SLOAN Foundation Webinar on Distributed Energy Resources May 28, 2022

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

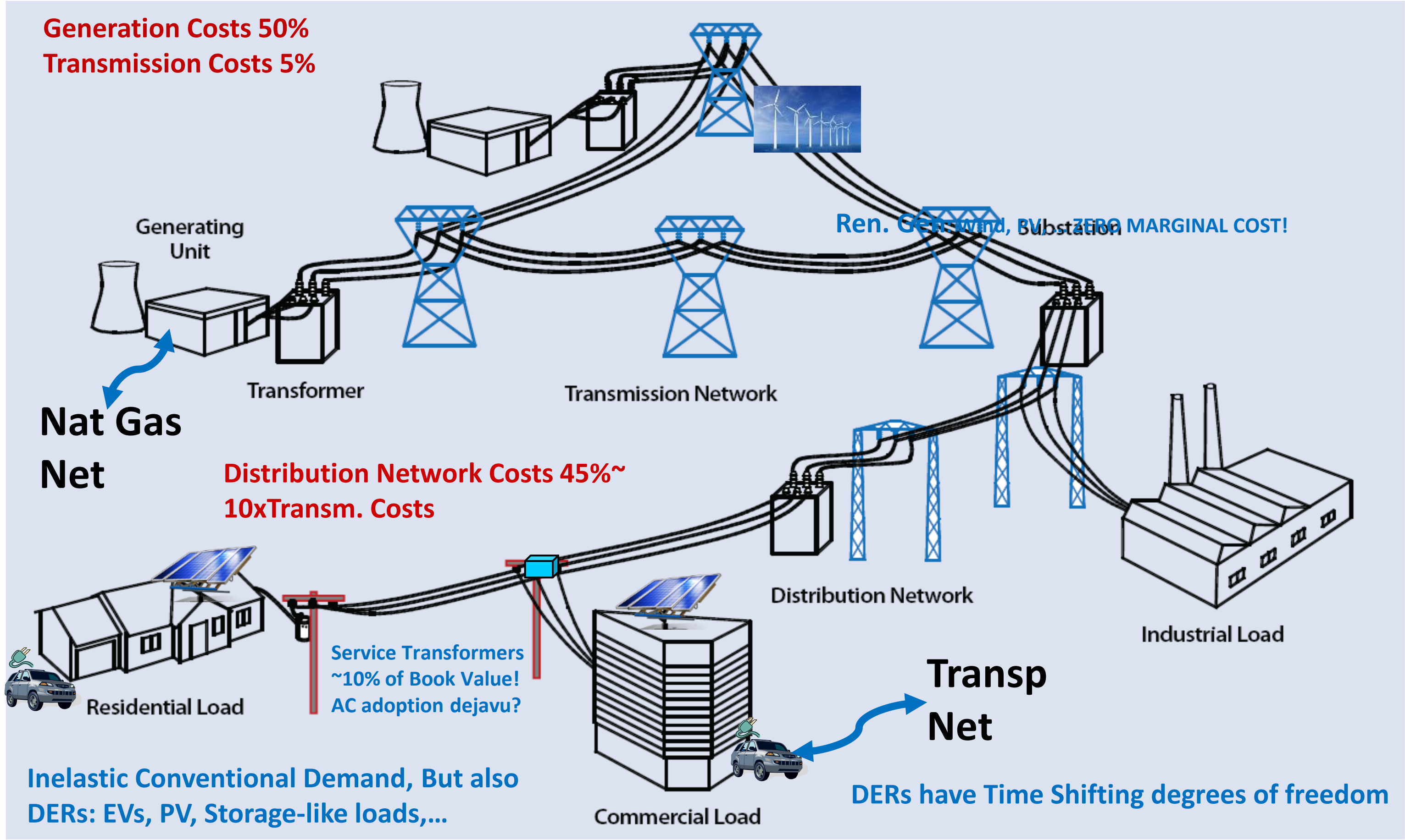
Opportunities

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)

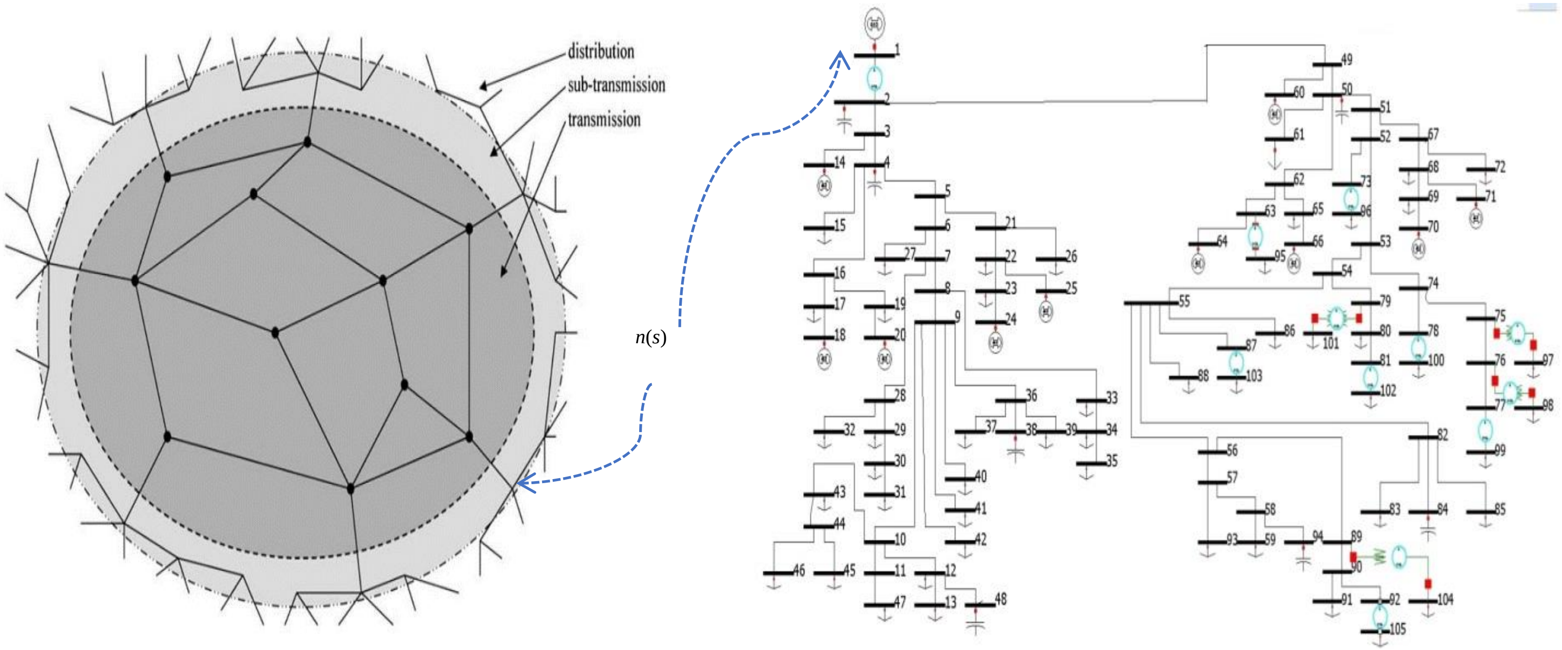
Networks: Transmission, Distribution, Natural Gas, Transportation, Data
Services:: Electric Power, Heating, Transportation, Comunication (Computing, Health)
Sustainability Challenges: Renewable Volatility, Capacity Utilization, Reliability/Energy Balance



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

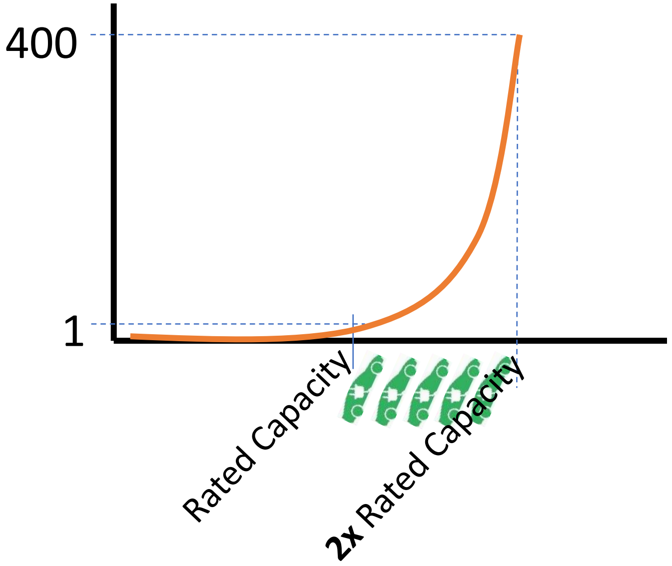


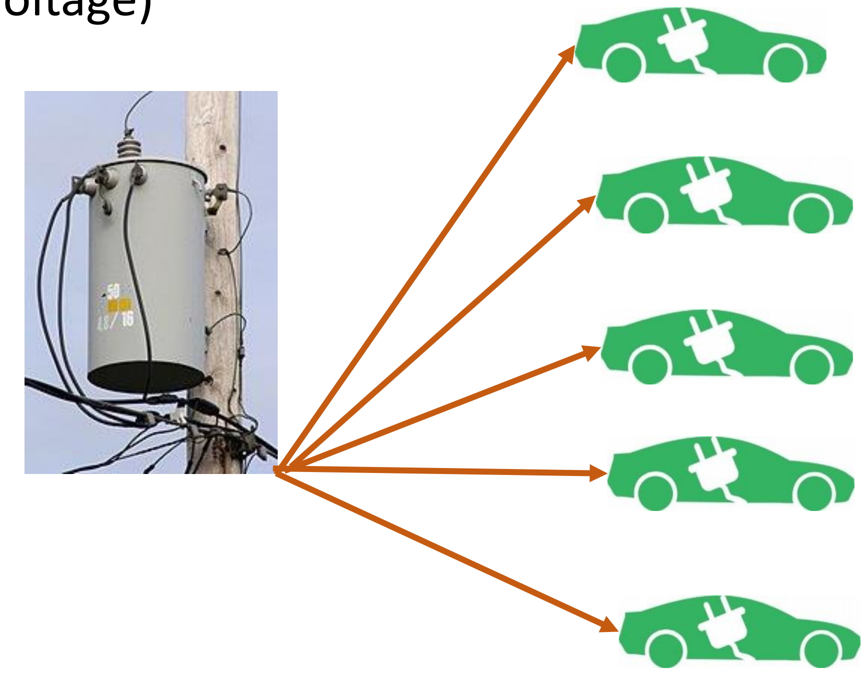
LMV Distrib.
Networks
-Nodes/Substation
10,000s
-METERS/Node
10s
-Substations/ISO
1000s

LMP <-- Non Coincident Peaks --> **DLMP** ~ LMP +

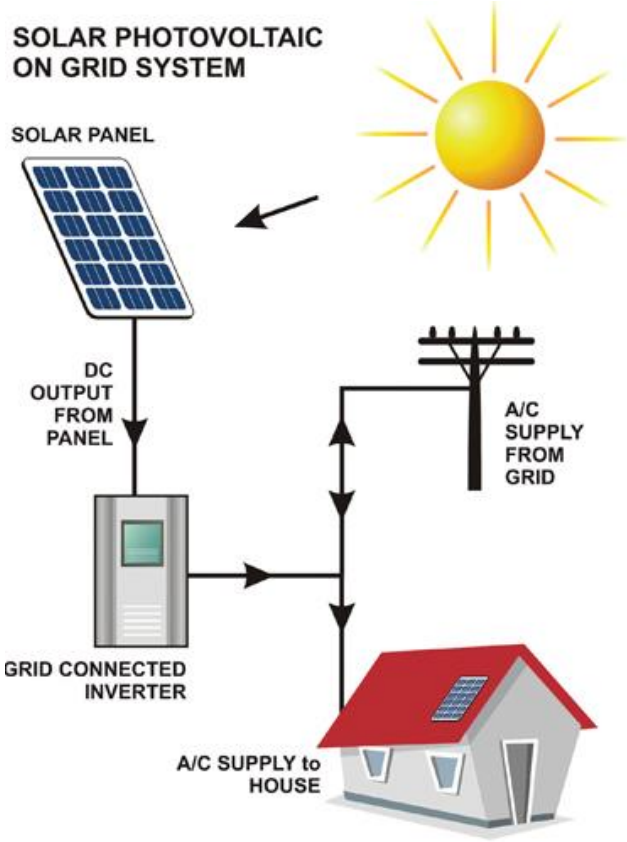
Uncertainty in Net Demand and Centralized Rebnewable Generation is **Game Changer**

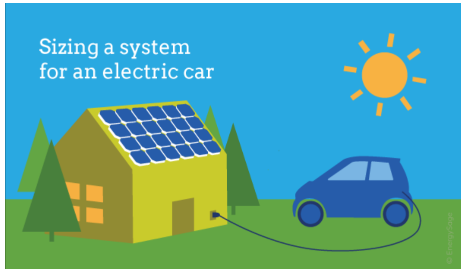
- Examples of Problems in Active Distribution Networks
  - Bi-directional flows
    - Protection Controls
  - Voltage (under-voltage/ over-voltage)
    - Photovoltaics
  - Coincident demand
    - Electric Vehicles

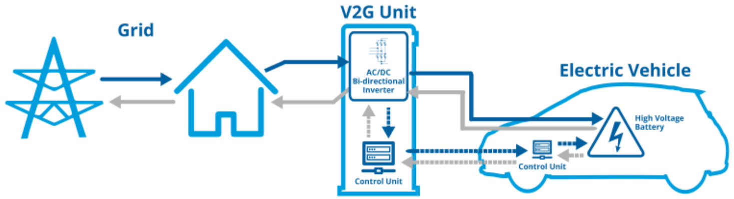




- But also Coordination Opportunities…





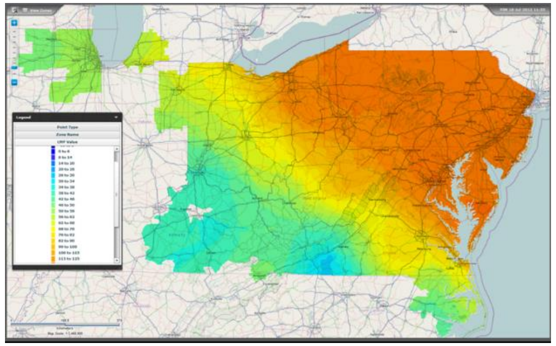


…and many more…

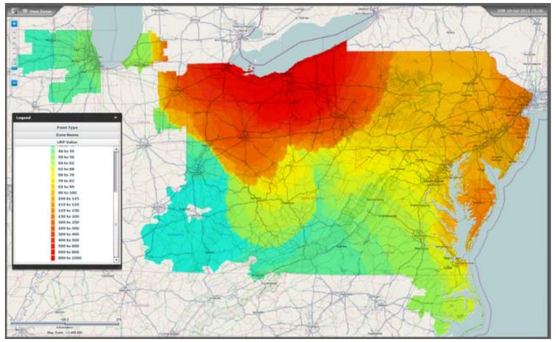
Congestion in Transmission Networkls

July 18, 2013 in PJM Wholesale 5 min Real Time Market

11:55 am



3:30 pm



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.

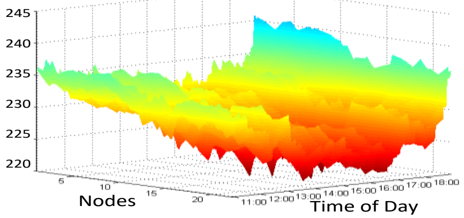
Distributed Voltage Control … *a new paradigm*

Courtesy Deepak Divan, ECE Georgia Tech

Centralized Control

Now …

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



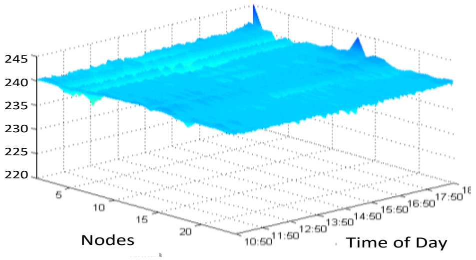
Centralized top-down control – poor system performance

Distributed Control

Need …

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

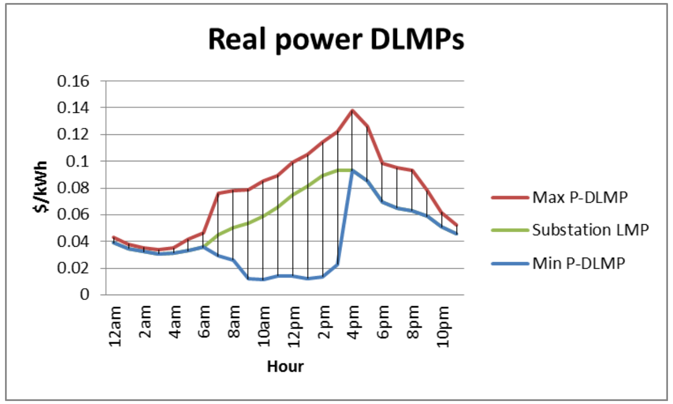
Edge-up real-time control - local & system level control

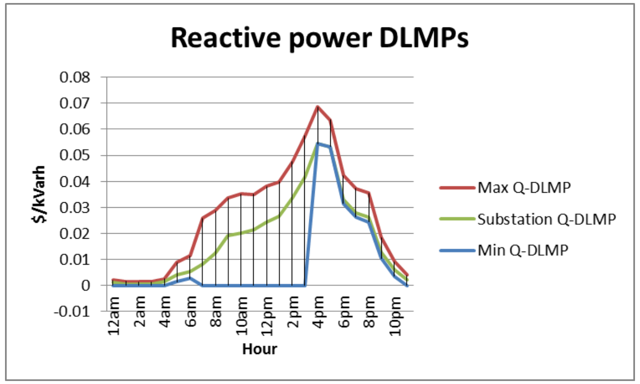


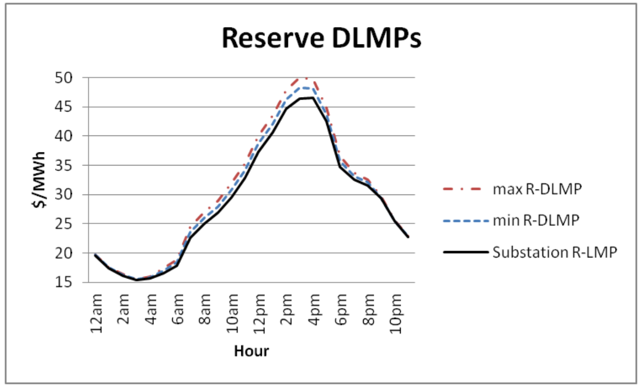
Source: Southern Company and Varentec

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)





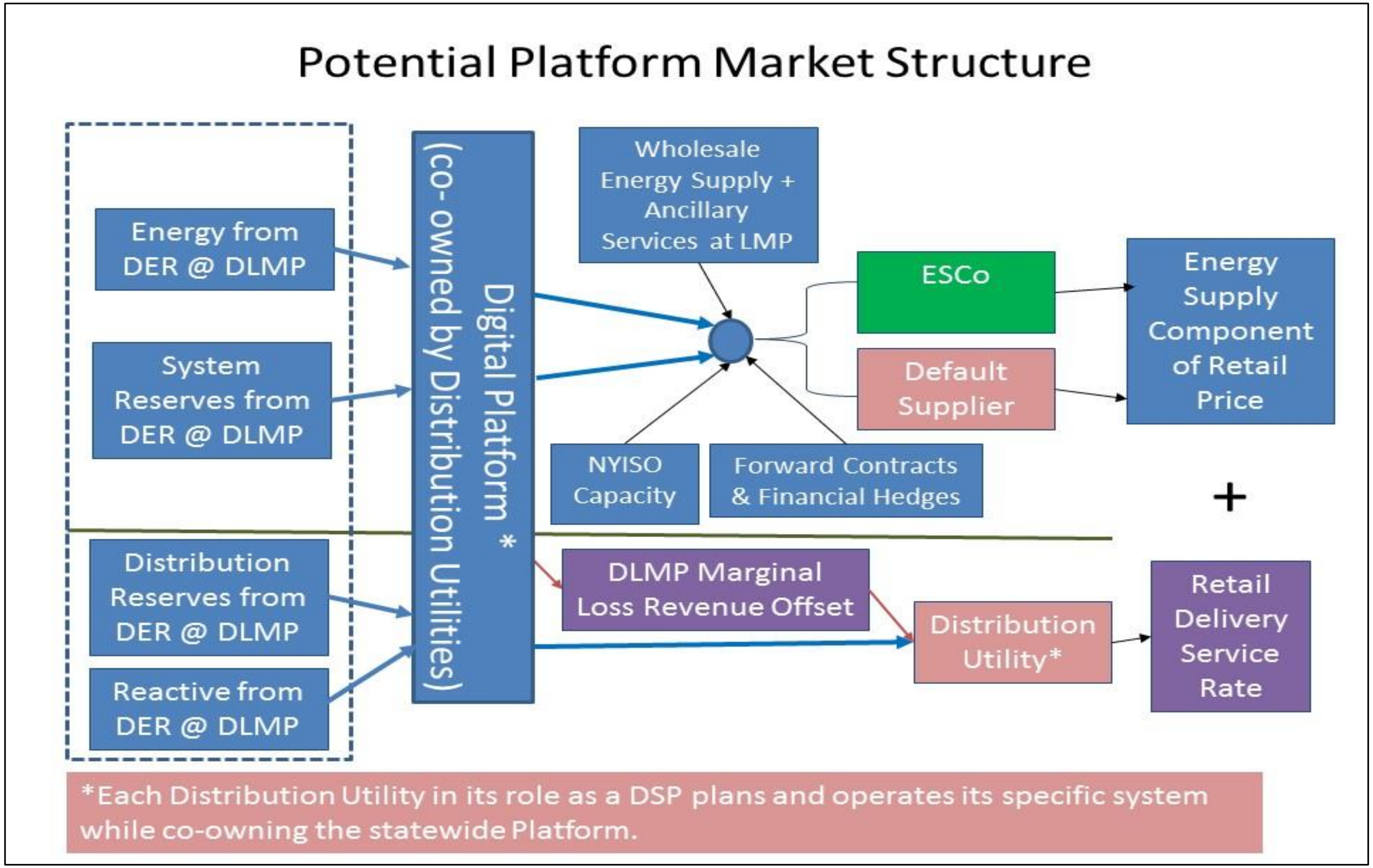


Illustrative Numerical Results of DLMP based Equilibrium (Marg Cost Based Valuations)

Upstate NY, 800 bus radial System, Summer Peak Day Loads http://www.bu.edu/pcms/caramanis/NYPSC%20TCR%20WhitepaperApril2016.pdf

	INCR. SPATIOTEMPORAL MARG. COST AWARENESS ->	Aver. Cost Price	LMP	DLMP
A	Substation Transaction Costs for P	13281	13172	13235
B	Substation Transaction Costs for Q	1182	1133	777
	Total **Substation Cost** A+B	**14463**	**14305**	**14013**
C	Charges to Space Conditioning for P	743	721	703
D	Charges to Space Conditioning for Q	212	188	140
	Total **Space Conditioning Charges** C+D	955	909	843
E	Charges to EV for P	220	127	127
F	Charges to Inflexible Loads for P	15102	15037	14869
G	Charges to Inflexible Loads for Q	2089	2027	1609
	Total **Inflexible Load Charges** F+G	**17190**	**17065**	**16478**
H	Income of EV for Q provision	0	0	134
	Net EV Charges E-H	220	127	-8
I	Income of PV for P provision	1494	1493	1408
J	Income of PV for Q provision	0	0	169
	Total PV Income I+J	1494	1494	1577
K	Total Charges (K=C+D+E+F+G)	18365	18101	17448
L	**Total DER Revenues** (L=H+I+J)	**1494**	**1494**	**1711**
M	Net Cost of Distribution Participants (M=K-L)	16871	16607	15737
N	Distribution **Network Rent** (N=M-A-B)	**2408**	**2302**	**1724**

Platform Market Structure



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:

-M. Caramanis, E. Ntakou , W. Hogan, A. Chakrabortty and J. Schoene, "Co-Optimization of Power and Reserves in Dynamic T&D Power Markets with Non-Dispatchable Renewable Generation and Distributed Energy Resources" The Proceedings of IEEE, Vol. 104, No. 4, pp. 807-836, DOI:10.1109/JPROC.2016.2520758.

-A. Rudkevich, A. Zlotbik, P. Ruiz, E. Goldis, A. Beylin, R. Hornby, R. Tabors, S. Backhaus, M. Caramanis, Russ Philbrick "Market Based Intraday Coordination of Electric and Natural Gas system Operation" Proceedings of the 51st HICSS, January 2018, pp 2586-2594

-P. A. Ruiz, E. A. Goldis, A. M. Rudkevich, M. Caramanis, C. R. Philbrick, and J. M. Foster, "Security-Constrained Transmission Topology Control MILP Formulation Using Sensitivity Factors", IEEE TPS, V32, No. 2, pp. 1597-1605, 2017.

-F. S. Yanikara, P. Andrianesis M. Caramanis, "Power Markets with Information-Aware Self-Scheduling Electric Vehicles", Dynamic Games and Applications (2019), paper shared at https://rdcu.be/bS6I8-

P. Andrianesis, M. Caramanis "Distribution Network Marginal Costs: Enhanced AC OPF Including Transformer Degradation" (2020) IEEE Transactions on Smart Grid, DOI: 10.1109/TSG.2020.2980538 http://arxiv.org/abs/1811.09001

-M. Heidarifar, P. Andrianesis, M. Caramanis "A Riemannian Optimization Approach to the Radial Distribution Network Load Flow Problem" Automatica, 2021.

-P. Andrianesis, M. Caramanis, N. Li, "Optimal Distributed Energy Resource Coordination: A Decomposition Method Based on Distribution Locational Marginal Costs" IEEE Transactions on Smart Grid, doi: 10.1109/TSG.2021.3123284, 2022.

-P. Andrianesis, D. Bertsimas, M. Caramanis, W. Hogan "Computation of Convex Hull Prices in Electricity Markets with Non-Convexities using Dantzig-Wolfe Decomposition" IEEE Trans. on Power Systems, doi: 10.1109/TPWRS.2021.3122000.