Distribution Systems in a High Distributed Energy Resources Future: Planning, Market Design, Operation and Oversight

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Caltech Resnick Institute   California ISO

Objectives and Approach

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- Innovative series of LBNL reports designed to inform ongoing discussions and decisions by utility regulators, policymakers and the electric industry
- Point-counterpoint approach sharpens debate on tradeoffs in achieving multiple objectives—e.g., reliability, affordability, clean, flexibility
- Report authors are thought-leaders in electric industry
- Primary funder: DOE Office of Electricity Delivery and Energy Reliability – National Electricity Delivery Division
- Advisory Group (next page)
  - Recognized experts including state regulators, utilities, stakeholders and academia
  - Prioritizes topics
  - Reviews issues, evaluation criteria, approaches and draft reports

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- Peter Zschokke, National Grid

Reports Underway So Far

1. *Distributed Energy Resources (DERs), Industry Structure and Regulatory Responses.* Steve Corneli (NRG) and Steve Kihm (Seventhwave) https://emp.lbl.gov/publications/electric-industry-structu
2. *Distribution Systems in a High DER Future: Planning, Market Design, Operation and Oversight.* Paul De Martini (Newport Consulting Group) and Lorenzo Kristov (CAISO) https://emp.lbl.gov/publications/distribution-systems-high
3. *Performance-Based Regulation in a High DER Future.* Tim Woolf (Synapse Energy Economics) and Mark Lowry (Pacific Economics Group) – December 2015
4. *Distribution System Pricing for Distributed Energy Resources.* Ryan Hledik (The Brattle Group) and Jim Lazar (Regulatory Assistance Project) – December 2015
5. *Future of Resource Planning.* E3 and LBNL – March 2016
6. *Recovery of Utility Fixed Costs: Utility, Consumer, Environmental and Economist Perspectives.* LBNL, utility rep (TBD), John Howat (NCLC), Ralph Cavanagh (NRDC), Severin Borenstein (UC) – March 2016

About the authors

Paul De Martini is a Visiting Scholar at the California Institute of Technology and Senior Fellow with ICF International. His research and advisory work focuses on customer-centric business models, integration of distributed energy resources and grid modernization, drawing on his prior experience at Cisco and Southern California Edison. He also facilitates California's More Than Smart initiative and is an advisor to the New York Reforming the Energy Vision, Market Design & Platform Technology working group.

Lorenzo Kristov is Principal, Market and Infrastructure Policy, at the California Independent System Operator (ISO). He was a lead designer of the ISO's locational market pricing-based spot market system and led the redesign of the ISO's transmission planning and generator interconnection processes to support development of renewable generating facilities to meet California's renewable portfolio standard. He currently focuses on expanding market participation by distributed energy resources and planning for the operational and market impacts of a more decentralized future electric system.

Ideas in this presentation are offered for discussion purposes only and do not reflect the views or policies of the California ISO.

Why we wrote this report

- Growth in distributed energy resources (DERs) is driving an evolutionary process that is reshaping all aspects of electric service.
- DER growth raises a vast range of policy issues that may seem impossible to prioritize and appear to require resolution all at once, overwhelming regulatory bodies and processes.
- This report provides a practical framework for regulators to:
  - Understand and consider DER growth in their jurisdictions
  - Address its impacts in a manageable, logical sequence, and
  - Guide distribution system evolution with clear lines of sight to overarching public policy objectives.
- It is written for regulators in jurisdictions with already high or rapidly increasing levels of DERs, as well as those that only anticipate DER growth in the future and want to take measured, proactive steps forward.

What factors are driving DER proliferation?

1. Bottom-up demand & adoption: customers want them
   - Individual R/C/I 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, and make renewable energy available to renters & underserved communities
2. Top-down policy directives: policy makers recognize that DERs can support environmental & energy policy goals
3. DER technologies continue to get cheaper & more powerful

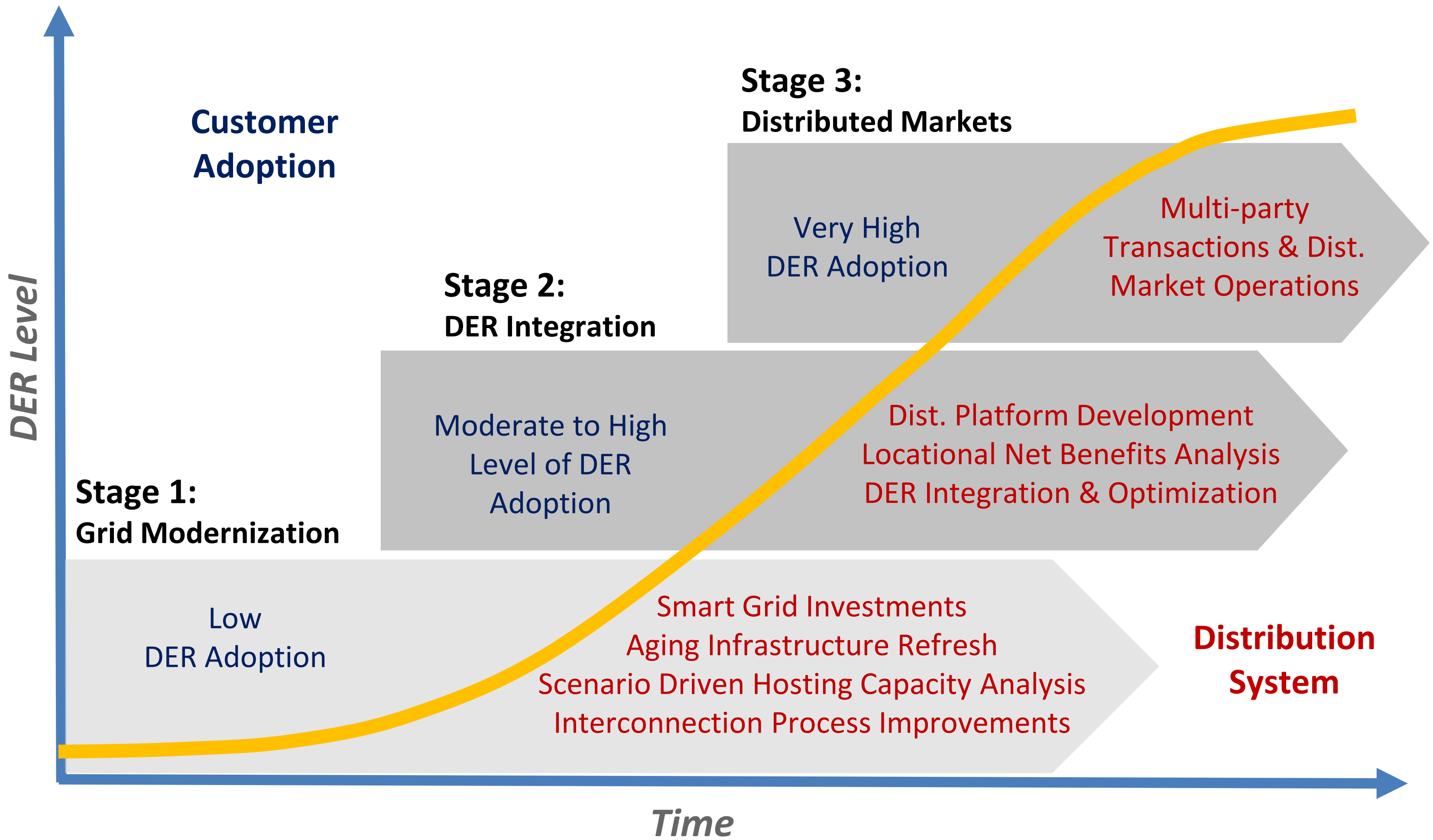
What will high DER penetration likely mean for electric distribution systems?

- From a purely operational perspective, diverse end-use devices & facilities with diverse owners/operators will dramatically change:
  - Net end-use load shapes, peak demands, total energy
  - Direction of energy flows
  - Variability & predictability of net loads & grid conditions
  - Not to mention kWh volumes & revenues
- Traditional distribution system function – passive one-way kWh delivery from central power plants to end-use customers – will be inadequate for a high DER future
- Distribution utilities will need new approaches for system operation, grid planning, interconnection procedures, and coordination with transmission system & wholesale markets

A framework to address the questions & issues in a manageable, logical sequence

- Focus on distribution system & UDC “wires” function of the utility
  - For this report, set aside retail load-serving functions, supply procurement, generation ownership, etc.
- Focus on what’s needed to provide reliable, safe operation of the distribution system & the T-D interface
  - Reliability & safe, efficient operation will always be essential, no matter how fast or slowly DER expansion unfolds
  - Consider what’s needed to facilitate & integrate DER expansion
  - Focus first on engineering studies, infrastructure planning, interconnection rules & procedures
  - Next consider DER service definitions & procurement mechanisms
- Set aside – initially – questions about new utility business models, organizational structures (DSO, DSP)

Stages of distribution system evolution



Stages of distribution system evolution

1. "Grid Modernization"
   - Low DER adoption – can be accommodated by existing system without enhancing infrastructure, operations or planning
   - Some new planning studies and review of interconnection rules and processes useful if greater DER expansion is anticipated
2. "DER Integration"
   - DER adoption level requires new operational capabilities – multi-directional flows, more variable grid conditions
   - DERs can provide system benefits => real-time operational services & infrastructure deferment for the distribution utility
3. "Distributed Markets"
   - "Peer-to-peer" transactions between DERs & customers
   - Requires distribution-level market structure, market services, & new regulatory framework; may be state regulated

Value of the Distribution Grid

Considerations:

Trends in the "economics of defection" plus increasing desire for local resilience raise the question, why stay connected?

- The electric system evolved from a microgrid (Pearl Street Station) into its current structure as a means of capturing the value of diversity and economies of scale that remain very relevant.
- Looking forward: The value of a multi-directional, transactive network increases in proportion to the number of interconnected entities/facilities.
- Discussions across U.S. focus on how to build upon the value of the current grid to capture the potential network benefits seen in other sectors.
- If grid defection occurs at scale, we will have failed from a societal perspective.

Value of the Distribution Grid

Three paths of grid evolution, in order of increasing value:

A. Current Path

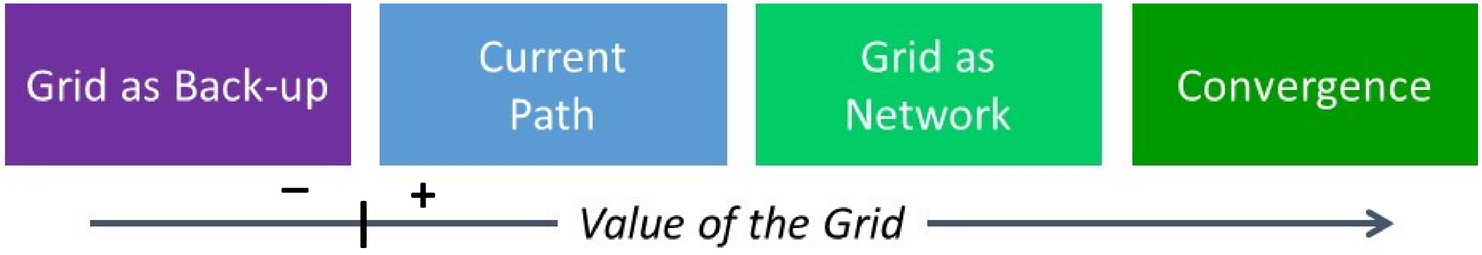
- Replace & upgrade existing infrastructure; add smart grid technology; incorporate new planning studies for DER

B. Grid as Enabling Platform

- Enable seamless integration of diverse DERs & independent microgrids; locate DERs for maximum system benefits; enable & facilitate peer-to-peer transactions

C. Convergence

- Electric distribution grid "converges" other energy, transport & municipal services; "smart cities"



Types of Distribution-level Markets

1. Wholesale energy and operational markets
   - DERs participate today in wholesale ISO/RTO markets; provide energy, capacity, ancillary services, infrastructure deferment
   - At larger penetration, DER wholesale participation will require enhanced coordination by the distribution operator
2. Distribution operational markets (distribution utility is sole buyer)
   - DER services may reduce distribution utility operating & capital expenses, and support renewables & DER integration
   - Voltage management, power quality, reliability & resilience, line-loss reduction, infrastructure deferment
3. Distribution-level energy market (many buyers)
   - Transactions among DERs, prosumers, customers
   - May be within a "local distribution area" (single T-D substation) & not rely on transmission grid, or between different local areas

Evaluating & choosing potential evolutionary paths for the future distribution system

1. High-level policy objectives
   - From DOE/PNNL 2015 “Grid Architecture” report: Safety, Robustness (reliability & resilience), Security, Affordability, Minimum environmental footprint, Flexibility (extensibility & optionality), Financeability (utility & non-utility assets)
2. System “qualities” needed to achieve objectives
   - Should be discrete, specific, quantifiable, able to be translated into specific functional capabilities the system must have

Reliability	Safety	Cyber-physical Security	Affordability	Environment	Finance-ability	Flexibility
Impact Resistance	Public Safety	Threat Detection & Mitigation	System Performance	GHG Reduction	Utility Credit Rating	Accommodate Tech Innovation
Minimal Recovery	Workforce Safety	Access Control & Data Protection	OpEx Management	Criteria Pollutants	DER Asset Finance	Accommodate New Busn Models
Operational Risk Management	Fail Safe Modes	Physical Security	Asset Optimization	Nexus w/Gas, Water & Transp.	Venture Capital Funding	Open & Interoperable

Source: Paul De Martini 2014, “More Than Smart”

Stage 1 Distribution system functions

- Integrated distribution system planning
  A. Scenario-based, probabilistic planning studies
     - Scenarios capture range of DER growth over planning horizon
     - Probabilistic methods model DER behavior impacts on grid
  B. Enhanced interconnection studies & processes
  C. Hosting capacity = maximum DER penetration consistent with reliable & safe grid operation (per feeder from T-D substation)
  D. Locational net value of DER (see table next slide)
     - Operating or capital expense reduction net of system costs
     - Locational customer & societal benefits
     - Assessed at T-D or D substation, feeder, or feeder segment
  E. Integrated T & D planning
     - E.g., iterative approach where results of one are input to the other
     - Degree to which DER variability is exported to T-system, or managed locally by distribution operator

Potential DER value components

Source: California's More Than Smart working group

	Value Component	Definition
Wholesale	WECC Bulk Power System Benefits	Regional BPS benefits not reflected in System Energy Price or LMP
	System Energy Price	Estimate of CA marginal wholesale system-wide value of energy
	Wholesale Energy	Reduced quantity of energy produced based on net load
	Resource Adequacy	Reduction in capacity required to meet Local RA and/or System RA
	Flexible Capacity	Reduced need for resources for system balancing
	Wholesale Ancillary Services	Reduced system operational requirements for electricity grid reliability
	RPS Generation & Interconnection Costs	Reduced RPS energy prices, integration costs, quantities of energy & capacity
	Transmission Capacity	Reduced need for system & local area transmission capacity
	Transmission Congestion + Losses	Avoided locational transmission losses and congestion
	Wholesale Market Charges	LSE specific reduced wholesale market & transmission access charges
Distribution	Subtransmission, Substation & Feeder Capacity	Reduced need for local distribution upgrades
	Distribution Losses	Value of energy due to losses bet. BPS and distribution points of delivery
	Distribution Power Quality + Reactive Power	Improved transient & steady-state voltage, harmonics & reactive power
	Distribution Reliability + Resiliency	Reduced frequency and duration of outages & ability to withstand and recover from external threats
	Distribution Safety	Improved public safety and reduced potential for property damage
Customer & Societal	Customer Choice	Customer & societal value from robust market for customer alternatives
	Emissions (CO2, Criteria Pollutants & Health Impacts)	Reduction in state and local emissions and public and private health costs
	Energy Security	Reduced risks derived from greater supply diversity
	Water & Land Use	Synergies with water management, environmental benefits & property value
	Economic Impact	State or local net economic impact (e.g., jobs, investment, GDP, tax income)

Distribution system operations

A. Design-build & ownership of distribution grid

B. Switching, outage restoration, grid maintenance
   - Fundamental safety & reliability responsibilities
   - More complex reliability functions are needed with diverse DERs, prosumers & multi-directional flows
   - Seamless islanding & reconnection of microgrids

C. Physical coordination of DER schedules & dispatches
   - Use of DERs for real-time reliability services, through dispatches or automated controls by the distribution operator

D. Coordination with transmission/wholesale at T-D interface
   - Support DER participation in wholesale markets
   - Assess pros & cons of managing DER variability at the local level (local real-time balancing) versus exporting variability to the transmission grid

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Distribution markets & market services

A. Sourcing distribution grid services
   - Define needed services & their performance requirements
   - Procure DERs to provide the services (RFO, contracts)

B. Dispatch of DERs providing grid services
   - Utilize DERs in real-time to support reliable operation

C. Aggregation of DERs for wholesale market participation
   - Who is eligible to do this: load-serving entities, independent aggregators, distribution operator?

D. Creation & operation of distribution-level energy markets
   - What is optimal degree of temporal & locational price granularity? Consider "diminishing returns to complexity"

E. Clearing & settlements for inter-DER transactions

F. Other possible market facilitation services
   - Facilitate bilateral markets; provide park & loan energy service

Functional evolution across the 3 stages

Distribution Functions	Stage 1	Stage 2	Stage 3
1. Planning			
A. Scenario based, probabilistic distribution engineering analysis	✓	✓	✓
B. DER Interconnection studies with new criteria	✓	✓	✓
C. DER Hosting capacity analysis	✓	✓	✓
D. DER Locational value analysis		✓	✓
E. Integrated T&D planning		✓	✓
2. Operations			
A. Design-build and ownership of distribution grid	✓	✓	✓
B. Switching, outage restoration & distribution maintenance	✓	✓	✓
C. Physical coordination of DER schedules		✓	✓
D. Coordination with ISO at T-D interface		✓	✓
3. Market			
A. Sourcing distribution grid services		✓	✓
B. Optimally dispatch DER provided distribution grid services		✓	✓
C. Aggregation of DER for wholesale market participation		✓	✓
D. Creation & operation of distribution level energy markets; transactions among DER			✓
E. Clearing and settlements for inter-DER transactions			✓
F. Market facilitation services			✓

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Focus on the T-D interface

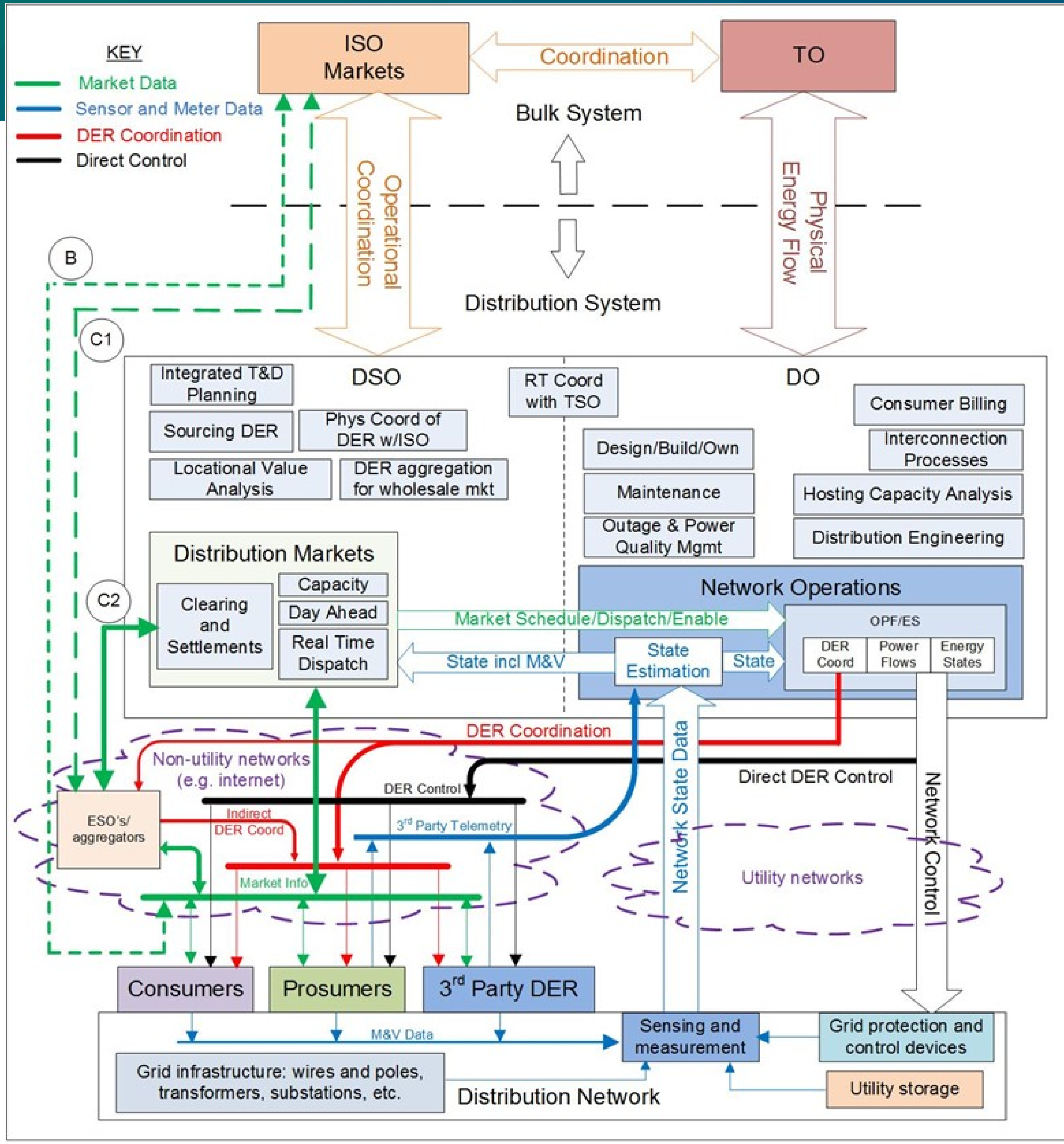
- Boundary between wholesale & retail markets; between meshed high-voltage network & radial, lower-voltage feeders; between federal & state regulatory jurisdiction
- With high DER penetration, DERs participate in wholesale market & may also provide services to the distribution system (Stage 2)
- DER & customers/prosumers may also transact in distribution-level energy markets (Stage 3)
- Question: What is the best way to structure roles & responsibilities of distribution system operator (DSO) and transmission/wholesale market operator (e.g., ISO)?
  - Reliable, safe operation is essential
  - Whole system should achieve policy objectives efficiently
  - Customer needs & demands – bottom-up drivers of change – must be satisfied

Three conceptual distribution system operational models (1)

1. Total ISO – Model A
   - ISO models & optimizes the whole system, from BAA level down to distribution circuits, with visibility to distribution grid conditions & all DER above a low size threshold (0.5 MW) modeled at actual locations
   - DSO has minimal new functions, only to ensure safety & reliability
   - Interesting concept, but not practical, due to operational complexity, system control challenges, & regulatory jurisdiction issues
2. Minimal DSO – Model B
   - ISO optimizes whole system, including large numbers of small DERs, but models DERs at the T-D interface with little or no visibility into the distribution system
   - DSO has significant coordination role, to manage DER responses to ISO dispatches as well as DER services provided to distribution grid
   - Requires substantial increased capability of the DSO, including procurement of DER services
   - Likely to be an effective model for Stage 2 evolution

Three conceptual distribution system operational models (2)

3. Market DSO – Models C1 & C2
   - Maximizes DSO role in operational coordination, to minimize the complexity for the ISO optimization
   - Model C1 – ISO sees only a small number of aggregate DERs at each T-D interface; DSO is the coordinator of the aggregators
   - Model C2 – ISO sees only one resource at each T-D interface; DSO is the aggregator for all DERs below that interface
     - Allows DSO to manage load & DER variability, balance supply & demand within each local area (below a single T-D substation), schedule “interchange” with the ISO at the substation
     - DSO essentially optimizes its local system, so that ISO only has to optimize its system up to the interchange at the substation
   - In Stage 3 the Market DSO (either C1 or C2) takes on the market creation & operation role to enable peer-to-peer transactions
     - Otherwise under Minimal DSO the distribution-level market would have to be operated by the ISO or a third party


KEY
Market Data
Sensor and Meter Data
DER Coordination
Direct Control
ISO Markets
Coordination
TO
Bulk System
Operational Coordination
Physical Energy Flow
Distribution System
B
C1
C2
DSO
DO
Integrated T&D Planning
Sourcing DER
Phys Coord of DER w/ISO
Locational Value Analysis
DER aggregation for wholesale mkt
RT Coord with TSO
Consumer Billing
Interconnection Processes
Design/Build/Own
Maintenance
Hosting Capacity Analysis
Outage & Power Quality Mgmt
Distribution Engineering
Distribution Markets
Clearing and Settlements
Capacity
Day Ahead
Real Time Dispatch
Network Operations
Market Schedule/Dispatch/Enable
OPF/ES
DER Coord
Power Flows
Energy States
State incl M&V
State Estimation
State
DER Coordination
Non-utility networks (e.g. internet)
DER Control
Direct DER Control
Network State Data
Network Control
ESO's/ aggregators
Indirect DER Coord
3rd Party Telemetry
Market Info
Utility networks
Consumers
Prosumers
3rd Party DER
Sensing and measurement
Grid protection and control devices
M&V Data
Grid infrastructure: wires and poles, transformers, substations, etc.
Distribution Network
Utility storage

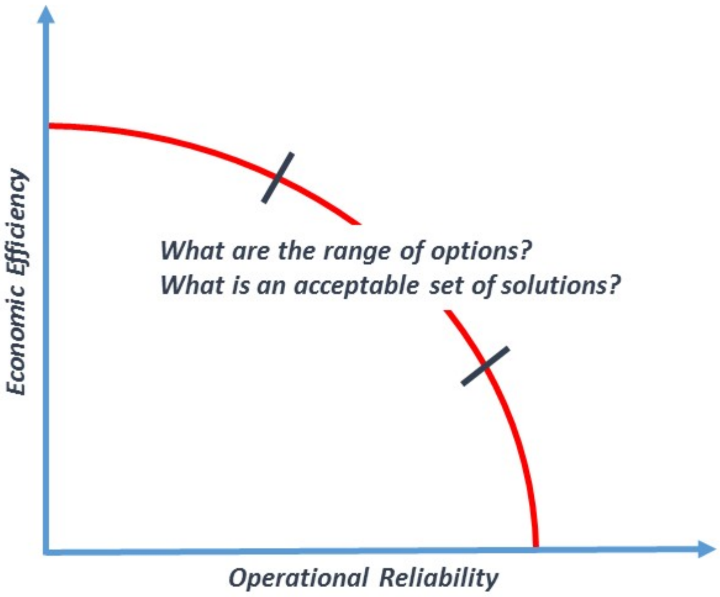
Architectural Considerations

DSO design involves key trade-offs, such as reliability vs. economic efficiency

Physical operation.
Design choices must respect the laws of physics and align with the physical grid, while achieving environmental goals. This set of issues derives from the fundamental question of how to plan and operate a high-DER, renewables-based electricity system so as to ensure affordability, reliability, resilience and safety.

Economic efficiency, market design, open access.
DER services need to be defined, and their performance requirements, measurement rules and mechanisms for procurement and compensation specified. This category also includes rules for interconnection of new resources, whether principles of "open access" should apply and, if so, how are they specified.

Institutional structure, business models.
Questions like whether the distribution system operator should be fully independent of the distribution asset owner, and the net customer benefits of distribution service in the high DER system.



A structured sequence for addressing distribution system evolution

1. Step 1: physical capability & operation of the distribution system
   - High-level policy objectives => desired system qualities => required functional capabilities
   - Focus first on grid planning & operation for safety & reliability
2. Step 2: market structures & market development
   - Design the tools to fully realize DER value – communications & control systems, markets, rates, programs, compensation …
     - A market is a tool, not an objective
   - Goal is to reduce T/D operating costs & challenges, create net benefits for all customers, and enable robust customer choice
   - Requires market & regulatory framework to procure effective & reliable DERs to meet specific grid needs
3. Step 3: organizational structure for realizing policy objectives
   - DSO/ISO roles; plus the things we set aside at the beginning

Suggested principles for policy makers & regulators

1. Start with clear statements of state & local policy objectives
2. Begin the design process by addressing safe & reliable operation
3. Further design decisions will depend on the current & desired future stage of evolution in the given jurisdiction
   - Desired future stage should be linked clearly to policy objectives
   - Feasibility of achieving a desired stage by a certain time depends on available resources, customer mix, regional & local needs, climate …
4. Given the significance of bottom-up drivers – customer demands & technological possibilities – there are limits to the ability to control the pace & extent of evolution => be adaptable
5. Given the differing needs of different local jurisdictions, system must exhibit high-level whole-system integration while allowing for bottom-up diversity of implementation => architectural approach
6. Electric service should be considered in the context of its uses in society; for example, convergences of electric service with other essential infrastructure and municipal services to achieve whole-system synergies

Additional resources

- Steve Corneli and Steve Kihm, “Electric Industry Structure and Regulatory Responses in a High Distributed Energy Resources Future,” Future Electric Utility Regulation Report No. 1, Lawrence Berkeley National Laboratory: https://emp.lbl.gov/future-electric-utility-regulation-series
- California PUC proceeding on Distribution Resources Plans (R.14-08-013)
  – OIR issued August 2014 (includes “More Than Smart” by Paul De Martini as Appendix B): http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M103/K223/103223470.pdf
  – Guidance ruling issued February 2015: http://www.cpuc.ca.gov/NR/rdonlyres/9F82A335-B13A-4F68-A5DE-3D4229F8A5E6/0/146374514finalacr.pdf
- Lorenzo Kristov & Paul De Martini (2014), “21st Century Electric Distribution System Operations”: http://smart.caltech.edu/papers/21stCElectricSystemOperations050714.pdf
- Lorenzo Kristov (2015) “The future history of tomorrow’s energy network,” (Public Utilities Fortnightly, May issue): http://www.fortnightly.com/fortnightly/2015/05/future-history-tomorrows-energy-network?page=0%2C0&authkey=afacbc896edc40f5dd20b28daf63936dd95e38713e904992a60a99e937e19028
- JD Taft and A Becker-Dippmann, Pacific Northwest National Laboratory, Grid Architecture, January 2015, http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24044.pdf

Thank you

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