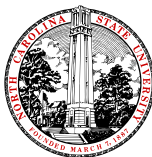# The Evolutionary Market Structure in the Smart Grid Era

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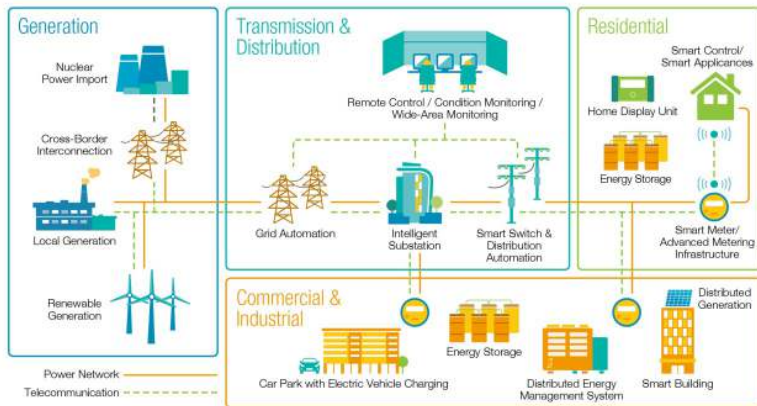

FREEDM Systems Center 2019 Research Symposium

April 11, 2019

What is Smart Grid?

- Modernized grid integrated with two-way communication
- Planning and operation: from deterministic to stochastic

Source: CLP Group

What is Electricity Market?

- From vertically integrated utilities to electricity restructuring
- Generation: competing generators offer their electricity output to resellers through wholesale electricity markets, operated by independent system operators (ISOs)
- Transmission: regulation shifted from individual states to FERC
- Distribution: retail electricity markets exist in some states where end users can buy electricity from competitive resellers
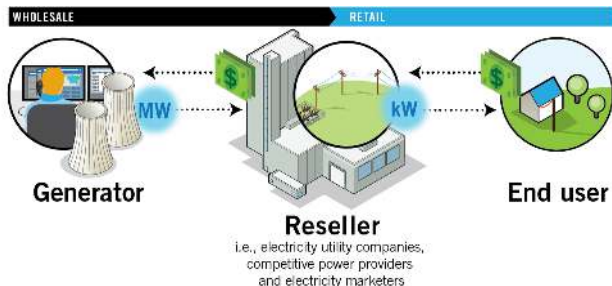
Source: PJM

Why Does Market Design Matter?

- Market manipulation led to large-scale blackouts
- Ambiguities in sophisticated rules led to long-lasting litigations

Source: Chronicle Graphic and ferclitigation.com

GAMES Group @ NCSU

- Scope: Grid Analytics, Markets, Economics, and Systems
- Subject: electricity markets in a broad sense (wholesale and retail, regulated and deregulated, centralized and decentralized, etc.)
- Vision: exploring the evolutionary market structure in the smart grid era
- Approach: integrating game theory and data analytics with control and optimization
- Impact: enriching curricula and fostering convergence research
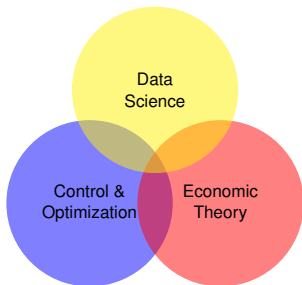
- Game theory and power system economics
- Data analytics of electricity markets
- Control and optimization of smart grids
- Energy systems and energy policy

ECE 452: Renewable Electric Energy Systems

- Plotting screening curves for conventional power plants
- Developing solar insolation calculators
- Creating spreadsheets for PV system design
- Cash flow analysis for energy system investments
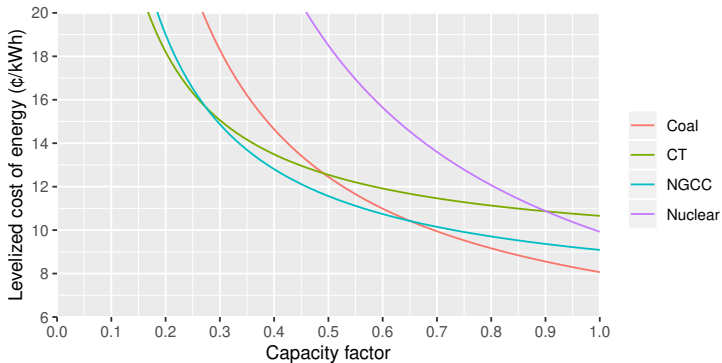
ECE 585: The Business of the Electric Utility Industry

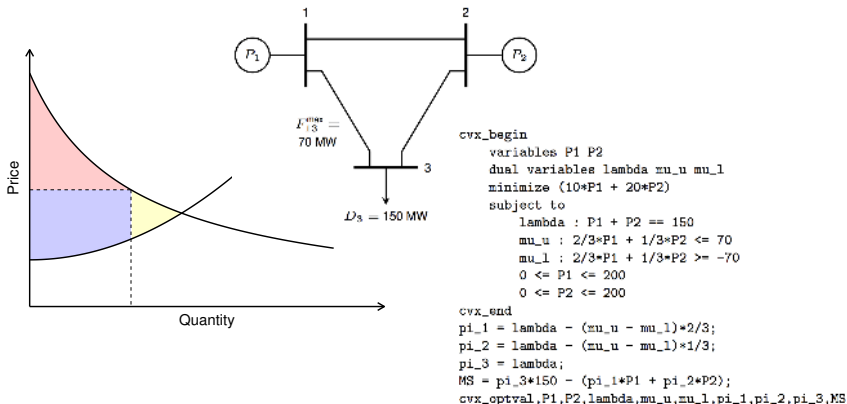- The course has been expanded to cover deregulated markets
- Exposure to microeconomics including game theory
- An illuminating treatment on the underlying optimization models using CVX


```
cvx_begin
    variables P1 P2
    dual variables lambda mu_u mu_l
    minimize (10*P1 + 20*P2)
    subject to
        lambda : P1 + P2 == 150
        mu_u : 2/3*P1 + 1/3*P2 <= 70
        mu_l : 2/3*P1 + 1/3*P2 >= -70
        0 <= P1 <= 200
        0 <= P2 <= 200
cvx_end
pi_1 = lambda - (mu_u - mu_l)*2/3;
pi_2 = lambda - (mu_u - mu_l)*1/3;
pi_3 = lambda;
MS = pi_3*150 - (pi_1*P1 + pi_2*P2);
cvx_optval,P1,P2,lambda,mu_u,mu_l,pi_1,pi_2,pi_3,MS
```

ECE 592: Data Analytics for Power Engineering

- Accommodating the fast-growing energy analytics jobs
- Exposure to data analytics and machine learning
- Please drop by the student's poster motivated by the take-home exam

Forecasted Load vs Actual Load Comparison for October 2018
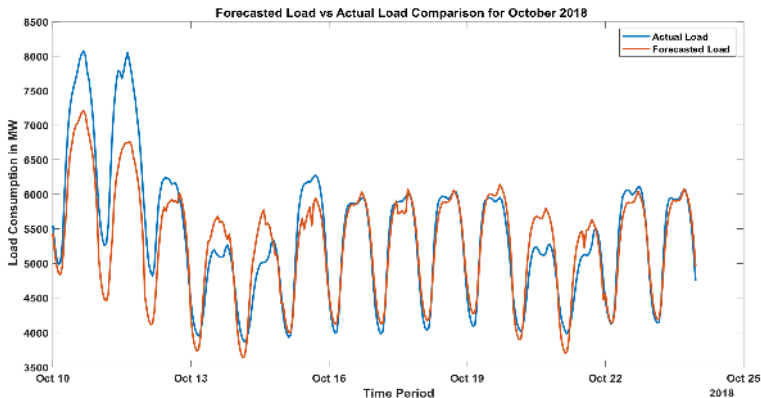
Research 1: Financial Instruments in the Wholesale Market

- The magnitudes of the spreads (differences between day-ahead and real-time prices) were observed greater than $1000/MWh at the PJM Northern Illinois Hub during the 2014 North American cold wave
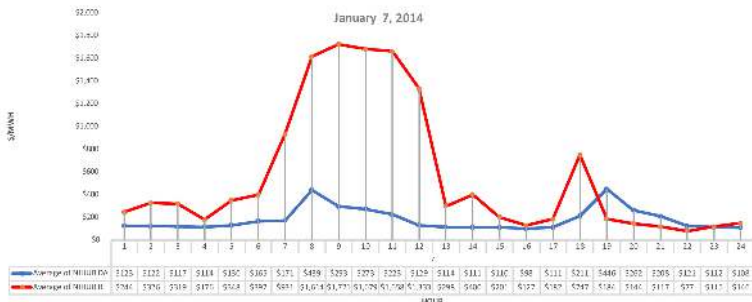

- Virtual bidding allows market participants including financial entities to hedge against or speculate on the spread, without physically consuming or producing power

Research 1: Financial Instruments in the Wholesale Market
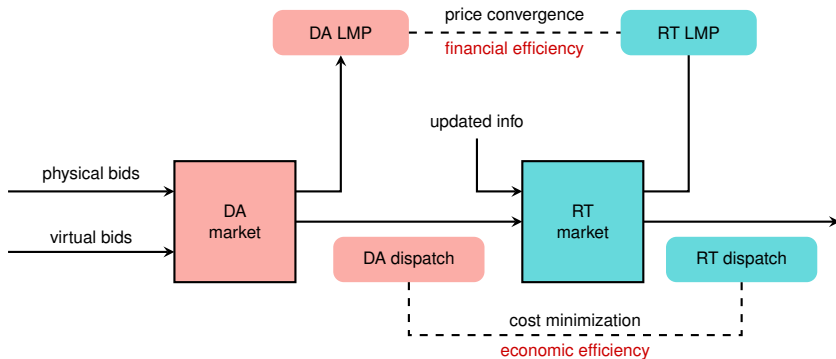
- How to formalize the interactions between day-ahead and real-time markets?
- How to analyze the impact of virtual bidding on market efficiency?
- How to evaluate the effectiveness of virtual bidding?

Research 1: Financial Instruments in the Wholesale Market

Average spread with and without virtual bids, PJM

Generation cost with and without virtual bids, PJM
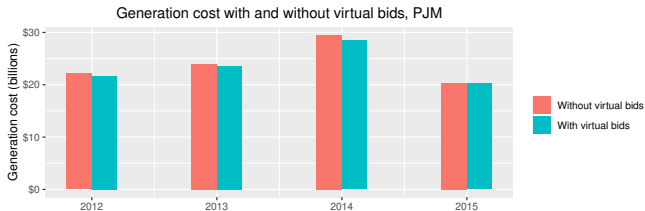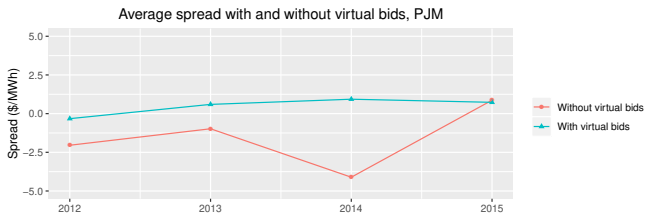
- Empirical estimation: the virtual bids drive the spread toward zero, and reduce the generation cost by an average of 2%

Research 2: Utility Rate Design for PV-Storage Systems

- How to control the PV-storage system to maximize the net profit of the customer?
- How to optimize the design parameters and the choice of the rate plan?
- How to improve rate structures and design market mechanisms to facilitate the integration of residential PV-storage systems, from the utility's perspective?
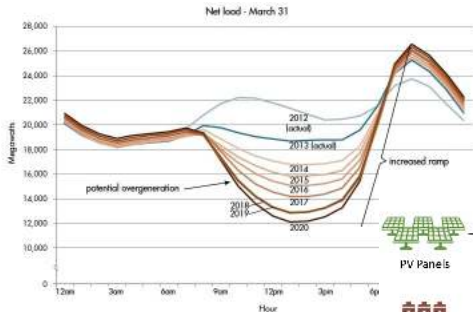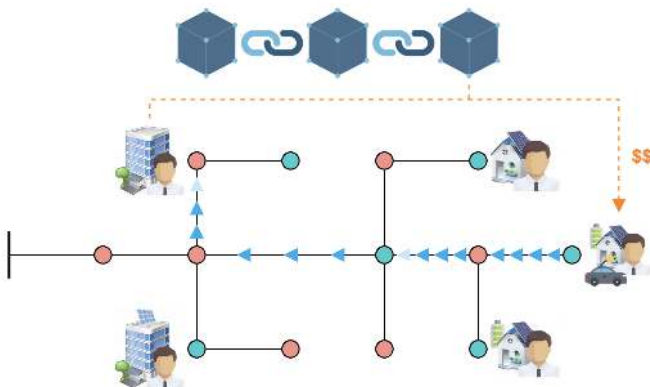

(This project is to be funded by)
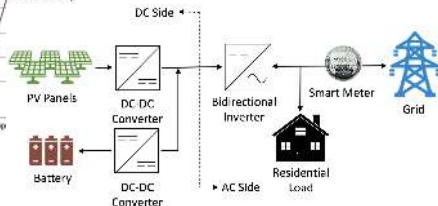
Research 3: Blockchain-Based Microgrid Markets

- Blockchain's trilemma of decentralization, security, and scalability
- We propose the decentralized continuous double auction, where the scalability issue is resolved by an efficient, bilateral line loss allocation, without any aggregation step

Research 4: The Evolutionary Market Structure

- Stochastic control models for analysis of baseline manipulation in demand response
- Business models and economic viability of third-party energy service providers