Modelling of Energy Storage Resources in New York Electricity Market

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NYISO

FERC technical conference: Increase Real-Time and Day-Ahead Market Efficiency and Enhancing Resilience Through Improved Software

June 23, 2020

NYISO by the numbers

19.8M
New Yorkers served

NYISO Footprint

435
Market Participants

11,173
circuit miles of transmission managed and monitored

161,114
total electric energy usage, in GWh, for 2018

Supply & Demand

33,956
record peak demand, in MW, July 2013

700+
power generating units

26%
of electric energy from renewables in 2018

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First stage: Commitment Model

- **Energy Market Design for Non-Continuous Storage Resources:**
  - Today, the NYISO treats large pumped storage as a generation when injecting and negative generation when withdrawing since they cannot continuously ramp from injection to withdrawal
  - NYISO does not impose a daily energy (MWh) constraint on its pumped storage resource. The MP manages the participation mode (injecting, withdrawing) of the resource via its offers
- **In the first stage, effort focused on changing its existing pumped storage model into a technology-agnostic energy storage resource (ESR) model while trying to meet the following objectives:**
  - Incorporate state-of-charge (SOC) or energy level management into the optimization
  - Incorporate the operating parameters for ESRs recommended in Order No. 841

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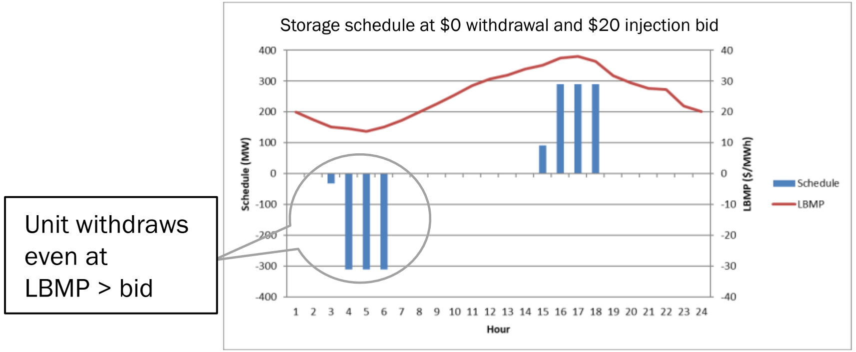
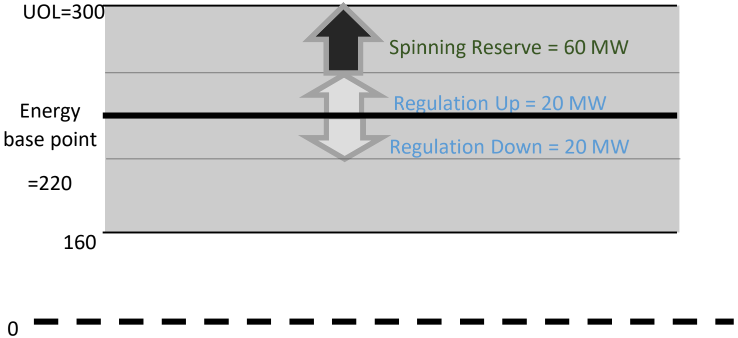
Some ESR Operational Features

- The general rule for evaluating offers is that resources should inject when LBMP > injectionOffer, and the resource should withdraw when LBMP < withdrawalBid
- This simple rule does not adequately address storage optimization when there is intertemporal coupling of schedules to withdraw and inject energy across the hours of the Day-Ahead Market (DAM) run, and the resource has a limited SOC
- ESRs will be able to provide ancillary services





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ESR Commitment Model Parameters

Registration		***Registration / Biddable***		***Biddable***	
Transition Time	*[minutes]*	Min. Load	*[MW]*	Incremental Bid Curve	*[$/MW]*
Upper Charge Limit	*[MWh]*	Min. Generation	*[MW]*	Beginning State of Charge	*[MWh]*
Lower Charge Limit	*[MWh]*	Min. Load Cost	*[$]*	Ending State of Charge	*[MWh]*
Charge Rate (Max. Load)	*[MW]*	Min. Generation Cost	*[$]*		
Discharge Rate (UOL)	*[MW]*	Start-up Cost	*[$]*	Bid Modes	*[-]*
Energy level (SoC)	*[Yes/No]*	Start-up Load Cost	*[$]*		
Min. Charge Time	*[minutes]*				
Max. Charge Time	*[minutes]*				
Min. Run Time	*[minutes]*				
Max. Run Time	*[minutes]*				
Min. Downtime	*[minutes]*				
Withdrawing conversion losses	*[%]*				
Injecting conversion losses	*[%]*				
Through-Put	*[MWh]*				
Response Rate(s)	*[MW/min]*				
Start-up Notification Time	*[minutes]*				
Maximum Stops per Day	*[n]*				

Key

Existing Parameter

Additional Storage Parameter

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Commitment Model Simulations

- Simulations showed that, under certain conditions, acceptable solution times for DAM clearing would be exceeded
- The simulations demonstrated that an ESR's capability normally can be more efficiently utilized by offering as a price taker in the DAM, and the solve time is within an acceptable range in this case
- Accurate ESR parameters, including inject/withdraw efficiency, are necessary to produce efficient DAM schedules for ESRs and other resources
- Some of the proposed constraints/parameters causing challenges to the optimization performance include:
  - Dead-band zone in the MW range
  - Min and max State of Charge (SOC)
  - Efficiency factor
  - Injection/withdrawal transition time
  - Offer incremental cost

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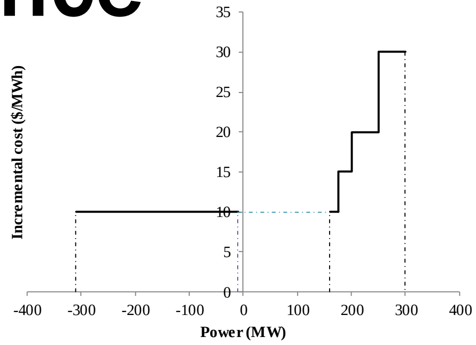
Constraints Impacting Performance



- **Dead-band**
  - Between withdrawal and injecting

$$Min.\ Injection\ Limit * Uwdr[S_{unit},t] \leq Inj[S_{unit},t] \leq Operating\ High\ Limit * Uinj[S_{unit},t] \quad \forall S_{unit} \epsilon Storage$$

$$Operating\ Low\ Limit * Uinj\ [S_{unit},t] \leq Wdr[S_{unit},t] \leq Min.\ Withdraw\ Limit * Uwdr[S_{unit},t] \quad \forall S_{unit} \epsilon Storage$$

- **Storage Mode Constraint**
  - A storage unit cannot be simultaneously injecting and withdrawing energy at the same time

$$Uwdr[S_{unit},t] + Uinj[S_{unit},t] \leq 1 \quad \forall S_{unit} \epsilon Storage$$

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Constraints Impacting Performance

- **Efficiency**

$$Energy[S_{unit}, t+1] = Energy[S_{unit}, t] - \frac{Inj[S_{unit}, t]}{EffG} - Wdr[S_{unit}, t] * EffP$$

  - It is necessary to differentiate withdrawing- and injecting- power (i.e. to use $Inj[S_{unit}, t]$ and $Wdr[S_{unit}, t]$) to model efficiency. This is true even without considering commitment statuses for the storage unit

- **Max. SOC**

$$Energy[S_{unit}, t] \leq Maximum\ Reservior\ Level\ \ (MWh)$$

- **Transition time**
  - Example: transition time of 1-hour

$$Uinj\ [S_{unit}, t] + Uwdr[S_{unit}, t+1] \leq 1 \qquad \forall S_{unit} \epsilon Storage$$

$$Uinj[S_{unit}, t+1] + Uwdr[S_{unit}, t] \leq 1 \qquad \forall S_{unit} \epsilon Storage$$

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Pursuing a Dispatch-Only Model

- **Due to complexities and performance concerns with the ternary design, the NYISO developed a dispatch only model for ESRs to comply with Order 841**
  - This decision was influenced by the fact that storage technology is almost exclusively batteries in the NYISO's interconnection queue
- **The dispatch-only model does not include a dead-band**

1. This approach reduces the number of binary variables needed to model an ESR from 2 to 1
2. A binary variable is still needed to model round-trip efficiency

- **ESR's are modeled as generators accounting for the following unique features:**

1. They can bid from negative to positive
2. ESR's are assumed to be always on (dispatch only, no commitment)
3. Their energy is limited
4. ESR's are assumed to be lossless when injecting, and having losses when withdrawing (ESR round-trip efficiency is applied on the withdrawal side). Therefor, their SOC rate of change is different when injecting and withdrawing

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Dispatch-Only Model Features

- **State of Charge**
  - $Energy[S_{unit},t+1]=Energy[S_{unit},t]-Inj[S_{unit},t]-Wdr[S_{unit},t]*Eff$
  - $Energy[S_{unit},t] \leq Maximum\ Storage\ Level\ \ (MWh)$

"Eff" is Roundtrip efficiency and is only applied when withdrawing

- **Efficiency**
  - It is necessary to differentiate injecting and withdrawing power (i.e. to use $Wdr[S_{unit},t]$ and $Inj[S_{unit},t]$) to model efficiency. This fact holds in a dispatch-only model as well
  - The following constraint is needed to ensure mutually exclusive injecting and withdrawing:

$$Inj[S_{unit},t] * Wdr[S_{unit},t] = 0$$

  - This type of constraint, called complementarity constraint, makes the problem nonlinear

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Linearization

- Complementarity constraint makes the problem non-linear. This linearization is proposed to make the problem convex:

$$0 \leq Inj[S_{unit}, t] \leq (1 - Us[S_{unit}, t]) * Inj^{max}[S_{unit}]$$
$$Us[S_{unit}, t] * Wdr^{min}[S_{unit}] \leq Wdr[S_{unit}, t] \leq 0$$

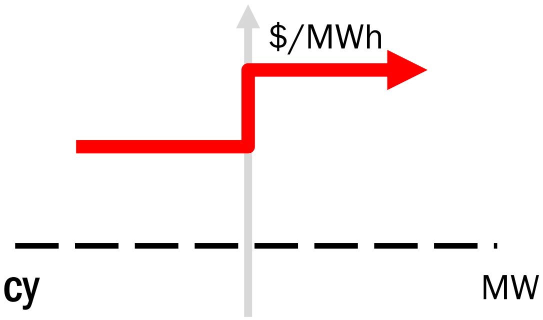
- Binary variable "Us" must be introduced to linearize this constraint, but its addition could make the problem much more difficult to solve.

Methods recommended to improve performance

- ABB's recommendation to improve performance include:

Consider a two-step bid-curve such that the following condition is met at the zero crossover point:

- Withdraw_incremental_cost ≤ Inject_incremental_cost * efficiency
- Under this condition, complementarity constraint is exactly relaxed:
  - If bids follow the condition, complementarity is never binding
  - Testing shows this conditions improve optimization performance



Reference: Z. Li, Q. Guo, H. Sun and J. Wang, "Sufficient Conditions for Exact Relaxation of Complementarity Constraints for Storage-Concerned Economic Dispatch," in *IEEE Transactions on Power Systems*, vol. 31, no. 2, pp. 1653-1654, March 2016.

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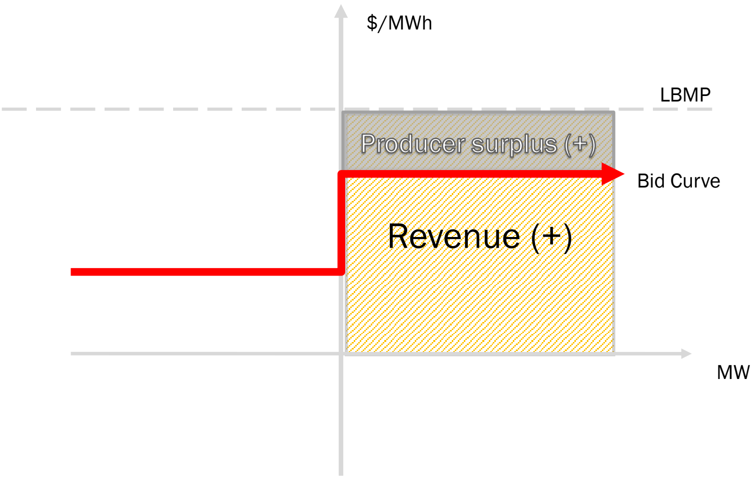
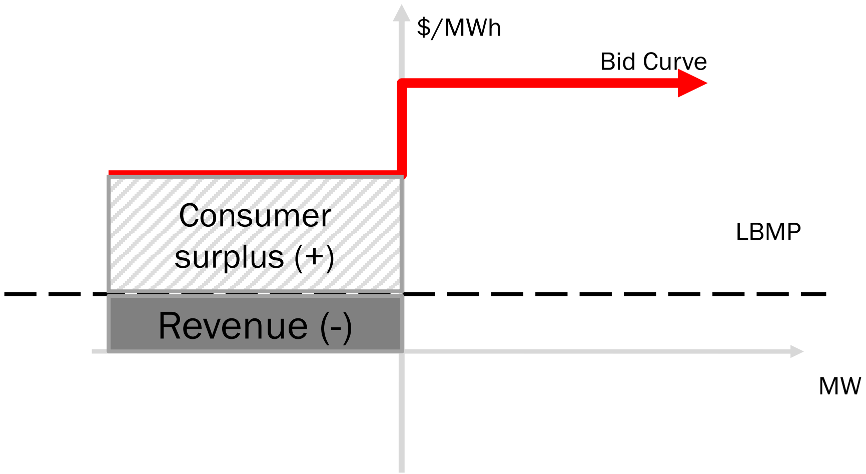
Revenue vs. Surplus

- Realistically, ESR would bid in such a way that net of injecting surplus and withdrawing surplus is positive



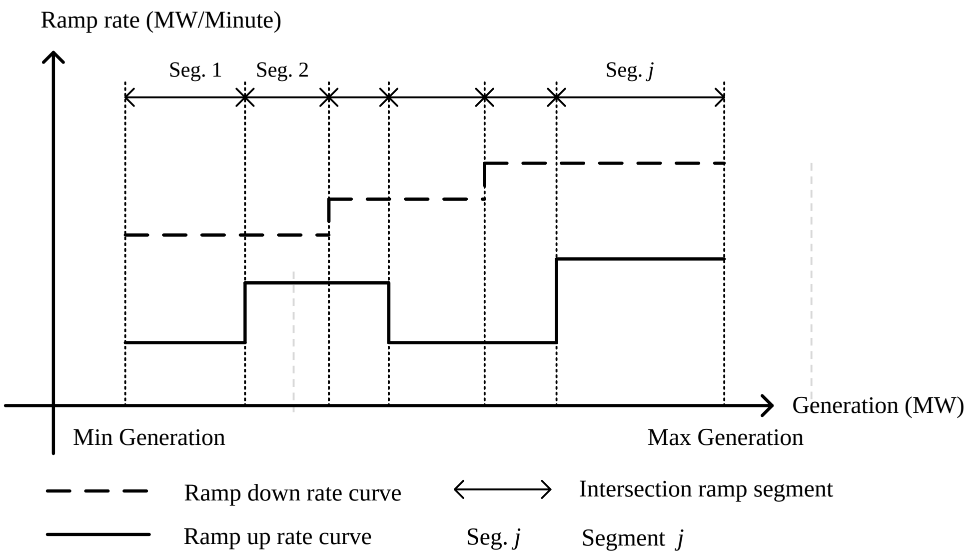


Efficiency Modeling

- There is already a mixed integer constraint in NYISO dispatch, modelling ramp rates as a piecewise constant curve

- Each segment j has binary variable $I_{i,t}^{H}$ to indicate whether it is dispatched or not

- These binary variables can be used to model efficiency, and inject-withdraw mode



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Conclusion

- NYISO's prototyping effort has achieved the goal of demonstrating acceptable performance for a model complying with the FERC order
- NYISO has successfully designed and tested an optimization prototype that considers physical features of ESR's, allows them to offer their full range (inject to withdraw) and set the price
- Future efforts will focus on further improving the model and introducing a full commitment model to ESR optimization

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Our mission, in collaboration with our stakeholders, is to serve the public interest and provide benefit to consumers by:

- Maintaining and enhancing regional reliability
- Operating open, fair and competitive wholesale electricity markets
- Planning the power system for the future
- Providing factual information to policymakers, stakeholders and investors in the power system

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Questions?