Network models for nodal pricing

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Outline

- Alternative models of AC networks & their application in nodal electricity spot markets:
  - Transport model, DC loadflow, AC loadflow
- Illustrative three & five node examples
- Five node network for AC loadflow studies
- AC loadflow results for five node network:
  - With nodal voltage constraints
  - With nodal voltage preference bids & offers
- Discussion & conclusions
Alternative models of AC networks for electricity spot markets

- **Transport model**
  - Models real power but ignores reactive power
  - Models series losses & flow constraints
  - Assumes independent flow on each element:
    - Can be used for the near-radial NEM but not meshed networks

- **DC load flow model:**
  - Models real power but ignores reactive power
  - Models series losses & flow constraints
  - Models flow sharing between parallel elements

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Alternative models of AC networks for electricity spot markets

- **AC loadflow model**
  - Models real & reactive power & nodal voltages
  - Accurate representation of network elements:
    - Series & shunt losses & reactive power
    - Thermal limits
    - Can model transformer tap-changers & reactive power resources
  - Extensive data requirements:
    - Network impedance data
    - Reactive power resources & voltage limits
Comparison of alternative models for AC networks

- Transport model (very abstract):
  - Judgement-determined parameters & constraints
  - Used in NEM to model “notional interconnectors”
- DC loadflow model (quite abstract):
  - Assumes voltage control is an ancillary service that can be de-coupled from network power flow
- AC loadflow model (least abstract):
  - Reactive power prices derived from node-voltage limits
  - Bids & offers can include voltage-value functions

Meshed networks

- A meshed network contains at least one loop:
  - At least two network elements operate in parallel
- Flows in parallel network elements are inversely proportional to element impedances:
  - Voltage drops across parallel elements are equal
- Impedance = reactance if no network losses:
  - Element resistances are then all zero
- Flow constraints can propagate through the network
Nodal spot markets: 3-node network, DC loadflow

No network flow constraints or losses

- **G1**: 1000 MW, $20/MWh
- **G2**: 1000 MW, $40/MWh
- **C3**: 900 MW

Spot market income ($/hr)
- **G1**: +18,000
- **G2**: 0
- **C3**: -18,000

Each line has:
- no losses
- equal reactance
- no flow constraints

Nodal spot markets: 3-node network, DC loadflow

One constrained link

- **G1**: 1000 MW, $20/MWh
- **G2**: 1000 MW, $40/MWh

100 MW Limit

Spot market income ($/hr)
- **G1**: +12,000
- **G2**: +12,000
- **C3**: -27,000
- **L12**: +2,000
- **L13**: +5,000
- **L23**: -4,000

Each line has:
- no losses
- equal reactance
- Line 1-2 has 100 MW flow limit
Nodal spot markets: 3-node network, DC loadflow

*Constrained link disconnected*

\[ \text{G1: 1000 MW} \quad \text{G2: 1000 MW} \]
\[ $20/MWH \quad $40/MWH \]

\[ \text{900 MW} \quad 0 \quad 2 \]
\[ \text{Infinite impedance} \]

\[ \text{C3: 900 MW} \]

Spot market income ($/hr)
- G1: +18,000
- G2: 0
- C3: -18,000
- L12: 0
- L13: 0
- L23: 0

Each line has:
- no losses
- equal reactance
- Line 1-2 has been disconnected

Meshed network elements are mutually dependent:
- Unless they can be independently controlled
- Switching ‘weak’ elements off may even improve economic outcome (unlike radial network)

Spot market alone gives perverse incentives:
- Network earns more when flows are constrained
- Some generators may benefit from constrained network operation

DC-loadflow model doesn’t incorporate voltage-related issues
Five node example
(no line losses, DC load flow, after PJM example)

<table>
<thead>
<tr>
<th>Node</th>
<th>Generation (MW)</th>
<th>Price ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>15</td>
</tr>
<tr>
<td>B</td>
<td>110</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>520</td>
<td>30</td>
</tr>
<tr>
<td>D</td>
<td>200</td>
<td>30</td>
</tr>
<tr>
<td>E</td>
<td>600</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Total dispatched generation = 900 MW = total load

Lessons from 5 node DC loadflow example

- Nodal prices for a 5 node network with a single line constraint can be computed:
  - Two marginal generators set local prices & remaining nodal prices derived from these:
    - Requires an accurate network model, including impedances & flow constraints
  - Low price at Node E ($10.4 /MWh) because a 1 MW load incr. at Node E would be met by:
    - Increasing the output of Ga2 >1MW @ $15/MWh
    - Reducing the output of Gd <1MW @ $30/MWh
    - To give a net cost of $10.4 /MWh
- DC loadflow doesn’t address voltage issues
Five-node network for illustrative studies of nodal pricing using AC loadflow model (Pamudji, UNSW, 1995)

Bid & offer data for 5 node model assuming preference-revealing behaviour (data sets A & B) (Pamudji, UNSW, 1995)
Bid & offer data sets A & B
(ignoring network effects) (Pamudji, UNSW, 1995)

Bid & offer price data for set A by node (c/kWh) (Pamudji, UNSW, 1995)
AC loadflow model with voltage constraints
(Pamudji, UNSW, 1995)

- Assumptions for this study:
  - Reactive power offer prices are always zero
  - Loads are constant power factor & independent of voltage
  - Line capacitances are modelled, but not line shunt losses
  - Node voltages must lie in the range: 0.95 ≤ V ≤ 1.05

- Examples considered
  1. Base case: unconstrained line flows, adequate generation
  2. Constrained generating capacity, unconstrained network
  3. Flow constraint on line 1 @ 0.8 pu (unconstrained 0.89pu)
  4. Binding voltage constraint, V = 0.97 @ node 5 (load pf 0.9)
  5. Increased network losses (line resistances +5%, +10%)
  6. Effects of different load power factors

Base case result (data set A) (Pamudji, UNSW, 1995)

- Values in bold indicate a marginal node
- Pr = price for real power

<table>
<thead>
<tr>
<th>Node</th>
<th>V (pu)</th>
<th>Pr (pu)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.05</td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.02</td>
<td>4.14</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.81</td>
<td>0.08 + j0.24</td>
<td>L3, 0.06 + j0.18</td>
</tr>
<tr>
<td>4</td>
<td>1.03</td>
<td>4.28</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.99</td>
<td>4.33</td>
<td></td>
</tr>
</tbody>
</table>

- Gen: 1.70
- Industry benefit: 75.6
- Losses: 0.05
- Network revenue: 2.1

Additional notes:
- No1: 0.75
- No2: 0.55
- Shb: 2.0
- Sol: 0.4
- Gen: 1.70
- Industry benefit: 75.6
- Losses: 0.05
- Network revenue: 2.1

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Constrained generation (data set B) (Pamudji, UNSW, 1995)

Line 1 constrained @ 0.8 pu (0.89 unconstrained) (Pamudji, 1995)
### Voltage constraint (0.9 pf loads, V ≥ 0.97 @ node 5) (Pamudji, 1995)

#### Nodal Active power price (c/kWh)

<table>
<thead>
<tr>
<th>Case</th>
<th>Data A</th>
<th>Data B</th>
<th>Voltage magnitude (per unit)</th>
<th>Case</th>
<th>Data A</th>
<th>Data B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>V const’d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V ≥ 0.97</td>
<td>North</td>
<td>1.05</td>
<td>0.98</td>
</tr>
<tr>
<td>North</td>
<td>4.00</td>
<td>5.53</td>
<td>4.00</td>
<td>South</td>
<td>1.00</td>
<td>1.01</td>
</tr>
<tr>
<td>South</td>
<td>4.14</td>
<td>5.72</td>
<td>5.01</td>
<td>Lake</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>Lake</td>
<td>4.28</td>
<td>5.90</td>
<td>4.66</td>
<td>Main</td>
<td>0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>Main</td>
<td>4.30</td>
<td>5.93</td>
<td>5.12</td>
<td>Elm</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Elm</td>
<td>4.36</td>
<td>6.02</td>
<td>5.96</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Nodal Reactive power price (c/kWh)

<table>
<thead>
<tr>
<th>Case</th>
<th>Data A</th>
<th>Data B</th>
<th>Voltage magnitude (per unit)</th>
<th>Case</th>
<th>Data A</th>
<th>Data B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>V const’d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V ≥ 0.97</td>
<td>North</td>
<td>1.05</td>
<td>0.98</td>
</tr>
<tr>
<td>North</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>South</td>
<td>0.10</td>
<td>0.13</td>
</tr>
<tr>
<td>South</td>
<td>0.10</td>
<td>0.13</td>
<td>1.55</td>
<td>Lake</td>
<td>0.16</td>
<td>0.20</td>
</tr>
<tr>
<td>Lake</td>
<td>0.16</td>
<td>0.20</td>
<td>1.80</td>
<td>Main</td>
<td>0.17</td>
<td>0.22</td>
</tr>
<tr>
<td>Main</td>
<td>0.17</td>
<td>0.22</td>
<td>2.03</td>
<td>Elm</td>
<td>0.21</td>
<td>0.27</td>
</tr>
<tr>
<td>Elm</td>
<td>0.21</td>
<td>0.27</td>
<td>4.22</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Value of consumption for bid Eb2 (Voltage constrained case)

<table>
<thead>
<tr>
<th>Nodal Price</th>
<th>Active P</th>
<th>Reactive P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption</td>
<td>0.0615</td>
<td>0.0298</td>
</tr>
<tr>
<td>Value</td>
<td>0.3663</td>
<td>0.1257</td>
</tr>
<tr>
<td>(0.3663+ 0.1257)/ 0.0615 = 8.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Effect of line resistance (% of base case) on active power prices (Pamudji, UNSW, 1995)

<table>
<thead>
<tr>
<th>Price change</th>
<th>Data set A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
</tr>
<tr>
<td>+1.0%</td>
<td></td>
</tr>
<tr>
<td>-1.0%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Price change</th>
<th>Data set B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

r = 105%

r = 110%

*Note: The table and diagram are not fully transcribed due to the limitations of text-based transcription.*
Summary of AC network results

- Either offers or bids can be marginal (data sets A or B)
- Line resistances cause nodal prices to differ even when network flow is not constrained
- More than one node can be marginal:
  - When network flow constraints or voltage limits restrict network arbitrage
- If reactive power is a free resource, voltages rise to reduce network series losses:
  - upper voltage constraint binds at a generator:
    - Network shunt losses not modelled

Summary of AC results (continued)

- Reactive power price >0 if no (or constrained) source at node:
  - Due to network losses, network constraints
  - Effects spread though the network (voltage is a shared resource)
- End-user’s cost includes reactive power:
  - If paying for reactive power, end-user not willing to pay as much for real power
  - Some supply side benefit goes to reactive power sources
AC loadflow with voltage-value functions
(an alternative to specifying voltage constraints)

- Outside a preferred voltage range:
  - A generator wants greater compensation
  - An end-user won’t pay as much
- bid (offer) price = [VVF]x[standard offer]
  - Where the voltage-value function (VVF) used for these studies was (Pamudji, UNSW, 1995):

  \[
  VVF = \begin{cases} 
  1 + \alpha(V_{\text{min}} - V)^3 & \text{if } V < V_{\text{min}} \\
  1 & \text{if } V_{\text{min}} < V < V_{\text{max}} \\
  1 + \beta(V - V_{\text{max}})^3 & \text{if } V > V_{\text{max}}
  \end{cases}
  \]

Effect of VVF’s on bids & offers (Pamudji, UNSW, 1995)

- Bid VVF
  - (an end-user won’t pay as much outside a preferred voltage range)
- Offer VVF
  - (a generator wants greater compensation outside a preferred voltage range)
Case studies for 5-node network (Pamudji, UNSW, 1995)

- **Base case** (α = β = 50 for bids, β = 2000 for offers)
  - Line resistances 105% of ‘standard’ network data
  - Increased loads: Eb1 = 0.8 pu (0.4), Eb2 = 0.27 pu (0.2)
  - Increased generation capacity, No1 = 1.35
  - Total generation = 2.45 pu, total load = 2.12

- **Change cases for generator VVFs:**
  - No1 & No2: β = 20000
  - No1 & No2: β = 200
  - No1 & No2: V_{max} = 1.1 (from 1.05)
  - No1 & No2: V_{max} = 1.0 (from 1.05)
  - So1: V_{max} = 1.0 (from 1.05)

Case studies (continued) (Pamudji, UNSW, 1995)

- **Change cases for end-user VVFs:**
  - Eb1: α = 50000, V_{min} = 1.0 (from 0.95)
  - With variations to test interaction between Eb1 & Eb2:
    - Eb1 bid price = 7, 8, 9 c/kWh (Eb2 bid price = 8)

- **Simultaneous generator & end-user changes:**
  - Eb1: α = 50000, V_{min} = 1.0 with one of the following changes at a time:
    - No1 & No2: β = 20000; 200
    - So1: V_{max} = 1.0
  - Changes are generally in the direction of more strict voltage requirements
Results for base case & generator
VVF changes (Pamudji, UNSW, 1995)

<table>
<thead>
<tr>
<th>Base case</th>
<th>$\beta_{north}$</th>
<th>$\beta_{north}$</th>
<th>$V_{max North}$</th>
<th>$V_{max North}$</th>
<th>$V_{max South}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20000</td>
<td>200</td>
<td>1.00</td>
<td>1.10</td>
<td>1.00</td>
</tr>
<tr>
<td>North</td>
<td>4.002</td>
<td>4.001</td>
<td>4.006</td>
<td>4.024</td>
<td>4.000</td>
</tr>
<tr>
<td>Main</td>
<td>4.441</td>
<td>4.446</td>
<td>4.429</td>
<td>4.732</td>
<td>4.365</td>
</tr>
<tr>
<td>Elm</td>
<td>4.648</td>
<td>4.658</td>
<td>4.628</td>
<td>5.199</td>
<td>4.537</td>
</tr>
</tbody>
</table>

Industry results

- Gen, pu: 2.228, 2.229, 2.225, 2.241, 2.217, 2.229
- Load, pu: 2.120, 2.120, 2.120, 2.120, 2.120
- Loss, pu: 0.108, 0.109, 0.105, 0.121, 0.097, 0.109
- Ind S, k$: 108.0, 107.9, 108.1, 106.6, 108.4, 107.9

Nodal voltages (pu)

- North: 1.056, 1.052, 1.069, 1.014, 1.102, 1.055
- South: 1.010, 1.006, 1.025, 0.964, 1.060, 1.008
- Elm: 0.951, 0.946, 0.966, 0.900, 1.005, 0.948

Dispatch, pu (other bids & offers fully accepted)

- No2: 0.478, 0.479, 0.475, 0.491, 0.467, 0.479

North has a ‘price-band’ monopoly over price setting (e.g. result for $V_{max North} = 1.00$). However North is still rewarded for low $\beta$. South is still fully dispatched for $V_{max South} = 1.00$ but paid less. Loss low & surplus high when $\beta$ low or $V_{max}$ high.

Results for base case & end-user
VVF changes (Pamudji, UNSW, 1995)

<table>
<thead>
<tr>
<th>Base case</th>
<th>Eb1 bid price (c/kWh)</th>
<th>9</th>
<th>8</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nodal active power prices (c/kWh)</td>
<td>price</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>4.002</td>
<td>4.418</td>
<td>4.404</td>
<td>4.277</td>
</tr>
<tr>
<td>South</td>
<td>4.262</td>
<td>5.786</td>
<td>5.748</td>
<td>5.306</td>
</tr>
<tr>
<td>Lake</td>
<td>4.406</td>
<td>5.991</td>
<td>5.952</td>
<td>5.490</td>
</tr>
<tr>
<td>Main</td>
<td>4.441</td>
<td>6.190</td>
<td>6.148</td>
<td>5.638</td>
</tr>
<tr>
<td>Elm</td>
<td>4.648</td>
<td>8.000</td>
<td>7.923</td>
<td>6.941</td>
</tr>
</tbody>
</table>

Industry results

- Gen, pu: 2.228, 2.138, 2.138, 2.078
- Load, pu: 2.120, 2.048, 2.048, 1.994
- Ind S, k$: 108.0, 100.8, 93.0, 86.0

Nodal voltages (pu)

- North: 1.056, 1.087, 1.087, 1.083
- Elm: 0.951, 0.995, 0.994, 0.995

Dispatch, pu (other bids & offers fully accepted)

- No2: 0.478, 0.388, 0.388, 0.328
- Eb1: 0.800, 0.800, 0.728, 0.674
- Eb2: 0.270, 0.198, 0.270, 0.270

Data:

- Eb1: $\alpha=50000$, $V_{min}=1.0$
- Eb2: bid price = 8 c/kWh

Two nodes are marginal

- Eb1 bid price = 9:
  - Eb2 is curtailed to increase V,
  - Elm price rises to Eb2 bid, industry surplus falls.

- Eb1 bid price = 8:
  - Eb1 is curtailed to increase V, Elm price rises, industry surplus falls.

- Eb1 bid price = 7:
  - Eb1 is curtailed to increase V, Elm price rises, industry surplus falls.
Simultaneous generator & end-user changes  
(Pamudji, UNSW, 1995)

<table>
<thead>
<tr>
<th>( \beta_{\text{north}} )</th>
<th>North</th>
<th>South</th>
<th>Lake</th>
<th>Main</th>
<th>Elm</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>4.080</td>
<td>4.477</td>
<td>4.619</td>
<td>4.675</td>
<td>5.102</td>
</tr>
<tr>
<td>2000</td>
<td>4.418</td>
<td>5.786</td>
<td>5.991</td>
<td>6.190</td>
<td>8.000</td>
</tr>
<tr>
<td>20000</td>
<td>4.312</td>
<td>5.841</td>
<td>6.000</td>
<td>6.232</td>
<td>8.000</td>
</tr>
<tr>
<td>200000</td>
<td>4.314</td>
<td>5.408</td>
<td>5.755</td>
<td>5.958</td>
<td>8.000</td>
</tr>
</tbody>
</table>

Nodal active power prices (c/kWh): 
- North: 4.080, 4.418, 4.312, 4.314
- South: 4.477, 5.786, 5.841, 5.408
- Lake: 4.619, 5.991, 6.000, 5.755
- Main: 4.675, 6.190, 6.232, 5.958
- Elm: 5.102, 8.000, 8.237, 8.000

Industry results

<table>
<thead>
<tr>
<th>( \beta_{\text{north}} )</th>
<th>North</th>
<th>South</th>
<th>Lake</th>
<th>Main</th>
<th>Elm</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>1.096</td>
<td>1.087</td>
<td>1.066</td>
<td>1.084</td>
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<tr>
<td>2000</td>
<td>1.087</td>
<td>1.090</td>
<td>1.090</td>
<td>1.090</td>
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</tr>
<tr>
<td>20000</td>
<td>1.078</td>
<td>1.064</td>
<td>1.056</td>
<td>1.056</td>
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</tr>
<tr>
<td>200000</td>
<td>1.058</td>
<td>1.033</td>
<td>1.022</td>
<td>1.022</td>
<td></td>
</tr>
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</table>

Dispatch, pu (other bids & offers fully accepted)

<table>
<thead>
<tr>
<th>( \beta_{\text{north}} )</th>
<th>No2</th>
<th>Lb2</th>
<th>Eb2</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0.468</td>
<td>0.150</td>
<td>0.270</td>
</tr>
<tr>
<td>2000</td>
<td>0.388</td>
<td>0.150</td>
<td>0.198</td>
</tr>
<tr>
<td>20000</td>
<td>0.030</td>
<td>0.021</td>
<td>0.165</td>
</tr>
<tr>
<td>200000</td>
<td>0.351</td>
<td>0.150</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Data:
- \( \beta_{\text{north}} = 200 \): Voltages high, Eb2 fully accepted, prices low, surplus high.
- \( \beta_{\text{north}} = 2000 \): Eb2 is curtailed to increase V, prices high, surplus low.
- \( \beta_{\text{north}} = 20000 \): Eb2 is rejected & Lb2 curtailed, prices high, surplus low.
- \( V_{\text{maxSouth}} = 1.00 \): Eb2 is curtailed to maintain V, prices high, surplus low.

Probable influences on auction outcomes:
- Not restricted to a particular node (shared network)
- Competing bids & offers correctly resolved between:
  - Generators & end-users
  - Participants at the same node
  - Participants at different nodes
  - Participants & network
Results of VVF studies (continued)  
(Pamudji, UNSW, 1995)

- Appropriate incentives and rewards:
  - Except for ‘price band’ local monopoly of marginal bid/offer:
    - No pressure to reveal preferences
  - Similar results for a 53 node, 73 line model of NSW:
    - VVF requests appropriately resolved, widespread effects

Conclusions #1

- A transport model sometimes adequate:
  - Used in NEM with ‘notional interconnectors’:
    - As yet no ‘loop flow’ effects between market regions
    - Voltage control treated as an ancillary service
  - Acceptable for an initial implementation

- DC loadflow models ‘loop flow’:
  - However network flow limits difficult to incorporate as voltage effects still ignored:
    - PJM market uses DC loadflow for real power flows but AC loadflow for reactive power flows
Conclusions #2

- AC loadflow accurately models network:
  - Both voltage and current constraints
  - Series & shunt impedances of network elements
  - However constraints have commercial value:
    - VVF preferable to nodal voltage constraints:
      - Permits valuation of voltage-related ancillary services

- AC network model essential for accurate implementation of a nodal spot market:
  - However complex bids & offers then required:
    - Demand-side bids as well as supply-side offers
    - AMI to measure interval energy plus availability & quality of supply

Conclusions #3

- Accurate network models can be incorporated in nodal spot markets:
  - Commercial model then closer to physical reality

- However problems remain:
  - Network models must be more accurate
  - Bid/offer structure becomes more complex:
    - Risk management also becomes more complex
  - Network constraints will always exacerbate local market power (& constraint settings matter):
    - AMI & active end-user participation become essential

- Further study needed to assess cost/benefits
Limits to the effectiveness of nodal markets

- For a given network, more nodal markets:
  - Mean fewer participants in each nodal market:
    - Local participants & network owners gain market power
    - Ancillary services, spot energy & risk harder to price
  - Require a more accurate network model
  - There is a lower limit to the level of network detail that nodal markets can resolve

- Regional markets provide one option:
  - Place major flow constraints on region boundaries:
    - Models of “notional interconnectors” then required
  - Resolve intra-regional network flow constraints by negotiation under regulatory supervision

Many of our publications are available at:
www.ceem.unsw.edu.au