On the Usage of Storage Systems in the Presence of Ramping Costs and High Penetration of Renewables

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Outline

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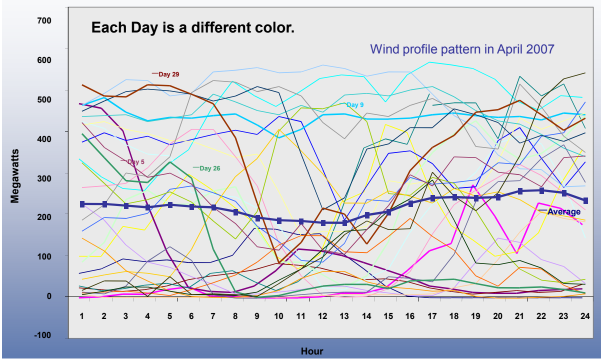
Variability of Wind

Source: NREL



And the press...

THE WALL STREET JOURNAL.
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REVIEW & OUTLOOK | DECEMBER 6, 2011

If the Lights Go Out

Regulators are letting EPA compromise U.S. electric reliability.

Say what you will about Obama Administration regulators, their problem has rarely been a failure to regulate. Which makes the abdication of the Federal Energy Regulatory Commission especially notable—and dangerous for the U.S. power supply.

Research Question and Contribution

Research Questions

- what is the capacity contribution of renewable energy sources (RES)?
- How to comply with reliability required by regulators?
- If using energy storage systems (ESS), how to optimally manage them?
- What is the economic cost to all participants in the market?

Contributions

- Framework for evaluating dynamic decisions for a SO. Salient features of physical system explicitly modeled.
- Potential for Demand Response, RES, ESS usage by system planners (ISO's)
- Stochastic model does contribute to explain decisions optimally

Outline

Day-Ahead Electricity Market without Random Generators

Problem Setup

Wind capacity task force: [Keane et al.(2010)], Reserve requirements for RES [Halamay et al.(2011)]

OPF

- [Carpentier et al.(1996)]
- [Kamat and Oren(2004)], Two Settlement Markets
- [Chen et al.(2005)], Co-Optimization
- [Condren et al.(2006)], Ex-post evaluation
- [Outhred(1998)], [Outhred(1998)], self-commitment
- [USCongress(2005)], Reliability Organization
- [NERC(2011)], Standards for Operation

UC

- [Baldwin et al.(1959)], [Baldick(1995)], UC problem
- [Sioshansi and Denholm(2010)], Ancillary Services
- [Meibom et al.(2010)], [Papavasiliou et al.(2011)]
- [Murillo-Sanchez and Thomas(1998)], [Bouffard et al.(2005)]
- [Wang and Shahidehpour(1995)] Integration UC, OPF
- [Bouffard et al.(2006)], Integration UC, SC-OPF

$\Downarrow$

Proposed Model

- Co-optimizing energy and reserves $\rightarrow$ solve optimal amounts [Chen et al.(2005)]
- Use of Network
- Economic management of demand
- Modeling of renewables uncertainty
- Engineering and Economical modeling of Energy Storage Systems (ESS)

Reserves in the System

Region	Requirement Definition
PJM	Based on 1% of the peak load during peak hours and 1% of the valley peak during off-peak hours.
NYISO	Set requirement based on weekday/weekend, hour of day, and season.
ERCOT	Based on 98.8th percentile of reserve utilized in previous 30 days and same month of previous year and adjusted by installed wind penetrations
CAISO	Use a requirement floor of 350-MW up and down reserves which can be adjusted based on load forecast, must-run instructions, previous CPS performance, and interchange and generation schedule changes.
MISO	Requirement made once a day based on conditions and before the day-ahead market closes.
ISO-NE	Based on month, hour of day, weekday/sat/sun.

Outline

Formulation

Stochastic program

$$f(x) = f_p(p, p_+, p_-) + f_r(r_+, r_-) + f_\delta(p) \\ + f_{\mathrm{lf}}(\delta_+, \delta_-) + f_s(p_{\mathrm{sc}}, p_{\mathrm{sd}}) \quad (1)$$

– cost of active power dispatch and redispatch

$$f_p(p, p_+, p_-) = \sum_{t \in T} \sum_{j \in J^t} \sum_{k \in K^{tj}} \psi_\alpha^{tjk} \sum_{i \in I^{tjk}} \Big[C_P^{ti}(p^{tijk}) \\ + C_{P+}^{ti}(p_+^{tijk}) + C_{P-}^{ti}(p_-^{tijk}) \Big] \quad (2)$$

– cost of contingency reserves

$$f_r(r_+, r_-) = \sum_{t \in T} \gamma^t \sum_{i \in I^t} \left[C_{R+}^{ti}(r_+^{ti}) + C_{R-}^{ti}(r_-^{ti}) \right] \quad (3)$$

Objective Function

– cost of load-following ramping (wear and tear)

$$f_\delta(p) = \sum_{t \in T} \gamma^t \sum_{\substack{j_1 \in J^{t-1} \\ j_2 \in J^t}} \phi^{tj_2j_1} \sum_{i \in I^{tj_20}} C_\delta^i (p^{tij_20} - p^{(t-1)ij_10}) \quad (4)$$

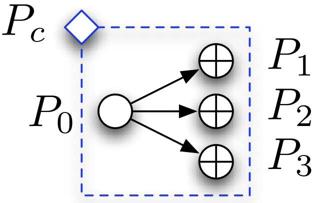
– cost of load-following ramp reserves

$$f_{\text{lf}}(\delta_+, \delta_-) = \sum_{t \in T} \gamma^t \sum_{i \in I^t} \left[C_{\delta+}^{ti}(\delta+^{ti}) + C_{\delta-}^{ti}(\delta_-^{ti}) \right] \quad (5)$$

– cost (or value, since it is negative) of expected leftover stored energy in terminal states

$$f_s(p_{\text{sc}}, p_{\text{sd}}) = -(C_{\text{sc}} p_{\text{sc}} + C_{\text{sd}} p_{\text{sd}}) \quad (6)$$

Co-Optimization



Graphically

1. power flow scenario, high probability case
2. power flow scenario, low probability case
3. root variable set, deviations, limits (e.g. contracts, incs/decs, reserves)
4. transition constraint

In a nutshell

→ Minimize the Expected Cost of Dispatch over Different States of the System

Constraints

Subject to the following constraints

- power balance equations

$$g^{tjk}(\theta^{tjk}, V^{tjk}, p^{tjk}, q^{tjk}) = 0 \tag{7}$$

- transmission flow limits, voltage limits, any other OPF inequality constraints

$$h^{tjk}(\theta^{tjk}, V^{tjk}, p^{tjk}, q^{tjk}) \leq 0 \tag{8}$$

Constraints

- reserve, redispatch and contract variables

$$0 \le p_+^{tijk} \le r_+^{ti} \le R_{\max+}^{ti} \quad (9)$$

$$0 \le p_-^{tijk} \le r_-^{ti} \le R_{\max-}^{ti} \quad (10)$$

$$p^{tijk} - p_c^{ti} = p_+^{tijk} - p_-^{tijk} \quad (11)$$

- ramping limits on transitions from base to contingency cases

$$-\Delta_-^i \le p^{tijk} - p^{tij0} \le \Delta_+^i, \quad k \neq 0 \quad (12)$$

- load-following ramping limits and reserves

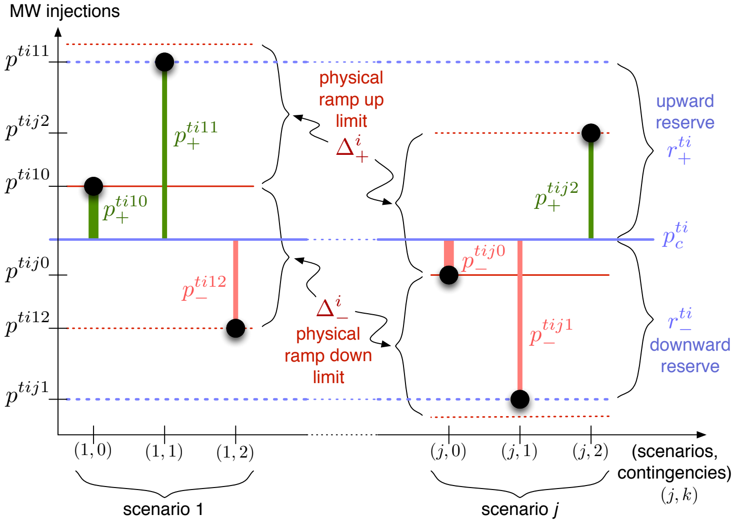
$$0 \le \delta_+^{ti} \le \delta_{\max+}^{ti} \quad (13)$$

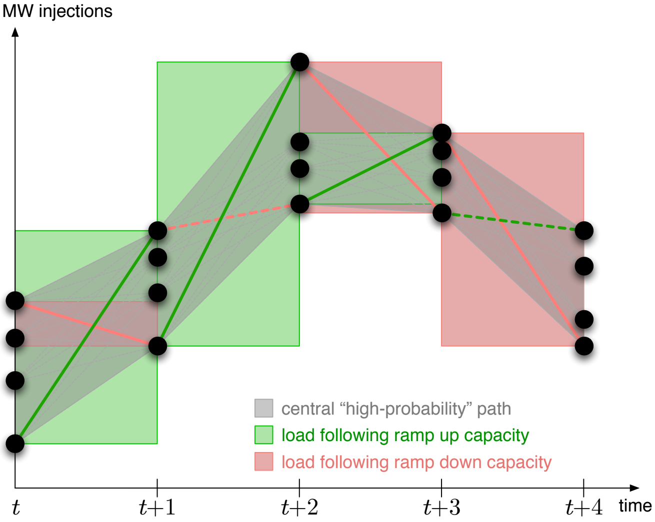
$$0 \le \delta_-^{ti} \le \delta_{\max-}^{ti} \quad (14)$$

$$p^{tij_2 0} - p^{(t-1)ij_1 0} \le \delta_+^{(t-1)i}, \quad j_1 \in J^t, j_2 \in J^{t+1} \quad (15)$$

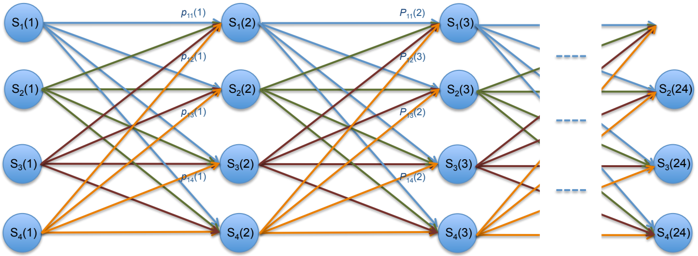
$$p^{(t-1)ij_1 0} - p^{tij_2 0} \le \delta_-^{(t-1)i}, \quad j_1 \in J^t, j_2 \in J^{t+1} \quad (16)$$

The Concept, Reserves

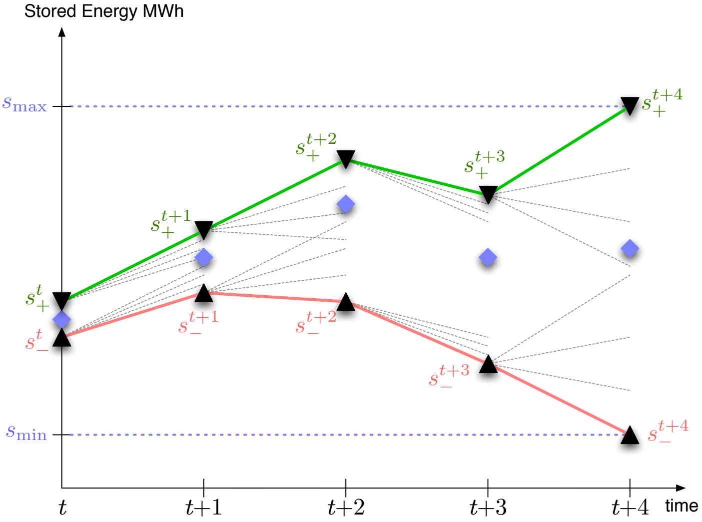



MW injections
central "high-probability" path
load following ramp up capacity
load following ramp down capacity
t
t+1
t+2
t+3
t+4
time

The Transitions between Periods



The Concept, Energy Storage



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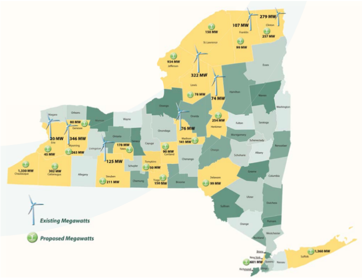
Input Information

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 et al.(2008)], heavily modified

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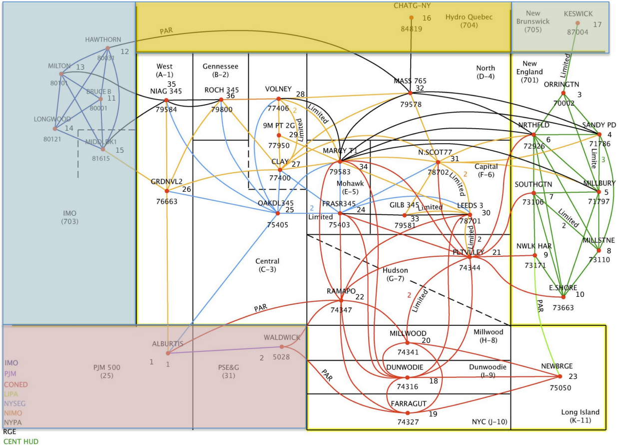
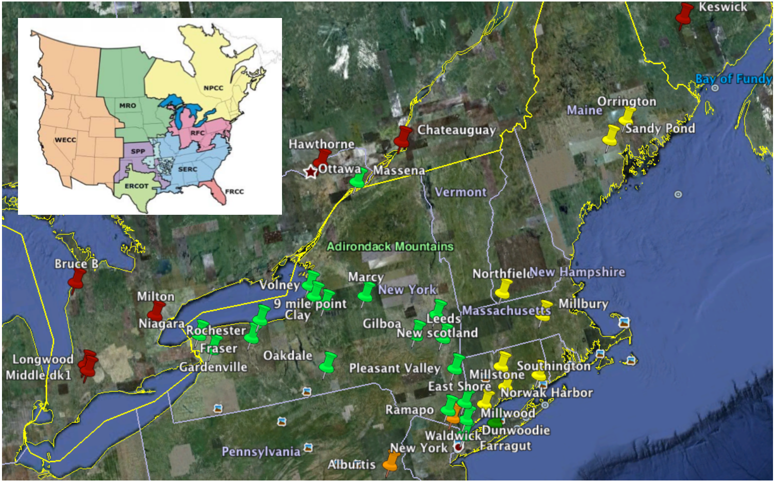
North East Test network

No changes in generation/load out of NY-NE



Geographical Location



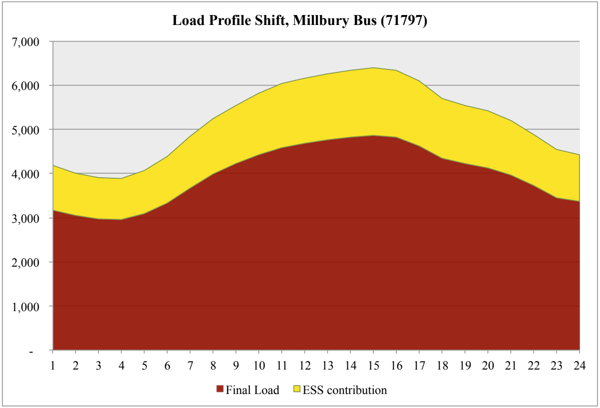
Details Fleet

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		

Back

How Deferrable Demand is Calculated



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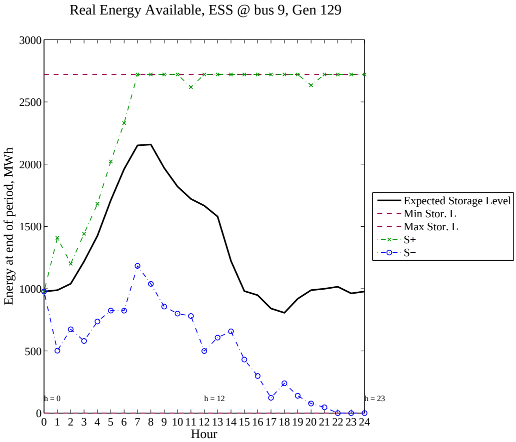
Cases Considered

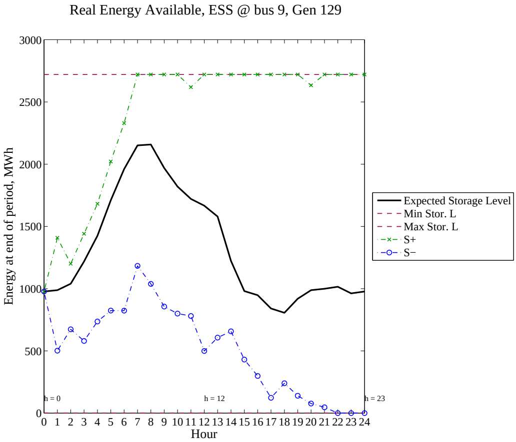
1. Case 1: Control Wind Case, status quo
2. Case 2: Wind case, 32 GW of wind power capacity added at 16 locations
3. Case 3: Deferrable Demand (DD), 34 GWh of storage energy capacity at demand centers
4. Case 4: Utility ESS (UE), 34 GWh of of storage energy capacity at wind sites

ESS Usage, Arbitrage



- Energy Available in ESS for Arbitrage Over Time

ESS Usage, Uncertainty



- Energy Available in ESS for Uncertainty Mitigation

Outline

Some Take-Aways

- The Markovian modeling of wind transitions and the topology used lead to capacity value of the wind considered
- It is is necessary to implement a layer of information with updated situational awareness, collecting the measurements necessary to price the new costs incurred and internalize the ramping of conventional demand.

	c1	(c2 - c1)	(c3 - c2)	(c4 - c2)
E[Wind Generation] (MWh/day)	0	143,638	16,929	20,502
E[Conventional Generation] (MWh/day)	1,174,081	(143,638)	(13,621)	(17,381)
LF Ramp-Up Reserve (MW/day)	22,226	60,814	(52,435)	(54,302)
LF Ramp-Down Reserve (MW/day)	19,822	55,917	(47,561)	(45,058)
Contingency Reserve (MW/day)	21,667	66,414	(64,838)	(64,245)
E[Load Shed] (MWh/day)	12.4	0.2	(8.9)	(10.1)

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Thank you

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