Integrating Renewables and Distributed Energy Resources into California’s Electricity Markets

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California ISO by the numbers

- **65,300 MW** of power plant capacity (net dependable capacity)
- **50,270 MW** record peak demand (July 24, 2006)
- **27,500** market transactions per day
- **26,000** circuit-miles of transmission lines
- **30 million** people served
- **235 million** megawatt-hours of electricity delivered annually
California’s electricity market system consists of two essential components.

**CAISO spot markets**
- Locational marginal prices (LMP) at 2500+ network nodes
- Day-ahead hourly markets for transacting wholesale energy (including imports & exports), procuring ancillary services & scheduling transmission service
- 15-minute day-of markets for energy, AS, transmission service
- 5-minute real-time dispatch for balancing, contingency dispatch
- Year- & month-ahead markets for financial transmission rights

**Resource Adequacy (RA) requirements**
- Administered by CPUC & municipal regulatory authorities
- Require each load-serving entity to procure sufficient capacity to meet its share of peak system load – with local & flexible portions
- Procured RA capacity must offer into CAISO markets
Energy Imbalance Market enhances west-wide coordination.

- **EIM incorporates 15-minute day-of market & 5-minute real-time dispatch**
- **Supports renewables integration through**
  - geographic diversity of resources
  - sharing of flexible capacity & reserves
  - reduction of unscheduled real-time flows
Renewable solar & wind generation are changing grid conditions & operating needs

- High solar production creates net load “duck curve” => low net output mid-day & steep ramp up to early evening peak
- “Over-generation” when output of renewables + base load + flexible gen at min load exceeds system load => negative spot prices
- Operational needs now emphasize “flexible” capacity, based on speed & duration of ramping capability
  - Flexible capacity requirement adopted by CPUC as part of RA program
  - CAISO developing flexible ramping product for day-ahead & real-time procurement => Fall 2016 implementation
- Latest preliminary CEC long-term forecast indicates rate of solar self-generation may be 3 times what was forecast in 2013
A recent event surpasses original estimate of net-load with higher solar generation.

Typical Spring Day

Net Load 14,160 MW on April 5, 2015 at 15:46
Negative energy prices indicating over-generation risk start to appear in the middle of the day.

Increasing frequency of negative real-time energy prices reveals over-generation in the middle of the day.
Statewide PV Self-Gen Peak Impacts

All 3 scenarios above CED 2013 Mid Case. Impacts range between 4,500 MW to 5,400 MW and correspond to installed capacity of 12,000 MW to 14,000 MW.
What are “distributed energy resources” (DER)?

DER include all energy resources connected at distribution level of the electric system, on customer side or utility side of the customer meter

- EE, DR, DG (rooftop & grid-connected), storage systems (battery, thermal, etc.), electric vehicle charging, CHP, BUG

Plus communications & control systems to combine or aggregate DER and optimize their use

- Consumers => “prosumers”
- DER aggregated into “virtual” resources
- Smart buildings & campus microgrids
- Community microgrids
- Smart cities, convergences of municipal services
What factors are driving DER proliferation?

1. **Bottom-up demand & adoption: customers want them**
   - Individual customers want more flexibility & control
   - Many customers want to participate in wholesale markets, individually or through aggregators
   - Local resilience is an increasing concern driving microgrid formation (Superstorm Sandy effect)
   - Cities & counties explore synergies among municipal services; want to implement climate action plans, make renewable energy available to renters & underserved communities

2. **Top-down policy directives: policy makers target DER to support environmental & energy policy goals & enhance system security**

3. **DER technologies continue to get cheaper & more powerful**
Drivers of change are moving the industry toward an “integrated decentralized” structure.

**Decentralized** network of local distribution systems (D) at each T-D substation

- Local energy production & “self-optimization” to meet local needs
- Capable of islanding in case of system disturbance

**Integrated** via interfaces to transmission grid & wholesale market

- Wholesale energy trading & access to distant renewable generation
- Provision of services to the ISO/TSO (balancing energy, reserves, voltage support, frequency response)
Several models exist for DER & DER aggregations to participate in ISO markets.

- **Proxy Demand Resource (PDR)**
  - Supplier can aggregate multiple end-use customers to create a virtual DR resource
  - May involve other DER types behind customer meter, but cannot result in net energy injection to the system

- **Non Generator Resource (NGR)**
  - Designed for a resource that can vary between consuming & producing energy (e.g., storage)

- **DER Provider (DERP)**
  - New ISO structure for an entity to aggregate any types of DER for ISO market participation

- **Energy Storage & Aggregated DER (ESDER)**
  - New ISO initiative to clarify & expand existing provisions for DER & grid-level storage to participate
What will high-DER penetration likely mean for electric distribution systems?

• Diverse end-use devices & facilities with diverse owners/operators – many subject to ISO dispatch – will dramatically change:
  o Net end-use load shapes, peak demands, total energy
  o Direction of energy flows, voltage variability, phase balance
  o Variability & predictability of net loads & grid conditions
  o Retail kWh volumes & revenues

• Traditional distribution system paradigm – passive one-way kWh delivery from central power plants to end-use customers – is becoming outmoded

• Distribution utilities need new capabilities for operations, DER coordination, infrastructure planning, interconnection procedures, & coordination with transmission system & wholesale markets

=> “Distribution System Operator (DSO)”
High-DER system will evolve in stages.

1. “Grid Modernization”
   - Low DER adoption – can be accommodated by existing system without enhancing infrastructure, operations or planning
   - Some new planning studies useful to facilitate greater DER expansion – hosting capacity, locational value of DER

2. “DER Integration”
   - DER adoption level requires new operational capabilities – multi-directional flows, more volatile grid conditions
   - DER can provide benefits to the distribution utility => real-time operational services & infrastructure deferment

3. “Distributed Markets”
   - “Peer-to-peer” transactions between DER & customers
   - Requires distribution-level market structure, market services, & new regulatory framework; may be state regulated
High-DER requires re-thinking the T-D interface for the integrated decentralized system.

- T-D substation is traditional boundary between wholesale & retail markets; network versus radial topology & operations; federal & state regulatory jurisdiction
- High DER penetration creates new control & coordination needs
  - DER variability can create severe impacts on transmission system unless managed locally
  - ISO dispatches of DER impact distribution – ISO models DER at T-D substation & has no visibility to distribution grid conditions
- **Question:** What is the best way to structure roles & responsibilities of DSO & ISO with respect to the T-D interface?
  - Reliable, safe operation is essential
  - Must work as a whole system to achieve policy objectives
  - Must satisfy customer needs for choice, flexibility & resilience – the bottom-up drivers of change
Design alternatives can be described in terms of the relevance of the T-D sub-station as an operational, market & regulatory boundary.

- **Model A** – ISO optimizes the whole integrated system – models distribution system, sees DER at actual locations
- **Model B** – ISO optimizes the whole integrated system – but sees DER as if located at the P-node or T-D substation
- **Model C** – ISO optimizes only the transmission system – sees multiple aggregated or “virtual” resources at each P-node
- **Model D** – ISO optimizes only the transmission system – sees a single aggregated or “virtual” resource at each P-node

Relevance of T-D boundary

- **Total TSO/ISO**
- **Minimal DSO**
- **Market DSO**
- **Total DSO**
Conceptual distribution system operational models

1. Total TSO/ISO – Model A
   - ISO models & optimizes the whole system, with visibility to distribution grid conditions & all DER modeled at actual locations
   - DSO has minimal new functions, only to ensure safety & reliability

2. Minimal DSO – Model B
   - ISO optimizes whole system, but models DER at the T-D interfaces with little or no visibility into the distribution system
   - Requires new DSO capabilities to coordinate DER responses to ISO dispatches & utilize DER services to operate distribution system

3. Market DSO – Model C
   - Reduces complexity for ISO; DSO coordinates DER aggregators at each P-node; may create & operate local peer-to-peer markets

4. Total DSO – Model D
   - ISO sees a single “resource” at each T-D substation, optimizes to net interchange with DSO
   - DSO optimizes local system & operates market in the local area
   - DSO manages local variability locally, rather than export to ISO grid
Simple transaction schematics show key differences between models A-B-C versus model D (J. Taft, PNNL).
Grid architecture perspective favors Total DSO within a layered hierarchy of optimizing sub-systems.

- Each tier only needs to see interchange with next tier above & below, not the details inside other tiers.
- Repeatable structure respects tier boundaries.
- Layered control structure reduces complexity, increases system resilience & security.
- Fractal structure mimics natural ecosystems.

**Diagram Notes:**
- Regional Interconnection
- Balancing Area
- BA
- D = Local Distribution Area or Community Microgrid
- Micro-grid
- Smart building
- Smart building
Thank you.

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