Energy Pricing with Non-Convexities: Education

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- Intuitively, it is useful to think of non-convexities as something that does not allow for a smooth or continuous representation of costs due to operational realities
  - Imagine a generator that only incurred costs when it produced energy and could produce from zero to its maximum as being smooth
- In reality, generation technologies have many non-convex operational characteristics
  - Start-up and shut-down costs
  - No load (minimum run level) costs
  - Minimum run and down times
  - Minimum output equal to maximum output like with CTs and Demand Resources

Market Clearing (Equilibrium Prices) Non-Convexities-1

- What are equilibrium or market clearing prices with smooth and continuous cost representations?
  – A set of prices such that
  1. The quantity demanded is equal to the quantity supplied…this is the energy balance constraint in SCED or the SCUC
  2. At these prices generation and load would not wish to change their respective output or consumption decision…this ensures prices are consistent with dispatch instructions

  – These are often referred to as "linear" prices and are not participant specific
  – LMPs are linear prices that are not participant specific…multiple market participants at the same location face the same prices

Simple Example…Assume Smooth, Continuous Operation

Simple Single Period Energy Only Example

Generator	Min Output if Committed (MW)	Max Output if Committed (MW)	Incremental Offer ($/MWh)
A	0	100	50
B	0	100	52
C	0	100	55
D	0	20	65

Source: Extended Locational Marginal Pricing (Convex Hull Pricing)
Paul Gribik and Li Zhang, Midwest ISO
June 2-3, 2010 FERC Technical Conference on Unit Commitment Software
Example altered to get continuous and smooth characteristics

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- In the previous example, prices would increase smoothly from $50/MWh for loads between 0 MW and 100 MW up to $65/MWh for load above 300 MW
- At a load of 250 MW, Generators A and B would be dispatched at their maximum 100 MW, Generator C would be dispatched at 50 MW. The price would be the marginal cost of C of $55/MWh
  - Generators A and B are happy with being at their maximums since the price is greater than marginal cost
  - Generator C is happy being dispatched anywhere in its range if the price is at least its marginal cost.

Market Clearing (Equilibrium Prices) Non-Convexities-2

- The problem is that with non-convexities, such prices may not exist that result in market clearing or an equilibrium
  - However, participant specific “uplift” payments act as a participant specific price by which a market clearing outcome can be ensured
  - The set of linear prices and participant specific prices are consistent with dispatch instructions
  - These participant specific prices can be derived solving a mixed integer program (MIP) where the optimal non-convex decision is set to equality in a linear or concave program to get linear and participant specific

Simple Single Period Energy Only Example

Generator	Min Output if Committed (MW)	Max Output if Committed (MW)	Incremental Offer ($/MWh)	No Load Offer ($/hr)
A	20	100	50	500
B	20	100	52	500
C	20	100	55	500
D	5	20	65	40

Source: *Extended Locational Marginal Pricing (Convex Hull Pricing)*
Paul Gribik and Li Zhang, Midwest ISO
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MidwestISO Energizing the Heartland

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- In the previous example, at a load of 250 MW, the equilibrium price was $55/MWh…will this price clear the market with non-convexities? NO.
  - Generator A is indifferent because it just covers its running cost plus its no load cost running at its maximum
  - Generator B requires an additional uplift payment, or unit specific price of $200 to ensure it will follow dispatch to be run at its maximum
  - Generator C requires an uplift payment or unit specific price equal to its no load cost of $500 to ensure it will follow dispatch.

Reflecting Costs of Non-Convexities in Linear Prices as Much as Possible

- <u>Problem:</u> How to get as much of these non-convex costs into prices ***AND*** also ensure that equilibrium conditions can be met
- In this simple example, at a load of 250 MW, we could set the price at the average cost of Generator C at $65/MWh
  - Generator D with a running cost of $65/MWh would still not want to be dispatched given its $40 no load cost
  - Using average cost of the last unit dispatched has the property of declining prices as load increases…load of 290 MW price is $60.55/MWh…likely not a desirable property for price formation
  - At a load of 230 MW the average cost of C would be $71.66/MWh…but now generator D would want to run full out and not follow dispatch instructions.

MISO Solution: Extended LMP

- Would allow the following to set price inclusive of their non-convex costs:
  - Inflexible fast start resources on-line or off-line to set prices and include start-up, shut down, and no load costs in the offers to be reflected in price
  - Emergency Demand Resources to set price in the real-time energy market and reserves market
  - Note this does not include the use of non-convex costs, or reliability needs for steam units to be run, but often at their minimums
- Pricing problems cited
  - Block loaded CTs and associated RSG
  - Transient shortage prices that are alleviated by starting up a fast resource
- Cannot eliminate uplift payments…trying to minimize them

MISO Solution: Extended LMP Implementation

- Requires *ex ante* and *ex post* prices
  - *Ex ante* LMP prices and dispatch signals are sent in RT operation such that prices and dispatch signals are consistent
  - *Ex post* LMP prices are calculated to minimize uplift and are used for settlement
  - Applies to day-ahead and real-time energy markets
- Only done looking at a single interval in SCED, and not using look-ahead logic
  - No inter-temporal effects or multi-interval dispatch costs included
  - Citing complexities of trying to do this
  - Often referred to in the December 2011 filing as approximate ELMP
- Implementation timeline
  - October 2014
  - Cites complexity and IT resources tied up through 2013 for a variety of reasons

- Assume for price formation purposes that inflexible CTs are perfectly flexible over their operating range to set prices
  - All Fixed Block Units are treated in the same way as inflexible CTs as described above
- The NYISO also has provisions in place to "confiscate" excess energy from resources not following dispatch so that there are no gains to be had from trying to deviate from dispatch
- Still requires uplift to be paid (in the form of opportunity cost) to units being backed down to make room for inflexible units