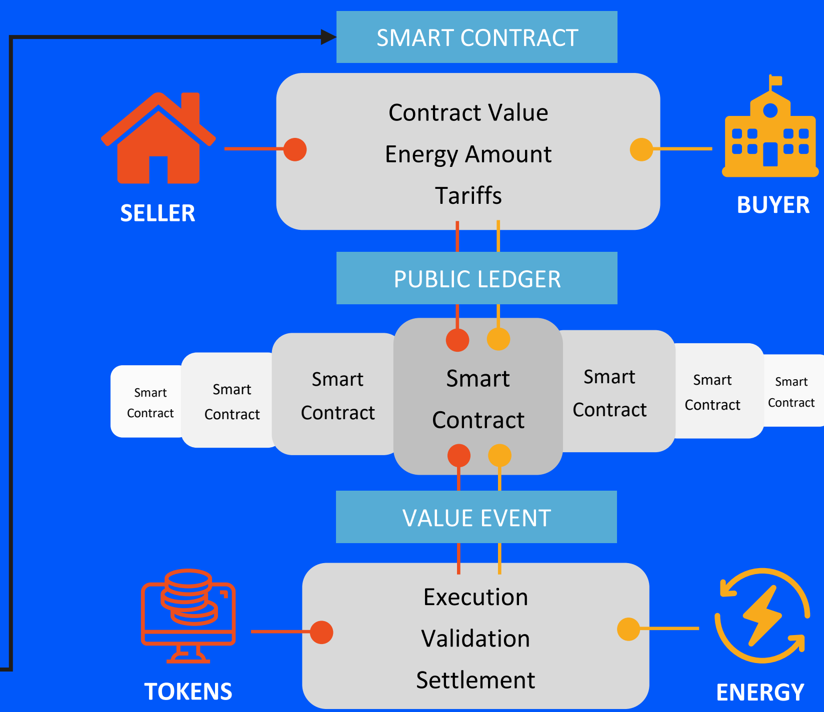
Distribution Asset Deferral
Reactive Supply
Voltage Control
Frequency Response
Islanding
Located BTM or IFOM

* Rocky Mountain Institute

Transactive Energy and Blockchain

TRANSACTIVE ENERGY

BLOCKCHAIN



Key Messages

- The emergence of hierarchical multi-tier energy markets is a reality and a requirement for the **energy transition** to a decarbonized economy
- The energy transition has created challenges to competitive energy markets with the massive penetration of zero marginal costs grid assets close to the customers
- It requires courageous political and regulatory policies, and different business models that create new potential revenue sources for DER assets
- The action has shifted from the wholesale ISO/TSO markets to distribution DSO markets
- Unfettered participation in hierarchical multi-tier energy market is needed for maximize the value of DERs to the grid and provide strong price signals
- New market products and services are needed for **flexibility and balancing** of the grid
- **The optimal energy market design is based on nodal, with full grid representation, bid and unit-based central scheduling and dispatch with co-optimization of all complementary market products**
- Location is important for DER valuations and DSO markets should include distribution constraints and produce prices that reflect locational effects

Key Messages

- Unlike the first two waves of competitive energy market reform, the development of the DER market is not motivated by efficiency considerations but rather by customer choice and a socio-economic movement toward “democratization” and “digitalization” of the grid
- Integration of DERs requires substantial investment in the distribution system to allow multidirectional flows and eventually, Peer-to-Peer transactions
- New business models that accommodate DER Aggregators and Virtual Power Plants are evolving
- The utility business model will change to be a provider of backup supply service and energy insurance and a platform for Peer-to-Peer energy trading and for network interconnections
- The hierarchical multi-tier energy market train is out of the station so the key question should be not why move to such a market but rather how to do it in a way that will continue to provide reliable service and affordable prices

Questions?