ASSESSMENT OF TRANSMISSION CONGESTION IMPACTS ON ELECTRICITY MARKETS

presentation by

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OUTLINE

- Transmission-unconstrained markets
- Transmission-constrained markets
- Market performance metrics
- Measures of congestion impacts
- Congestion and local market power
- Congestion impact evaluation examples in various systems
THE TIME FRAME FOR MARKETS

- We define one hour as the smallest indecomposable unit of time and focus on a specified hour $h$.
- We discuss the market decisions for that specified hour.

Markets decisions:

- Year-ahead ($h$-year)
- Month-ahead ($h$-month)
- Day-ahead ($h$-day)
- Specified hour
- Settlement time ($h + \text{month}$)
THE CENTRALIZED ELECTRICITY MARKET (CEM)

- We discuss the structure of the forward market by examining the day-ahead centralized electricity market.
- In fact, the day-ahead market is a collection of 24 separate commodity markets, one for each hour of the day; we focus on the market corresponding to the specified hour $h$ and suppress the hour $h$ in our notation.

$h - year$  $h - month$  $h - day$  $h$  $h + month$
CEM STRUCTURE

seller 1 \[ M\text{Wh} \] \[ \$ \] \[ M\text{Wh} \] \[ \$ \] \[ M\text{Wh} \] \[ \$ \] seller \( i \)

buyer 1

buyer \( j \)

buyer \( N \)

CEM operator
CEM PARTICIPANTS

- The CEM *operator* is in charge of this market and uses auctions to determine the prices and quantities bought and sold for each hour.
- Sellers are generation entities and brokers/marketers.
- Buyers are consumers, brokers/marketers, distribution entities and generation entities.
THE COMPETITIVE ELECTRICITY MARKET

- Sellers and buyers in the market submit sealed offers and bids, respectively, describing the price and quantity at which they are willing to sell/buy energy.
- The CEM operator determines the successful offers and bids and the market clearing price by maximizing the social surplus.
- The auction results determine the unit commitment and dispatch of the physical units.
SELLER \( i \) OFFER AND COSTS

The costs of seller \( i \) are given by the area under the curve:

\[
C_i(p_{S_i}) = \int_0^{p_{S_i}} \alpha_i(\xi) d\xi
\]

With offer curve \( \alpha_i(p_{S_i}) \) and price range \( [p_{S_i}^{\min}, p_{S_i}^{\max}] \).
BUYER $j$ BID AND BENEFITS

The benefits of buyer $j$ are given by the area under the curve

$$\mathcal{B}_j(p_{Bj}) = \int_0^{p_{Bj}} \beta_j(\xi) d\xi$$
THE SOCIAL WELFARE

The social welfare is defined as the total benefits of the buyers minus the total costs of the sellers:

\[ S \triangleq \sum_{j=1}^{N} B_j(P^{B_j}) - \sum_{i=1}^{M} C_i(P^{S_i}) \]

- **social welfare**
- **total benefits**
- **total costs**
MAXIMIZATION OF THE SOCIAL WELFARE

- The objective in markets is to maximize the social welfare, so as to determine the maximum net benefits for society.
- We neglect the transmission network constraints.
- The CEM operator solves the resulting optimization problem to determine the successful offers and bids.

\[
\begin{align*}
\text{max } & \quad S = \sum_{j=1}^{N} B_j(p_{B_j}) - \sum_{i=1}^{M} C_i(p_{S_i}) \\
\text{s.t. } & \quad \sum_{j=1}^{N} p_{B_j} = \sum_{i=1}^{M} p_{S_i} \quad \text{supply-demand balance}
\end{align*}
\]
MAXIMIZATION OF THE SOCIAL WELFARE

$/MWh

demand curve

market clearing price

social welfare

supply curve

market clearing equilibrium point

MWh/h

market clearing quantity
The market clearing price $\rho^*$ (system marginal price) is the change in the social welfare for a unit change in the market clearing quantity.

Each seller receives $\rho^*$ from the CEM operator for each MWh sold.

Each buyer pays $\rho^*$ to the CEM for each MWh bought.

The market clearing price is different from the offer/bid price of nearly every player.
THE THREE-BUS SYSTEM EXAMPLE

lossless system

$S_1$ ~ $S_2$

bus 1 ~ bus 2

$B_1$ ~ $B_2$

$B_3$

$S_3$

$\mathbf{f}_{13}^{\text{max}} = 200 \text{ MW}$

$\mathbf{j} 0.1$

$\mathbf{j} 0.1$

$\mathbf{j} 0.1$

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THREE-BUS SYSTEM: OFFERS AND BIDS

\[ S_1 \]
\[ \begin{array}{c}
10 \\
5 \\
\end{array} \]
\[ \begin{array}{c}
300 \\
600 \\
\end{array} \]

\[ B_1 \]
\[ \begin{array}{c}
70 \\
50 \\
\end{array} \]
\[ \begin{array}{c}
200 \\
300 \\
\end{array} \]

\[ S_2 \]
\[ \begin{array}{c}
20 \\
10 \\
\end{array} \]
\[ \begin{array}{c}
200 \\
600 \\
\end{array} \]

\[ B_2 \]
\[ \begin{array}{c}
80 \\
60 \\
\end{array} \]
\[ \begin{array}{c}
200 \\
400 \\
\end{array} \]

\[ S_3 \]
\[ \begin{array}{c}
29 \\
20 \\
\end{array} \]
\[ \begin{array}{c}
200 \\
450 \\
\end{array} \]

\[ B_3 \]
\[ \begin{array}{c}
300 \\
\end{array} \]
\[ \begin{array}{c}
800 \\
\end{array} \]

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THREE-BUS SYSTEM: TRANSMISSION UNCONSTRAINED EQUILIBRIUM

\[ S = 265,600 \]

\[ \lambda^* = 29 \]

<table>
<thead>
<tr>
<th>MWh/h</th>
<th>$/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 @ 5</td>
<td>300 @ 10</td>
</tr>
<tr>
<td>200 @ 10</td>
<td>400 @ 20</td>
</tr>
<tr>
<td>200 @ 20</td>
<td>100 @ 50</td>
</tr>
<tr>
<td>100 @ 29</td>
<td>1500</td>
</tr>
</tbody>
</table>

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## UNCONSTRAINED SYSTEM REVENUES AND PAYMENTS

<table>
<thead>
<tr>
<th>participant</th>
<th>quantity [MWh]</th>
<th>price [$/MWh]</th>
<th>revenue [$]</th>
<th>payments [$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>600</td>
<td>29</td>
<td>17400</td>
<td>-</td>
</tr>
<tr>
<td>S2</td>
<td>600</td>
<td>29</td>
<td>17400</td>
<td>-</td>
</tr>
<tr>
<td>S3</td>
<td>300</td>
<td>29</td>
<td>8700</td>
<td>-</td>
</tr>
<tr>
<td>B1</td>
<td>300</td>
<td>29</td>
<td>-</td>
<td>8700</td>
</tr>
<tr>
<td>B2</td>
<td>400</td>
<td>29</td>
<td>-</td>
<td>11600</td>
</tr>
<tr>
<td>B3</td>
<td>800</td>
<td>29</td>
<td>-</td>
<td>23200</td>
</tr>
<tr>
<td>total</td>
<td>1500</td>
<td>29</td>
<td>43500</td>
<td>43500</td>
</tr>
</tbody>
</table>
MARKET PERFORMANCE BASIC MEASURES

- The social welfare is a measure of the performance of the market as a whole but it does not provide insights about the performance of the individual players.

- We define two components of social welfare:
  - producer surplus
  - consumer surplus
For a seller $i$, the *individual producer surplus* measures the difference between the revenues received for the sale at the *market clearing price* and those that would be received at the offer price:

$$S_i^S = \rho^* \cdot p_{S_i} - C_i(p_{S_i}) \quad i = 1, \ldots, M$$

The total *producer surplus* is

$$S^S = \sum_{i=1}^{M} S_i^S$$
CONSUMER SURPLUS

For each buyer \( j \), the *individual consumer surplus* measures the difference between the payments for the commodity at the bid prices of the buyer and those at the *market clearing price*

\[
S_j^B = B_j(p_{B_j}) - \rho^* \cdot p_{B_j} \quad j = 1, \ldots, N
\]

- The total *consumer surplus* is

\[
S^B = \sum_{j=1}^{N} S_j^B
\]
THREE-BUS SYSTEM: TRANSMISSION UNCONSTRAINED EQUILIBRIUM

$/MWh

$MWh/h

$\lambda^* = 29$

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THREE-BUS SYSTEM: TRANSMISSION UNCONSTRAINED DISPATCH

\[ f_{13}^{\text{max}} = 200 \text{ MW} \]

\[ B_1 = 300 \text{ MW} \]

\[ S_1 \sim 600 \text{ MW} \]

\[ B_2 = 400 \text{ MW} \]

\[ S_2 \sim 600 \text{ MW} \]

\[ B_3 \]

\[ S_3 \sim \]

\[ 800 \text{ MW} \]

\[ 300 \text{ MW} \]

IGO

lossless system

\[ \lambda^* = 29 \]
THREE-BUS SYSTEM: PTDFs
THREE-BUS SYSTEM: TRANSMISSION UNCONSTRAINED DISPATCH

\[ f_{13} = \frac{2}{3} \cdot 300 + \frac{1}{3} \cdot 200 = 266.67 \]

violation of the line constraint since \( f_{13} > f_{13}^{\text{max}} \)

\[ \lambda^* = 29 \]
THREE-BUS SYSTEM: TRANSMISSION UNCONSTRAINED DISPATCH

- The transmission unconstrained dispatch is infeasible because the line flow $f_{13}$ violates limit $f_{13}^{max}$.

- The net injections at buses 1 and 2 have to be modified to drive the network to feasibility.

- The only choice of buyer $B_3$ is to bid sufficiently high to induce seller $S_3$ to provide supply to meet his load.
SOCIAL WELFARE MAXIMIZATION UNDER TRANSMISSION CONSTRAINTS

\[
\text{max } S = \sum_{j=1}^{N} B_j(p_{B_j}) - \sum_{i=1}^{M} C_i(p_{S_i})
\]

s.t.
\[
g_n(p_{S_1}, \ldots, p_{S_M}; p_{B_1}, \ldots, p_{B_N}) = 0 \quad \forall \text{ node } n
\]

\[
f_\ell(p_{S_1}, \ldots, p_{S_M}; p_{B_1}, \ldots, p_{B_N}) \leq f_\ell^{\text{max}} \quad \forall \text{ line } \ell
\]
CONGESTED LINE AND SYSTEM

- We call a transmission line \( \ell \) congested if the real power line flow violates the line limit, i.e., the corresponding inequality constraint becomes binding:

\[
f_\ell(p_{S_1}, \ldots, p_{S_M}; p_{B_1}, \ldots, p_{B_N}) = f_\ell^{\text{max}}
\]

- We call the transmission system congested if there are one or more congested lines in the network.
CONGESTION

- Power system reliability considerations require secure operations not only under base case conditions but also under the set of postulated contingency cases.
- Congestion occurs if one or more limit violations are detected either under the base case or in any of the contingency cases.
- The incorporation of transmission considerations requires the representation of the base case and all the postulated contingency cases.
THREE-BUS SYSTEM: TRANSMISSION UNCONSTRAINED DISPATCH

- The transmission unconstrained dispatch is infeasible because the line flow $f_{13}$ violates limit $f_{13}^{\text{max}}$.

- The net injections at buses 1 and 2 have to be modified to drive the network to feasibility.

- The only choice of buyer $B_3$ is to bid sufficiently high to induce seller $S_3$ to provide supply to meet his load.
THREE-BUS SYSTEM: ENSURING TRANSMISSION FEASIBILITY

\[
(300 - x) \, MW \quad \rightarrow \quad 1 \quad \rightarrow \quad 2 \quad \rightarrow \quad (200 - 2x) \, MW
\]

\[
(500 - 3x) \, MW
\]

\[
\frac{2}{3} \cdot (300 - x) + \frac{1}{3} \cdot (200 - 2x) = 200 \, MW
\]
THREE-BUS SYSTEM: REDISPATCH OF SUPPLY

- $x$ is the amount of redispatch due to the impacts of the $f_{13}^{\text{max}}$ constraint on seller $S_1$.
- $2x$ is the amount of redispatch due to the impacts of the $f_{13}^{\text{max}}$ constraint on seller $S_2$.

Redispatch calculation:

\[
\frac{2}{3} \cdot (300 - x) + \frac{1}{3} \cdot (200 - 2x) = 200 \text{ MW}
\]

so that

\[
x = 50 \text{ MW}
\]
THREE-BUS SYSTEM: REDISPATCH OF SUPPLY

- Then, the IGO reduces the output of seller $S_1$ by 50 MW and that of seller $S_2$ by 100 MW.
- Since there is a willingness to pay by the buyer $B_3$, the IGO increases the output of seller $S_3$ by 150 MW.
- The constrained dispatch changes the output of each seller and may impact the load supplied to buyer $B_3$. 
THREE-BUS SYSTEM: TRANSMISSION CONSTRAINED DISPATCH

\[ S_1 \sim 550 \text{ MW} \]

\[ S_2 \sim 500 \text{ MW} \]

\[ b_{13}^{\text{max}} = 200 \text{ MW} \]

\[ B_1 \sim 300 \text{ MW} \]

\[ B_2 \sim 400 \text{ MW} \]

\[ B_3 \sim 800 \text{ MW} \]

\[ S_3 \sim 450 \text{ MW} \]

lossless system
THREE-BUS SYSTEM: \textit{LMPs}

\[ \begin{align*}
\lambda_1^* &= 10 \\
\lambda_2^* &= 20
\end{align*} \]

\textit{lossless system}
THREE-BUS SYSTEM: \( LMPs \)

\[
S_1 \sim 550 + \Delta P_1 \text{ MW} \quad 500 + \Delta P_2 \text{ MW} \sim S_2
\]

\[
\lambda_1^* = 10 \quad \lambda_2^* = 20
\]

Lossless system

\[
\begin{align*}
B_1 & = 300 \text{ MW} \\
B_2 & = 400 \text{ MW}
\end{align*}
\]

\[
\begin{align*}
\Delta P_1 + \Delta P_2 & = 1 \\
\frac{2}{3} \cdot \Delta P_1 + \frac{1}{3} \cdot \Delta P_2 & = 0 \\
\Delta P_1 & = -1 \\
\Delta P_2 & = 2
\end{align*}
\]
THREE-BUS SYSTEM: $LMPs$

$S_1 \sim 550 \text{ MW}$
$S_2 \sim 500 \text{ MW}$

$\lambda_1^* = 10$
$\lambda_2^* = 20$

$B_1 = 300 \text{ MW}$
$B_2 = 400 \text{ MW}$

$Ico$

$\lambda_3^* = 2 \cdot 20 + (-1) \cdot 10 = 30$

$B_3 = 800 \text{ MW}$
$S_3 \sim 450 \text{ MW}$

lossless system
THREE-BUS SYSTEM: \( \text{LMPs} \)

\[
\begin{align*}
\lambda_1^* &= 10 \\
\lambda_2^* &= 20 \\
\lambda_3^* &= 30
\end{align*}
\]

\[
\begin{align*}
S_1 &\sim 550 \text{ MW} \\
S_2 &\sim 500 \text{ MW} \\
B_1 &\sim 300 \text{ MW} \\
B_2 &\sim 400 \text{ MW} \\
f_{13}^{\text{max}} &= 200 \text{ MW} \\
B_3 &\sim 800 \text{ MW} \\
S_3 &\sim 450 \text{ MW}
\end{align*}
\]

lossless system
SOCIAL WELFARE AND SURPLUSES

$/MWh

consumer surplus

producer surplus

MWh/h
SOCIAL WELFARE AND SURPLUSES

$/MWh

consumer surplus

$/MWh

ρ_B

congestion rents

ρ_S

market efficiency loss

dead-weight loss

producer surplus
IMPACTS OF CONGESTION

- Congestion in the system leads to a change from the single market equilibrium point to different nodal equilibrium points.
- Change in the preferred schedule for the required generation – demand balance may lead to possible curtailment in production or consumption.
- The individual surpluses of the players change from the unconstrained market values to those in the markets at each bus under constrained conditions.
CONGESTION MEASURES

- The impacts of congestion may be measured in terms of the energy that needs to be redispached and/or the financial costs on the various players.

- Measures of congestion impacts in $
  - redispach costs
  - congestion rents
  - market efficiency loss
CONGESTION RENTS

- In the constrained case we have different prices at the different zones, so the players may face different clearing prices depending on their locations.

- The social welfare in this case is given by

\[
S^\ast = S^S + S^B + \sum_{j=1}^{N} \rho_j \cdot p_{Bj} - \sum_{i=1}^{M} \rho_i \cdot p_{Si} + \kappa
\]

where **\kappa** represents the congestion rents.
CONGESTION RENTS

- In the constrained case, the congestion rents are part of the social welfare
  \[ S^\hat{} = S^{\hat{}B} + S^{\hat{}S} + \kappa \]

- The congestion rents are also known as *merchandising surplus* and correspond to the difference between the amounts paid by buyers and the amounts received by sellers; the congestion rents are collected by the IGO.
Market Efficiency Loss

- Congestion may produce a reduction in the social welfare of the market due to the physical network constraints.

- This reduction is called *market efficiency loss* and is defined by

\[
\tilde{E} = - (S_c - S_u)
\]

- In economics, the *market efficiency loss* is also known as *deadweight loss*.
THREE - BUS SYSTEM: MARKET EFFICIENCY LOSS

- For the unconstrained case we have

\[ S \bigg|_u = 265,600 \]

- For the constrained case we have

\[ S \bigg|_c = 263,750 \]

- The market efficiency loss is

\[ \mathcal{E} = - \left( S \bigg|_c - S \bigg|_u \right) = 1,850 \]
### THREE - BUS SYSTEM: CONSTRAINED CASE

<table>
<thead>
<tr>
<th>seller</th>
<th>surplus ($)</th>
<th>buyer</th>
<th>surplus ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$B_1$</td>
<td>16,000</td>
</tr>
<tr>
<td>$S_1$</td>
<td>1,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_2$</td>
<td>2,000</td>
<td>$B_2$</td>
<td>20,000</td>
</tr>
<tr>
<td>$S_3$</td>
<td>2,250</td>
<td>$B_3$</td>
<td>216,000</td>
</tr>
<tr>
<td>total</td>
<td>5,750</td>
<td>total</td>
<td>252,000</td>
</tr>
</tbody>
</table>

| congestion rents ($) | 6,000 |
| social welfare ($)   | 263,750 |
CAUSES OF SOCIAL WELFARE REDUCTION

- The redispatch of higher-priced units to replace the output of the lower-priced generation
- The decrease in market efficiency
- The decrease in the producer surplus of some sellers
- The decrease in the consumer surplus of some buyers
- The needs for ancillary services provided by sellers charging higher prices
- The creation of situations that may lead to the exercise of market power
ADDITIONAL CONGESTION IMPACTS

- Increase of costs for delayed connection of new generation
- Reduction in reliability
- Pollution from older and less efficient plants that must be operated only for reliability purposes
THREE-BUS SYSTEM: \( LMPs \)

\[
\begin{align*}
S_1 &\sim 550 \text{ MW} \\
\lambda_1^* &= 10 \\
S_2 &\sim 500 \text{ MW} \\
\lambda_2^* &= 20 \\
B_1 &\sim 300 \text{ MW} \\
\lambda_3^* &= 30 \\
S_3 &\sim 450 \text{ MW} \\
B_2 &\sim 400 \text{ MW} \\
\end{align*}
\]

*LOSSLESS SYSTEM*
We investigate the impacts of changing the offer of seller $S_3$ for his second block by varying the offer price from 29 to 330 \$/MWh; the other offers/bids remain unchanged.

We evaluate the resulting surpluses for the various values of the offers submitted.
THREE-BUS SYSTEM: $\lambda_3^*$ AND $S_{S_3}$

The graph shows the offer for the last block of seller $S_3$ in $$/MWh. The price interval where increasing price does not impact the market outcomes is highlighted. The graph also indicates $\lambda_3^*$ and $S_{S_3}$. © 2003 George Gross, University of Illinois at Urbana-Champaign, All Rights Reserved.
THREE-BUS SYSTEM: PRODUCER SURPLUS

offer for the last block of seller $S_3$ in $$/MWh

$S_1$, $S_2$, $S_3$
THREE-BUS SYSTEM: CONSUMER SURPLUS

offer for the last block of seller $S_3$ in $$/MWh

$S_{B_1}$

$S_{B_2}$

$S_{B_3}$
THREE-BUS SYSTEM: MARKET PERFORMANCE MEASURES

congestion rents

market efficiency losses

offer for the last block of seller $S_3$ in $$/MWh$
LOCAL MARKET POWER

Market power is the ability of a firm to profitably raise the price of a product.

The exercise of market power may be carried out by:

- the physical withholding of units
- the financial withholding of units

Transmission constraints may create locational market power since they may set up area markets with limited importing capability.
SIMULATION STUDIES

- A seller changes his offer prices by varying the offer price for the last block offered.
- We study the resulting variations of the producer surplus, consumer surplus, congestion rents and market efficiency loss.
- The simulations performed on different systems of various sizes are reported.
THE SEVEN-BUS SYSTEM EXAMPLE

<table>
<thead>
<tr>
<th>offers</th>
<th>S_1</th>
<th>200@5</th>
<th>600@10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S_3</td>
<td>200@40</td>
<td>100@60</td>
</tr>
<tr>
<td></td>
<td>S_4</td>
<td>200@10</td>
<td>300@15</td>
</tr>
<tr>
<td></td>
<td>S_5</td>
<td>100@20</td>
<td>300@40</td>
</tr>
<tr>
<td></td>
<td>S_7</td>
<td>200@30</td>
<td>200@40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>bids</th>
<th>B_1</th>
<th>100@80</th>
<th>100@50</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B_2</td>
<td>200@100</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>B_3</td>
<td>800@500</td>
<td>-</td>
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<td></td>
<td>B_4</td>
<td>200@140</td>
<td>200@120</td>
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<tr>
<td></td>
<td>B_5</td>
<td>100@80</td>
<td>200@50</td>
</tr>
<tr>
<td></td>
<td>B_6</td>
<td>200@120</td>
<td>200@110</td>
</tr>
<tr>
<td></td>
<td>B_7</td>
<td>100@90</td>
<td>100@50</td>
</tr>
</tbody>
</table>
SEVEN-BUS SYSTEM: PRODUCER SURPLUS

impacts of changes in the flow directions

offer for the last block of seller $S_3$ in $$/MWh
SEVEN-BUS SYSTEM: CONSUMER SURPLUS

Offer for the last block of seller $S_3$ in $\$/MWh
SEVEN-BUS SYSTEM SENSITIVITY

congestion rents

market efficiency losses

offer for the last block of seller $S_3$ in $\$/MWh
THE 57-BUS SYSTEM
THE 57-BUS SYSTEM: CONGESTION RENTS

offer of seller $S_2$ in $$/MWh
THE 57-BUS SYSTEM:
MARKET EFFICIENCY LOSS

$ \text{offer of seller } S_2 \text{ in } \$/\text{MWh}$
SIMULATION RESULTS

- Congestion situations produce, typically, changes in the consumer and social surpluses, the additional *congestion rents* component of the *social welfare*, and the market efficiency loss with respect to the unconstrained case.

- Congestion creates situations which are conducive to the exercise of market power.

- Under price-responsive demand, when a particular seller increases his offer prices, the impacts of congestion on the individual players and the entire market are bounded due to the asymptotic nature of the outcomes.
SIMULATION RESULTS

- We observe the existence of *free-riders* in the market on both the supply- and demand-sides.
- There are also players that are negatively impacted by the exercise of market power.
- The simulations underline the critical role of the network topology and the relative location of the market players in determining who are the losers and the gainers as a result in such a market power exercise attempt.
RTO CONGESTION COSTS

CAISO data excludes intra-zonal congestion ISO-NE data represents mitigated congestion costs
FUTURE WORK

- Modeling
  - incorporation of real power losses
  - detailed representation of additional constraints
  - incorporation of contingency case analysis

- Parametric analysis
  - demand-side variation
  - multiple players variation of offer/bid prices

- Study of the market efficiency loss composition
AN ALTERNATE VIEW OF CONGESTION