Markets and Demand Management Coupling with Renewable Energy Sources

Alberto J. Lamadrid

Eighth Annual Carnegie Mellon Conference on the Electricity Industry, 2012
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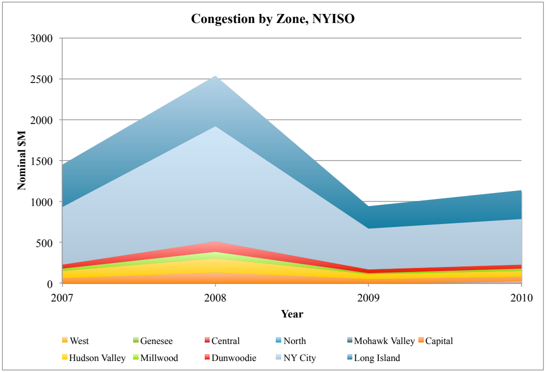
Outline

What is the cost of network congestion?

New York State



[nyiso(2011)]

2011 Congestion Assessment and Resource Integration Study (CARIS)

Four metrics used: Bid- Production Cost (BPC) as primary metric, then Load Payments , Generator Payments, and Congestion Payments.

Relevance

This research addresses a fundamental issue in the operation of the system with storage resources

1. How to securely dispatch a set of previously committed generators
2. The use of inter-temporal resources for both time arbitrage and uncertainty mitigation
3. Point of view of ISO (social planner), maximizing social welfare
4. Research combines engineering, economic models, and knowledge of system constraints to identify solutions for better renewable integration

Ongoing research at Cornell, Tim Mount, Dick Schuler, Bob Thomas, Ray Zimmerman, Carlos E. Murillo-Sanchez, Lindsay Anderson, support provided by PSERC

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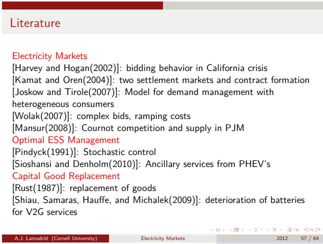
Where does this research stand?


Literature

Electricity Markets
[Harvey and Hogan(2002)]: bidding behavior in California crisis
[Kamat and Oren(2004)]: two settlement markets and contract formation
[Joskow and Tirole(2007)]: Model for demand management with heterogeneous consumers
[Wolak(2007)]: complex bids, ramping costs
[Mansur(2008)]: Cournot competition and supply in PJM
Optimal ESS Management
[Pindyck(1991)]: Stochastic control
[Sioshansi and Denholm(2010)]: Ancillary services from PHEV's
Capital Good Replacement
[Rust(1987)]: replacement of goods
[Shiau, Samaras, Hauffe, and Michalek(2009)]: deterioration of batteries for V2G services

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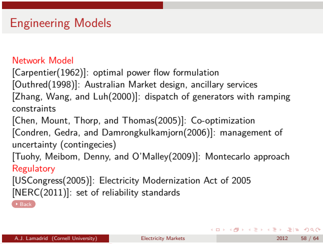
Engineering Models

Network Model
[Carpentier(1962)]: optimal power flow formulation
[Outhred(1998)]: Australian Market design, ancillary services
[Zhang, Wang, and Luh(2000)]: dispatch of generators with ramping constraints
[Chen, Mount, Thorp, and Thomas(2005)]: Co-optimization
[Condren, Gedra, and Damrongkulkamjorn(2006)]: management of uncertainty (contingecies)
[Tuohy, Meibom, Denny, and O'Malley(2009)]: Montecarlo approach
Regulatory
[USCongress(2005)]: Electricity Modernization Act of 2005
[NERC(2011)]: set of reliability standards
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- Co-optimizing energy and reserves → solve optimal amounts
- Use of Full AC Network
- Economic management of demand (deferrable)
- Modeling of renewables uncertainty
- Engineering and Economical modeling of Energy Storage Systems (ESS)

Full Literature

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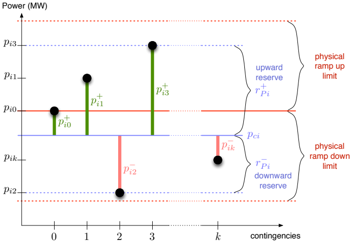
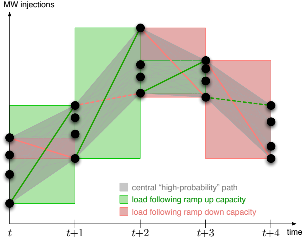
A Multiperiod, Security Constrained Optimal Power Flow

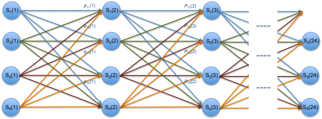
Determining the optimal power flows for operations and planning on an AC network using Kirchhoff's Laws.

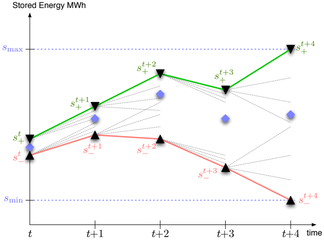
Traditional Approach	Our Approach
Break into manageable sub-problems.	Simultaneous co-optimization with explicit contingencies and load following requirements
Sequential optimization using proxy constraints	Combine into single mathematical programming framework.
DC approximations	AC Network and Dispatch coordination Scheme
Inter-temporal Constraints in UC model	Explicit Inter-temporal constraints for generators AND Energy Storage Systems (ESS)
misleading prices	more accurate prices

Overall Characteristics









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Simplified objective function and eq. constraints

Objective:

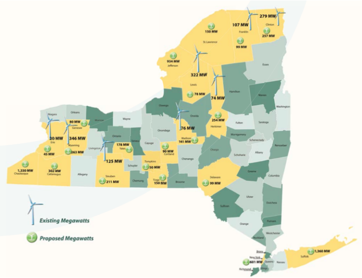
$$\min_{G_{itsk}, R_{itsk}, \mathrm{LNS}_{jtsk}} \sum_{t \in \mathscr{T}} \sum_{s \in \mathscr{S}^t} \sum_{k \in \mathscr{K}} \pi_{tsk} \Bigg\{ \sum_{i \in \mathscr{I}} \Big[C_{G_i}(G_{itsk}) + \mathrm{Inc}^+_{its}(G_{itsk} - G_{itc})^+ + \mathrm{Dec}^-_{its}(G_{itc} - G_{itsk})^+ \Big] \sum_{j \in \mathscr{J}} \mathrm{VOLL}_j \mathrm{LNS}(G_{tsk}, R_{tsk})_{jtsk} \Bigg\} + \sum_{t \in \mathscr{T}} \rho_t \sum_{i \in \mathscr{I}} [C^+_{R_{it}}(R^+_{it}) + C^-_{R_{it}}(R^-_{it}) + C^+_{L_{it}}(L^+_{it}) + C^-_{L_{it}}(L^-_{it}) +] + + \sum_{t \in \mathscr{T}} \rho_t \sum_{s_2 \in \mathscr{S}^t} \sum_{s_1 \in \mathscr{S}^{t-1}} \sum_{i \in \mathscr{I}^{ts_2 0}} \Big[\mathrm{Rp}^+_{it}(G_{its_2} - G_{its_1})^+ + \mathrm{Rp}^-_{it}(G_{its_2} - G_{its_1})^+ \Big] \tag{1}$$

Subject to meeting demand and all network constraints (e.g. Active power flow equations)

$$p_{it} - \sum_{j \in n_B} |v_{jt}||v_{it}| \Big[G_{ijt} \cos(\theta_i - \theta_j) + B_{ijt} \sin(\theta_i - \theta_j) \Big] = 0, \forall i \in \mathscr{B}, t \in \mathscr{T}$$

Input Information

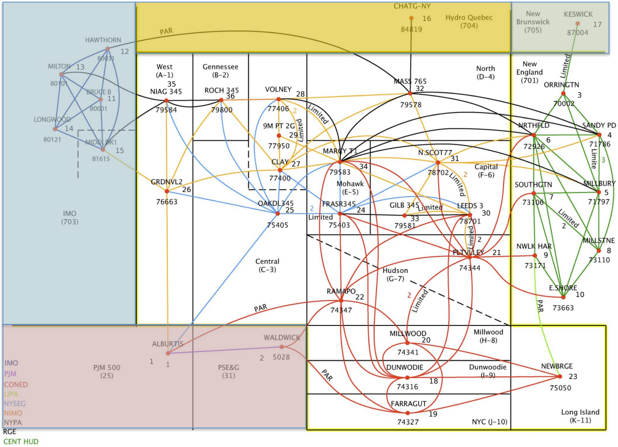
1. PCA on historical data to determine wind sites [NREL(2010)]



2. k-means clustering to specify the scenarios for the day[Guojun Gan(2007)]
3. Data from New York and New England to calibrate load profile [NYISO(2011)]
4. Network based on [Allen, Lang, and Ilic(2008)], heavily modified

North East Test network

No changes in generation/load out of NY-NE



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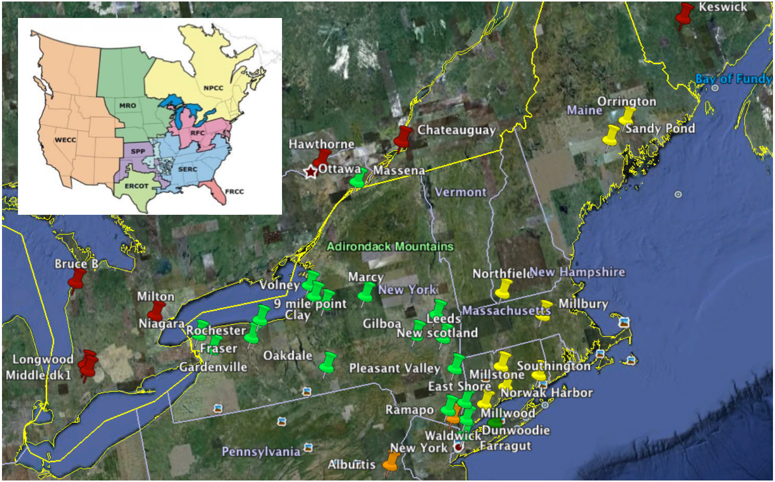
Geographical Location



Details Fleet

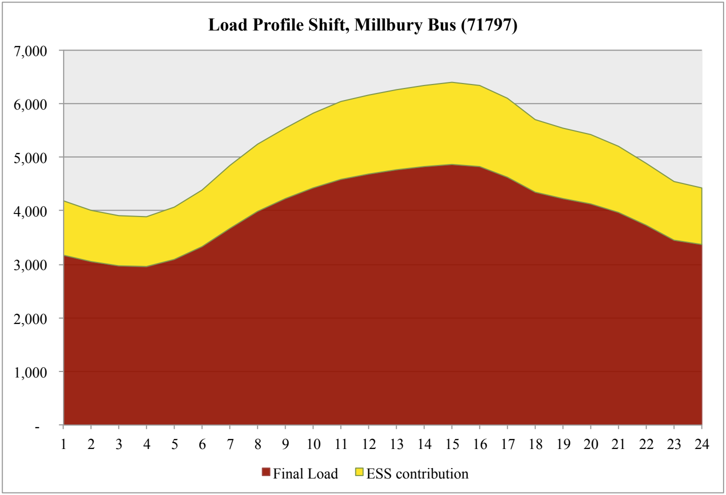
Cases studied

Main Cases Studied

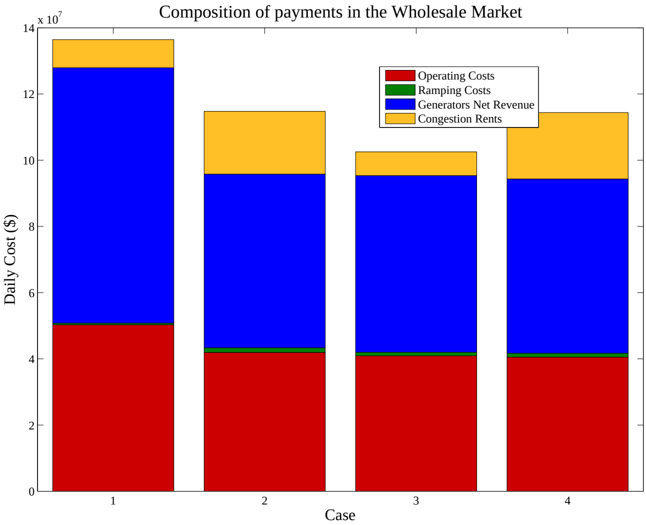
1. Case 1: Base Case, no wind
2. Case 2: Wind added in 16 locations in NYNE
3. Case 3: Wind + Deferrable Demand (DD).
4. Case 4: Wind Collocated with Storage

▸ Details Location

How Deferrable Demand is Calculated

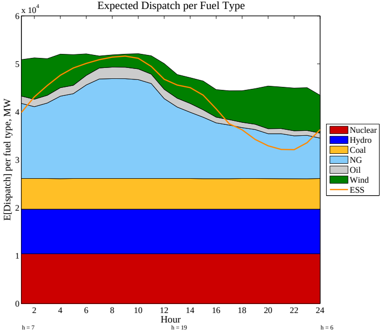


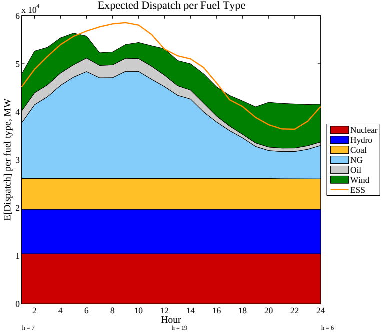
Payments in the System



Expected Dispatch per Case

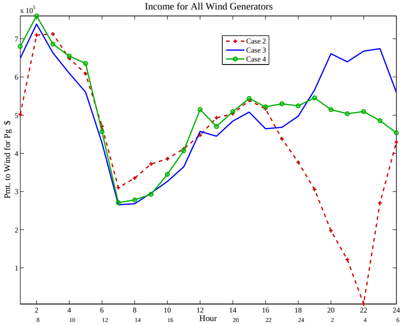
Cases 3 and 4





Dispatch 1 and 2

Wind Compensation

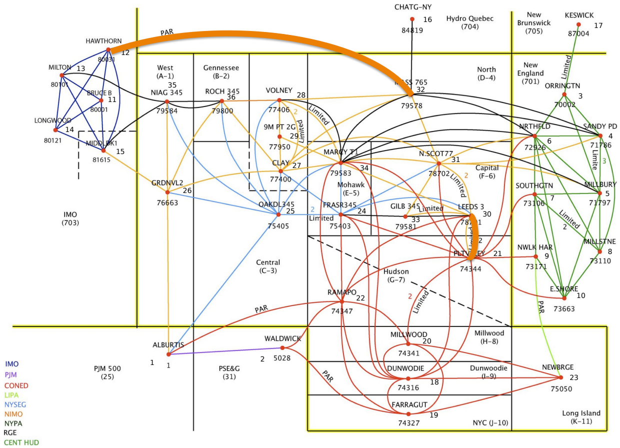


Total Wind Compensation (USD Millions)

Case 2	Case 3	Case 4
10.112	12.262	12.094

Observed Congestion

Upgrades improves overall welfare in the system



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Congestion in Real System

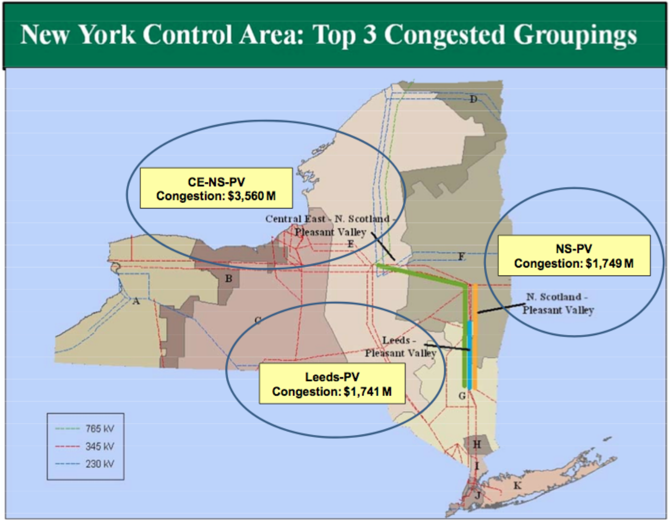
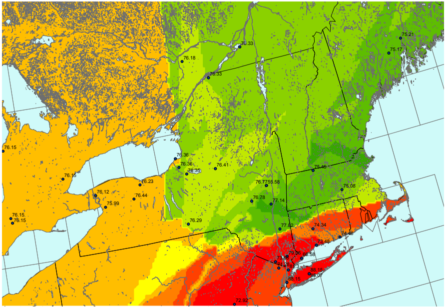
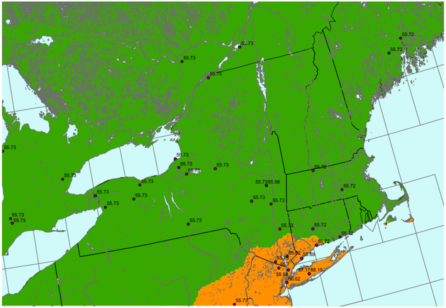


Figure 2: Congestion on the Top Three CARIS Studies (Present Value in 2011 $M)

Geographical Effects

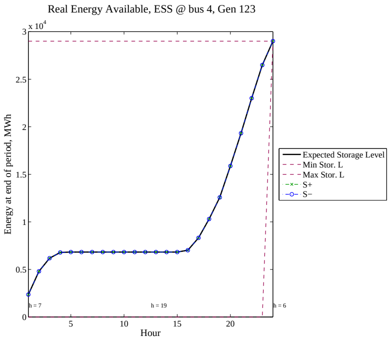
Nodal Prices at low demand periods

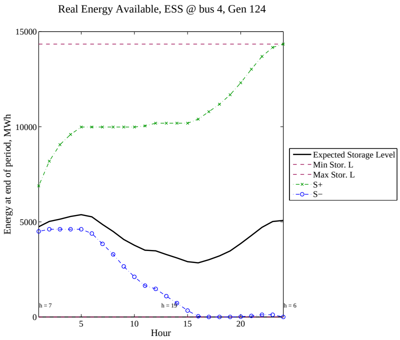




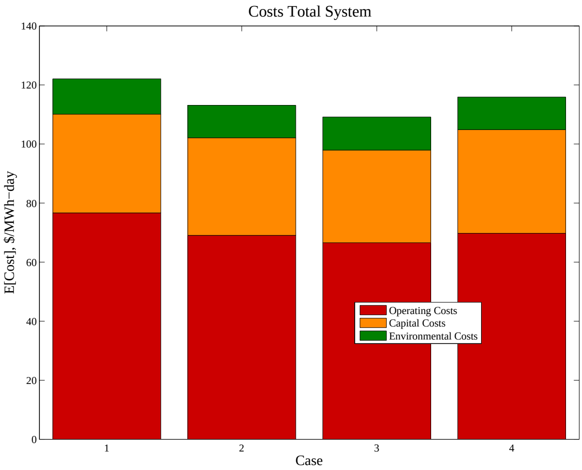
Storage Management

Time Arbitrage versus Uncertainty Mitigation





System Costs per Energy Delivered



Conclusions

- Deferrable Demand both reduces capacity requirements and weighted operating costs
- Value of Storage lies in mechanisms for trading off uncertainty and time arbitrage
- Stochastic solution properly maintains system security and adequacy.
- Intelligent management of demand delivers higher value than transmission upgrades

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Thank you

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Sensitivity to Wind and Network Specification

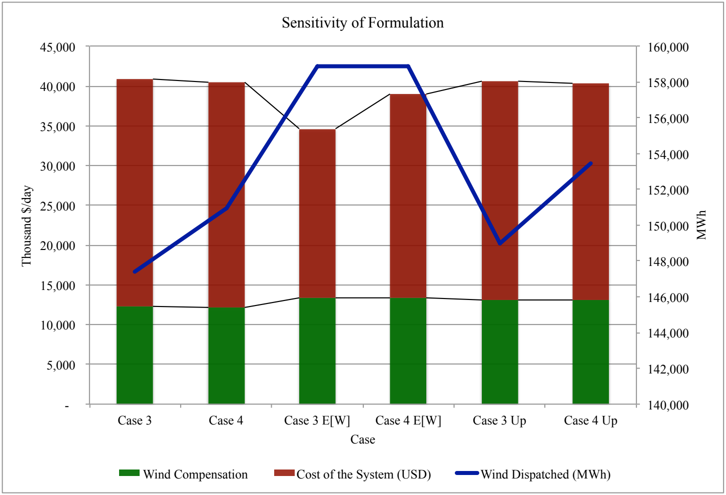
Consider the following two cases:

1. Assume Wind is perfectly forecastable, and its output is at the expected level over the day (Case E[W])
2. Assume the network is not constrained, (Case Up)

How does this affect the following four metrics?

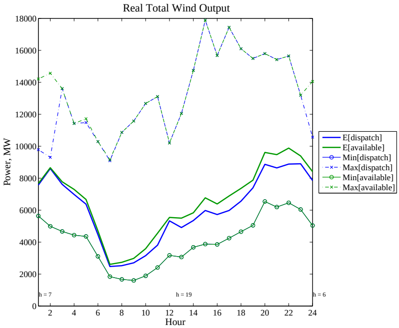
1. Operating Costs
2. Wind Dispatched
3. Generation Capacity Needed
4. Compensation to Wind Owners

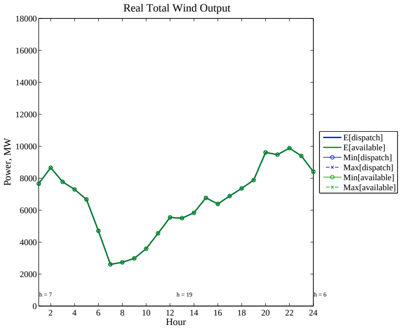
Costs, Dispatches and Wind Compensation



How the Available Wind is Dispatched

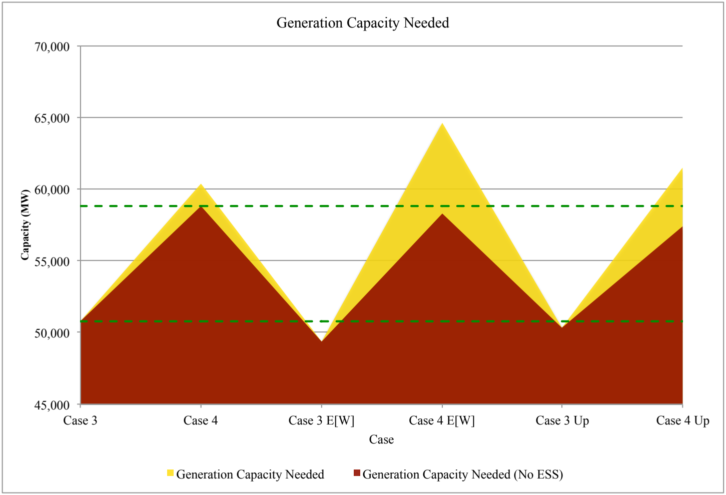
Cases 3 and 3E





Prices system

Capacity Needed for Adequacy



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Regulatory

[USCongress(2005)]: Electricity Modernization Act of 2005
[NERC(2011)]: set of reliability standards

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Some of the Constraints...

And reactive power flow equations

$$q_{it} - \sum_{j \in n_B} |v_{jt}||v_{it}| \left[G_{ijt} \sin(\theta_i - \theta_j) - B_{ijt} \cos(\theta_i - \theta_j) \right] = 0, \quad \forall i \in \mathscr{B}, t \in \mathscr{T} \tag{2}$$

And inequalities, e.g.,

$$-R_{Pi}^{\mathrm{PHYS}-} \leq p_{it} - p_{i,t-1}^{t} \leq R_{Pi}^{\mathrm{PHYS}+}, \forall i \in \mathscr{G}, t \in \mathscr{T} \tag{3}$$

$$\textstyle\sum_{t \in \mathscr{T}} e_{it} \cdot t = 0, \forall i \in \mathscr{E} \tag{4}$$

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Characteristics of the generation fleet, 36-Bus system

Summary of Generation Capacity and Load, NPCC system

	Capacity per Fuel Type (MW)							Total Cap.	Load
RTO	coal	ng	oil	hydro	nuclear	wind	refuse	(GW)	(GW)
isone	1,840	9,219	4,327	1,878	5,698	0	0	22.9	23.8
marit.	2,424	1,072	22	641	641	0	0	4.8	3.5
nyiso	4,557	18,185	5,265	7,345	4,714	30	55	40.1	38.2
ont.	5,287	3,594	0	779	12,249	0	0	21.9	21.1
pjm	14,453	14,611	8,915	2,604	12,500	0	0	53.1	51,6
quebec	0	0	0	800	0	0	0	800	0
Total	28,562	46,681	18,530	14,048	35,802	30	55	143.7	138.4
Total NYNE	6,397	27,404	9,592	9,223	10,412	30	55	63	62
Rp.C.	30	10	10	60	60	0	60		

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Wind and Storage Locations

Area	Bus	Place	Wind (MW)	ESS (MWh)	DL (MWh)
NE	70002	Orrington	1725	7,332	
NE	71786	Sandy Pond	3375	14,345	29,000
NE	71797	Millbury	1560	6,630	15,000
NE	72926	Northfield	2157	9,168	
NE	73106	Southington	1145	4,867	
NE	73110	Millstone	1478	6,282	
NE	73171	Norwalk Harbor	2560	10,881	
NY	74316	Dunwodie	241	1,024	24,000
NY	74327	Farragut (NYC)			52,000
NY	75050	Newbridge	142	604	
NY	77950	9M. Point	1922	8,169	
NY	78701	Leeds	1327	5,640	
NY	79578	Massena	3000	12,751	
NY	79581	Gilboa	1705	7,247	
NY	79583	Marcy	1373	5,836	
NY	79584	Niagara	3672	15,607	16,000
NY	79800	Rochester	4616	19,619	
Total			31,998	136,000	136,000

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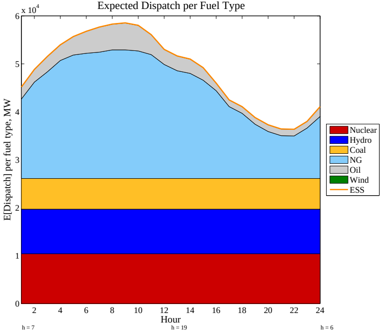
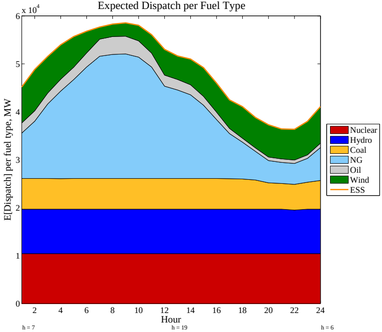
Expected Dispatch per Case

Cases 1 and 2





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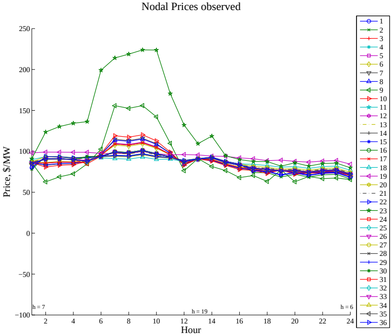
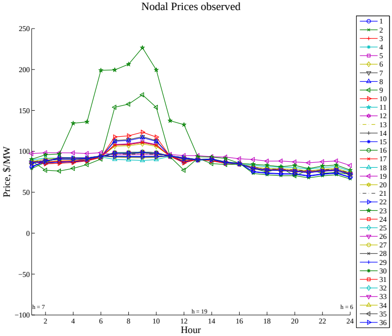
Final Nodal Prices

Cases 3 and 3E





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