AN INTEGRATED SIMULATION/OPTIMIZATION APPROACH TO THE MODELING AND ANALYSIS OF THE DECENTRALIZED TURKISH ELECTRICITY MARKET

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Overview

- Scope of the Study
- Simulation Framework
- Simulation Actors’ Structure
- System Operator
- Current State
- Suggestions
Scope of the Study

• To simulate the competitive market structure under transmission line capacity and production technology based constraints.
• To investigate market restructuring and deregulation
• To understand the implications of a competitive Turkish power market
Scope of the Study

- Beside the main objective we want it also:
  - To be usable for investment planning in the long run.
  - Capable to identify the most appropriate electricity production technology, size and region based on simulation history.
  - CO2 emissions resulting from power generation can be accounted.
  - Featuring a scenario-based analysis of energy-environment interactions.
Simulation Framework

- An agent based simulation approach is adapted. (Bower and Bunn (2000), Bunn and Oliveira (2001), North et al. 2002; Veselka et al. 2002).
- Transmission system is constructed in the simulation for modeling network constraints between generators and demand points.
- Each agent has its’ own objective and related behavioral algorithm.
Simulation Agents

Self learning & autonomous agents:

- Power User Agents (Power Demand)
- Independent Power Producer Agents (IPP)
- Power Generator Agents
- Power Transmission Operator Agent
- Power Transmitter Agents
- System Operator (SO)
Power User Agents

- These agents form the demand side of the electricity market.
- Try to minimize the cost of electricity needed.
- Each has its’ own daily, seasonal demand pattern and growth trend.
- Currently inelastic demand but ready for elastic demand cases.
- At each time interval power user agents will use the power supplied by suppliers and/or power transmitter agents.
- Lack of supplying electricity to the power user agents will result electricity cuts at that region/consumer.
Independent Power Producer Agents

- These agents are the investors in the market.
- They own the power producer agents.
- Objective is to maximize its profit.
- For this objective it invests in new power producer agents (power producing technologies).
Power Generator Agents

- These are the power plants that are producing the electricity.
- These agents are owned by IPPs,
- They mainly have technological parameters.
- They bid prices to the SO at each time interval.
- Relatively complex structure compared to other agents due to:
  - Technical constraints implemented
  - Self reinforcement learning algorithm.
Power Generator Agents

- Self learning and autonomous agents.
- Based on previous pool prices and possible pricing strategies it tries to determine best strategy to maximize the profit for the next day.
- Strategy formation is for the whole day.
- Pricing strategy is based on critical time strategy where:
  - Critical time is Minimum Shut Down Time if last state is Up or vice versa.
Power Generator Agents

• At the stage of pricing:
  • If the selected pricing under regular circumstances lead to a profitable choice then selected pricing strategy will be selected.
  • Else marginal cost plus a fix profit rate is sent to the SO for bidding purposes.
• Able to realize the advantage of the position at the grid.
• For base power plants (nuclear, large coal etc.) pricing under marginal cost is possible.
Power Transmission Operator Agents

- This agent is the operator of overall interconnection system.
- It is the owner of all transmission lines.
- Natural monopoly.
- It tries to maximize its profit accordingly.
- New transmission line investments based on transmission line loading levels and congestions.
Power Transmitter Agents

• These are the agents that are transmitting the electricity
• Their descriptive parameters are:
  • Voltage
  • Capacity
  • Impedance Values
  • No load cost
  • Operating cost
  • Setup Cost
  • Construction Time
  • Starting - Ending regions
System Operator

- System Operator (SO) is the central planner agent which tries to satisfy the demand of users with minimum cost.
- System operator looks at the following parameters during decision process:
  - bid levels and quantities,
  - generators region;
  - available transmission line capacities,
  - bid levels from power transmitter operator agent,
  - and power user agents demand quantities and region,
System Operator (AC OPF)

- SO solves an AC-OPF to achieve the objective.
  - Currently a linearized version of AC-OPF.
- It generates day ahead schedule of all generators and transmission lines and prices.
- It posts the schedule to generators and their owners.
- Prices at each node is posted by SO.
Grid Structure

- A transmission network system with
  - 30 bus, 41 transmission lines,
  - 9 generators, and 21 power users is adopted from Shahidehpour *et.al.* 2002.
Simulation Setup

Grid Structure

- Network Generator Structure

<table>
<thead>
<tr>
<th>Generators</th>
<th>Capacity (MW)</th>
<th>MinLoad (MW)</th>
<th>NoLoad Energy (MWh)</th>
<th>Startup Energy (MWh)</th>
<th>Minimum Up Time (MWh)</th>
<th>Minimum Down Time (MWh)</th>
<th>Primary Resource</th>
<th>Connected Bus</th>
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<tbody>
<tr>
<td>Generator 1</td>
<td>133</td>
<td>0</td>
<td>10</td>
<td>2.058</td>
<td>3</td>
<td>2</td>
<td>Gas</td>
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<td>0.882</td>
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<td>0</td>
<td>5</td>
<td>0.882</td>
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<td>1</td>
<td>Gas</td>
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<td>0</td>
<td>10</td>
<td>2.94</td>
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<td>2</td>
<td>Oil</td>
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<tr>
<td>Generator 5</td>
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<td>2.352</td>
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<td>2</td>
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<td>0</td>
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<td>3</td>
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<tr>
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<td>2.793</td>
<td>4</td>
<td>2</td>
<td>Oil</td>
<td>13</td>
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<tr>
<td>Generator 9</td>
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<td>0</td>
<td>10</td>
<td>2.793</td>
<td>4</td>
<td>2</td>
<td>Oil</td>
<td>15</td>
</tr>
</tbody>
</table>

- Transmission network capacity fixed at 300MW for test this point forward.
Simulation Setup

Grid Structure

- Network Power User Structure

<table>
<thead>
<tr>
<th>Power users</th>
<th>Max Load (MW)</th>
<th>MinLoad (MW)</th>
<th>Connected Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power user 1</td>
<td>71</td>
<td>43</td>
<td>2</td>
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<tr>
<td>Power user 2</td>
<td>7</td>
<td>4</td>
<td>3</td>
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<tr>
<td>Power user 3</td>
<td>221</td>
<td>134</td>
<td>4</td>
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<tr>
<td>Power user 4</td>
<td>114</td>
<td>69</td>
<td>5</td>
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<tr>
<td>Power user 5</td>
<td>72</td>
<td>43</td>
<td>7</td>
</tr>
<tr>
<td>Power user 6</td>
<td>100</td>
<td>60</td>
<td>8</td>
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<tr>
<td>Power user 7</td>
<td>21</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Power user 8</td>
<td>36</td>
<td>22</td>
<td>12</td>
</tr>
<tr>
<td>Power user 9</td>
<td>21</td>
<td>13</td>
<td>14</td>
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<tr>
<td>Power user 10</td>
<td>29</td>
<td>17</td>
<td>15</td>
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<tr>
<td>Power user 11</td>
<td>14</td>
<td>9</td>
<td>16</td>
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<tr>
<td>Power user 12</td>
<td>28</td>
<td>17</td>
<td>17</td>
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<tr>
<td>Power user 13</td>
<td>7</td>
<td>4</td>
<td>18</td>
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<tr>
<td>Power user 14</td>
<td>28</td>
<td>17</td>
<td>19</td>
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<td>Power user 15</td>
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<td>4</td>
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<td>Power user 17</td>
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<td>23</td>
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<tr>
<td>Power user 18</td>
<td>28</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>Power user 19</td>
<td>14</td>
<td>9</td>
<td>26</td>
</tr>
<tr>
<td>Power user 20</td>
<td>7</td>
<td>4</td>
<td>29</td>
</tr>
<tr>
<td>Power user 21</td>
<td>36</td>
<td>22</td>
<td>30</td>
</tr>
</tbody>
</table>
Simulation Setup

Demand

Load Levels for year 2002

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Simulation Setup

Demand

Average/MIN/MAX Loads for year 2002 for day times (normalized)

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Initial Simulation Results

- 4 different day times are selected.
Behavioral Algorithms
Price Tracking

- Motivation is to generator agents to be able to see their power in the price formation procedure.
- Compare the prices they bid and prices announced by SO.
- Algorithm follows the steps:
  For every day time hour = i
  \[ \text{Price Gap (i)} = \text{Price (i)} - \text{Bid Price (i)} \]
  Take average and standard deviation of last 30 simulation time step
  Look \( T \) value of the sample with 29 degree of freedom.
  If \( T \) value is less than or equal to \( T_{0.95,29} \) Then
  \[ \text{PriceTrackingEff} = -\text{PriceTrackingEffFact} \times \frac{T}{T_{0.95,29}} + (1 + \text{PriceTrackingEffFact}) \]
  Else
  \[ \text{PriceTrackingEff} = 1 \]
  Next day time

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Behavioral Algorithms

price tracking

Base Case

Price Tracking with factor of 5%

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Behavioral Algorithms
price tracking

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Behavioral Algorithms

Market Share

- Focuses on the share of the generator agents on the spot market on daytime basis (hourly).
- One generator with high market share may affect the prices other than its marginal production cost by manipulation.
- Algorithm follows the steps:
  
  For every day time hour=\(i\)

  \[
  \text{Market Share (i)} = \frac{\text{Load (i)}}{\text{Demand (i)}} - \left(\frac{1}{\text{Number of Generators}}\right)
  \]

  \[
  \text{Expected Market Share (i)} = \text{Expected Market Share (i)} + \alpha \ast \left(\text{Market Share (i)} - \text{Expected Market Share (i)}\right)
  \]

  \[
  \text{Market Share Effect (i)} = \left(\text{Expected Market Share (i)}\right)^3 \ast \left(\text{Market Share Effect Factor+1}\right)
  \]

  Next day time
Behavioral Algorithms
Market Share

Base Case

Market Share with factor 10%

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Focuse on demand, physical capacity and generator load triple interaction.

The algorithm may be summarized as follows:

For every day time hour = i

\[
\text{Market Power}[i] = \frac{\text{Generator Load}(i)}{\text{Physical Capacity} - \text{Demand}(i)}
\]

\[
\text{Expected Market Power}(i) = \text{Expected Market Power}(i) + \alpha \times (\text{Market Power}(i) - \text{Expected Market Power}(i))
\]

\[
\text{Market Power Effect}(i) = \max(1, \frac{1}{1.2 - \text{Expected Market Power}(i)})^{1/8}
\]

Next day time
Behavioral Algorithms
Market Power

Base Case

Market Power

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Behavioral Algorithms
Market Power

Base Case

Market Power

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Conclusions

- The learning algorithms have led more realistic outcomes.
- Algorithms developed has opened up the area for hourly price speculation and manipulation.
  - Market Power for manipulating gap between demand and physical capacity.
  - Market Share algorithm for manipulating prices by the share of production.
  - Price Tracking algorithm for showing the power price clearing producer.
Conclusions

- Market Power is found to be effective for price formations at peak hours.
- Market Share algorithm is found to be effective where the number of producers are less in number.
- Price Tracking algorithm is effective for all day hours where the higher the number of competitive producers, less effect can be sensed.
- Combinations of the algorithms show very reasonable price spikes and collapses due to demand and capacity changes.
Conclusions

- Regarding transmission constraints:
  - Price of transmitting electricity from one point to another has dramatically effect on price formation.
  - Both average prices and variation of prices increases with transmission line fee.
  - Keeping same transmission line fees with decreasing transmission capacities lead to lower prices and variations compared to price changes.
  - Transmission line fees may be used to encourage distributed electricity production???
Conclusions and further study

- Next step is to develop an algorithm for capacity with holding cases.
- Also nonlinear optimization and introduction of renewables will also be established.
- Based on the 30 bus network, policy analysis and design will studied in detail.
- Based on this policy study suggestions for Turkey electricity market will be developed and applied with real data.