SLOAN Foundation Webinar on Distributed Energy Resources
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The Economics of Sustainable Networks Under High Renewable Generation and DER Presence
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Sustainable Networks

Smart/Active T&D Power Grids
- Distributed Energy Resources: Storage Like Loads
- Coordination of DERs with Renewables
- Natural Gas Networks Interacting with Electricity Grid

- Networks Play a key Role in Efficient and Reliable Resource Sharing (Energy Primarily)
- Networks Are Growing Increasingly Coupled

**Challenges:**

Uncertainty (Renewable Generation)
Capacity Utilization - Reliability Tradeoffs
Distributed Decision Making is a Must but Requires Acceptable and Achievable Efficient Pricing
Significant Non-Convex Settings result in Open Optimal Scheduling and Acceptable Pricing Problems

**Opportunities**

New Demand Types with Storage-Like Degrees of Freedom (EVs, HVAC)
Dynamic Control of Network Resources (Topology control)
Dual Use of Network Connected Components (e.g., Inverters)
Networks: Transmission, Distribution, Natural Gas, Transportation, Data
Services: Electric Power, Heating, Transportation, Comunication (Computing, Health)
Sustainability Challenges: Renewable Volatility, Capacity Utilization, Reliability/Energy Balance

Sustainability Goals: Intra and Inter Network Spatiotemporal Coordination Supply and Demand, Topology Control Coordination of DERs (EVs, HVAC) and NEW Supply types (Distributed Microgeneration, Inverters)
Socially Optimal Scheduling Requires Acceptable Pricing. For **Distributed Decision Making**, Pricing under **Non-Convex** (Complex/Irregular Optimization) Settings is Emerging Challenge.

**HV Transm Networks**
- Nodes/ISO 1000s
- ISOs 10s

**LMV Distrib. Networks**
- Nodes/Substation 10,000s
- METERS/Node 10s
- Substations/ISO 1000s

**LMP** ← Non Coincident Peaks → **DLMP ~ LMP +**

**Uncertainty** in Net Demand and Centralized Rebnewable Generation is **Game Changer**
• Examples of Problems in Active Distribution Networks
  • Bi-directional flows
    • Protection Controls
  • Voltage (under-voltage/ over-voltage)
    • Photovoltaics
  • Coincident demand
    • Electric Vehicles
• But also Coordination Opportunities...

...and many more...
In the course of a day, congestion patterns and prices can change significantly:

- Fuel diversity
- Lack of flexibility in the resource mix

Having the ability to dynamically increase transfer capability from low price areas to high price areas will help to relieve congestion, improve dispatch of renewable resources, reduce dispatch costs and increase system flexibility.
Distributed Voltage Control ... *a new paradigm*

*Courtesy Deepak Divan, ECE Georgia Tech*

**Centralized Control**
- Scheduled Generation
- Centralized Top-Down Control
- Planning Based, Dispatched
- Unidirectional Flows, Consumers
- Redundancy, N-X Contingencies

**Need ...**
- Non-Dispatchable Variable Generation
- Distributed Edge-Up Real-Time Control
- Flexible, Secure, Predictable Virtual Resources
- Bidirectional Flows, Prosumers
- Support Transactive and Ancillary Services

**Centralized top-down control – poor system performance**

*Source: Southern Company and Varentec*
Hourly DLMP Profiles Demonstrate Non-Intuitive Behavior:
1. Not LMP+D!
2. Granularity is significant!
3. Peaks not coincident!

(Upstate NY, 800 bus radial System, Summer Peak Day Loads)
### Illustrative Numerical Results of DLMP based Equilibrium (Marg Cost Based Valuations)


<table>
<thead>
<tr>
<th>INCR. SPATIOTEMPORAL MARG. COST AWARENESS ↑ &gt;</th>
<th>Aver. Cost Price</th>
<th>LMP</th>
<th>DLMP</th>
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<tbody>
<tr>
<td>Substation Transaction Costs for P</td>
<td>13281</td>
<td>13172</td>
<td>13235</td>
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<tr>
<td>Substation Transaction Costs for Q</td>
<td>1182</td>
<td>1133</td>
<td>777</td>
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<tr>
<td><strong>Total Substation Cost A-B</strong></td>
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<td><strong>14305</strong></td>
<td><strong>14013</strong></td>
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<td><strong>Space Conditioning Charges C-D</strong></td>
<td><strong>955</strong></td>
<td>909</td>
<td>843</td>
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<tr>
<td>Charges to Space Conditioning for P</td>
<td>743</td>
<td>721</td>
<td>703</td>
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<tr>
<td>Charges to Space Conditioning for Q</td>
<td>212</td>
<td>188</td>
<td>140</td>
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<tr>
<td><strong>Total Space Conditioning Charges C-D</strong></td>
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<td><strong>17065</strong></td>
<td><strong>16478</strong></td>
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<td><strong>Net EV Charges E-H</strong></td>
<td>220</td>
<td>127</td>
<td>114</td>
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<td>Income of EV for Q provision</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td><strong>Total PV Income H-J</strong></td>
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<td><strong>1494</strong></td>
<td><strong>1577</strong></td>
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<tr>
<td>Income of PV for P provision</td>
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<tr>
<td>Income of PV for Q provision</td>
<td>0</td>
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<td>169</td>
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<td><strong>Total DER Revenues L</strong></td>
<td><strong>1494</strong></td>
<td><strong>1494</strong></td>
<td><strong>1711</strong></td>
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<tr>
<td><strong>Total Cost of Distribution Participants M</strong></td>
<td><strong>16871</strong></td>
<td><strong>16607</strong></td>
<td><strong>15737</strong></td>
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<tr>
<td><strong>Distribution Network Rent N</strong></td>
<td><strong>2408</strong></td>
<td><strong>2302</strong></td>
<td><strong>1724</strong></td>
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</table>
Potential Platform Market Structure

*Each Distribution Utility in its role as a DSP plans and operates its specific system while co-owning the statewide Platform.
Grants (Collaborators: Caramanis, Andrianesis, Rudkevich, Zlotnik, Bertsimas, Hogan, Ruiz, Kulatilaka)
- **ARPA E** Topology Control for Infrastructure Resilience to the Integration of Renewable Generation, 2011-2015
- **ARPA E** Gas and Electricity Coordination (GECO), 2016 - 2018
- **NSF AIF** Distribution Network Reconfiguration, September 2017-August 2021, $300K
- **SLOAN** Foundation, the Economics of Distribution Networks, 2017-2020.
- **DOE PERFORM** A New Risk Assessment And Management Paradigm (NewRAMP) In Electricity Markets”, 2020-2023

Selected Publications: