Capacity Expansion Model
Technical Workshop

Carl Huppert
Henwood Energy Services, Inc.
(A Global Energy Decisions Company)
chuppert@globalenergy.com
916 609-7753
Agenda

» Overview
» Model Scope
» Model Objective and Constraints
» Model Variables
Overview

» Henwood developed a capacity expansion model (CEM) for automated screening and evaluation of generation capacity expansion and retirement options

» This economic optimization model to be used as part of the larger IRP effort

» The CEM answers the key investment decisions of (1) what to build, (2) where to build, (3) how much to build, and (4) when to build
Overview

Planning Margin "Gap" Analysis (Sample Utility)

- Demand
- Existing Resource Portfolio
- Planning Reserve Margin

Resources Required to Meet 15% Planning Reserve
Overview – Feature Set

The features of the CEM (soon to be called CapX™)

» State-of-the-art MIP algorithm
» Multi-regional hourly interchange (up to X regions)
» Expansion alternatives (up to 30 simultaneous options)
» Up to 100 existing resources
» Variable time granularity for hourly dispatch
» Fast execution
» Flexible constraint set: energy balance, planning margin, generation, must-run, limited energy, site build, emission limits, group mix, group capacity, aggregate capacity, capital budget
» Significant production detail: fuel, VOM, MOR, emissions, FOR
» Calculates inter-regional and external market energy transfers
Overview – Objective Function

» The goal is to minimize the present value cost of generation, construction, and expansion subject to load balance equations, reliability constraints, and capacity constraints

» Thus, the criteria for evaluation is minimization of the expected present value of revenue requirements (PVRR)

» Mixed integer program for which the objective minimizes the sum of the discounted expansion and generation costs of supplying regions with power. Creates a least cost dispatch of existing resources and installed proposed resources considering heat rates, fuel costs, location, capacities, emissions costs, and variable O&M

  • Includes all existing and proposed plants
  • All expansion choices are represented by build/not build binary variables to characterize the large fixed capital costs involved
Despite the considerable advantages of the CEM (or any automated expansion tool), it is still best used as a preliminary screening tool for narrowing the choice set from tens or hundreds of possible resource plans down to a few “good” alternatives.

Why? Does not include all the operational detail needed for use as the sole investment decision tool. Less granularity of dispatch and commitment, no stochastics.
Model Scope - General

» Study period is 20 years

» Currently set up for allows portfolio positions (generators, loads, DSM activities, and contracts) in two distinct geographical areas

» The model accommodates approximately 100 existing resources and 30 potential new resources. Valid resource options include the following types of investments:
  • Supply resource additions, including renewables
  • Supply resource retirements (PacifiCorp will not use this)
  • Demand side options
  • Additional inter-node transmission
Model Scope - Topology

» Each geographic area has access to an external market to buy and sell power
» CEM models the hourly transmission constraints between the East and West
Model Scope – Dispatch Granularity

- CEM makes use of representative or aggregate hours
- The user can choose the level of aggregation with the understanding that less aggregation can increase solution time
- Three levels:
  1. 12 months/year x 1 week/month x 3 days/week x 6 hours/day = 216 hours/year
  2. 12 months/year x 1 week/month x 7 days/week x 6 hours/day = 504 hours/year
  3. 12 months/year x 1 week/month x 7 days/week x 24 hours/day = 2016 hours/year
Model Scope – Plant Level Detail

» Existing Plant characteristic details include:
  • Maximum Capacity – monthly
  • Minimum Capacity – monthly
  • Energy Limit (hydro, DSM) – monthly
  • Average Heat Rate – monthly
  • Fuel Costs ($/mmBtu) – monthly
  • Emissions (NOx, SO2, CO2, Hg) $/MWh - monthly
  • Forced and Planned Outage Rates – monthly
  • Variable O&M / MWh – annual
  • Fixed O&M – monthly
  • Decommission Cost (not used yet)

» Potential Resources - all of the above, plus:
  • Capital Cost, Service Life, Finance Rate
  • Maximum MW installed per site
  • Size per unit installed
Capital recovery factors for candidate resources are calculated given an interest rate and an expected life of the resource.

- Allows for the impact of the profit or loss and investment recovery in the time period outside the study period. The so-called “end effect.”

Expected values (deterministic) for inputs such as load, fuel prices, hydro availability will be used. There are no stochastic inputs.
Model Objective and Constraints

» CEM is formulated and solved as a mixed integer linear programming (MILP) model
  • An off-the-shelf modeling package called GAMS (General Algebraic Modeling System) is employed along with CLPEX, which solves large scale optimization problems
» Objective function is to minimize the NPV of portfolio operating cost (fuel, fixed and variable maintenance, un-served energy, and un-served reserves) plus the cost of generation and transmission capacity expansion over the study period
» The model has two sub-objectives:
  • Minimize thermal and hydro dispatch costs
  • Determine an optimal system-wide resource build plan
Model Objective and Constraints cont.

» Major constraints:

- **Energy balance constraints.** These perform the hourly dispatch of resources to satisfy demand as well as do market purchases and sales.
- **Planning margin constraints.** These build resources to ensure that the target planning margin is met while not going over the upper limit on planning margin.
- **Generation constraints.** These enforce lower and upper limits on generation in each time period for each resource.
- **Must run constraints.** These ensure that must run resources are always run in the dispatch.
- **Limited energy constraints.** These enforce monthly energy limits on hydro and energy limited resources.
- **Site build constraints.** These allow a number of units to be build on a given site.
Model Objective and Constraints cont.

» Major constraints cont.

- **Duct firing unit constraints.** These ensure that duct firing units are built in the same year as the corresponding CCCT
- **Group capacity mix constraints.** These ensure that resource groups are built according to a desired percentage distribution
- **Group capacity level constraints.** These ensure that resource groups are built according to user defined MW limits
- **Aggregate capacity expansion constraints.** These allow the user to specify minimum and maximum MW capacity to build by year
- **Capital budget constraints.** Allows user to limit capital expenditure in a given year across all investments to a specified amount
Model Variables

- **Energy dispatch variables.** By time period and resource, these determine optimum dispatch levels.
- **Firm capacity variables.** By month and resource, these add proposed resources to respect the planning margin limits.
- **Firm capacity transfers.** These allow the transfer of firm capacity between the East and West for use in planning margin constraints.
- **Energy transfers.** These allow the transfer of dispatched energy between the East and West.
- **Un-served energy variables.** These indicate un-served when the energy balance constraints cannot meet load.
- **Un-met capacity variables.** These indicate unmet capacity when the planning margin constraints cannot meet peak loads.
Model Variables cont.

» **Market purchases.** These allow the model to purchase from market to augment dispatch to meet hourly load

» **Market sales.** These allow the model to sell to market after hourly load has been met

» **Site build variables.** These 0/1 integer variables allow the model to build or not build a given resource site in a given year

» **Unit build variables.** These integer variables allow the model to add units to a site up to the maximum number of units per site
CEM Model Status

Stan Williams
Model Status Agenda

» Overview
» Model Validation
» Resource Options
» Preliminary portfolio
» Conclusions
» Next steps
Model Status - Overview

» Received LP engine of the model
» Have not received interface
  • Makes full implementation difficult
    ⇒ Many types of runs can be made
    ⇒ More complicated runs cannot
    ⇒ Would be difficult without LP background
  • Should receive it in 2 or 3 months

» Model validation continues
  • Two of three validations steps are complete
  • Third step will proceed over the next several weeks

» Preliminary model Implementation begins
  • A resource list has been defined
  • An example preliminary portfolio has been generated
Model Status - Validation

» Continuing with third step of model validation
  ✓ Generation and variable costs of existing resources have been validated between the CEM and PROSYM
    ✓ Completed before last PIM
  ✓ Validate the short position the CEM computes to L&R balance
    ✓ Short positions validated by comparing peak load capacity of existing resources of CEM to L&R balance
      – CEM is very close to actual L&R
      – Results are on next two slides
  ❏ Validate CEM portfolio PVRR against PROSYM
    • Most difficult one
Model Status – Validation - East Positions

The graph illustrates the model status validation for East Positions from 2008 to 2015. The horizontal axis represents fiscal years (FY) from 2008 to 2015, while the vertical axis indicates MW (megawatts) with negative values. Two categories are shown: CEM East Position and L&R East Position. The position values vary each year, with some years showing a notable drop in MW values.
Model Status – Validation - West Positions

![Bar chart showing West Positions for Model Status from 2008 to 2015. The chart compares MW (Milwaukee Water) and L&R (L & R West Position).]
Third and final step is to validate CEM PVRR against PROSYM

- Most difficult of the three validation steps
- Portfolios will be generated with the CEM and then simulated with PROSYM. The PVRR outputs of both models will then be compared
  - For each year, the “All in” cost of the CEM will be compared to the consolidated fixed and variable costs generated in PROSYM
  - This validation should be complete in about two months

Meanwhile, examples of preliminary portfolios can be generated

- First step is to create the candidate resource list
## Model Status - Resource Options

<table>
<thead>
<tr>
<th>Resource Options</th>
<th>East</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCCT 2x1 - Dry Cooling / Duct Firing</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Intercooled Aero SCCT</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Coal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brownfield Pulverized Coal (PC)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Greenfield IGCC</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Greenfield PC</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>DSM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial Cooling Control</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Res./Small Comm’l Air Conditioner Control</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>*Extension of Cool Keeper past FY2014</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Electric Space/Water Heat Control</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Commercial Lighting Control</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Irrigation Control</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>*Extension of Idaho Irrigation Program past FY2014</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Distributed Generation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*Standby Generators</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

* - Not currently active in model
### Preliminary Portfolio - Example

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>Brownfield Pulverized Coal (PC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>575</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>575</td>
</tr>
<tr>
<td></td>
<td>Intercooled Aero SCCT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>87</td>
<td>87</td>
<td>174</td>
<td></td>
<td></td>
<td></td>
<td>348</td>
</tr>
<tr>
<td></td>
<td>CCCT 2x1 - Dry Cooling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>420</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>840</td>
</tr>
<tr>
<td></td>
<td>CCCT 2x1 - Dry Cooling / Duct Firing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>105</td>
<td></td>
<td></td>
<td>105</td>
<td></td>
<td></td>
<td>210</td>
</tr>
<tr>
<td></td>
<td>Commercial Cooling Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Irrigation Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>44</td>
</tr>
<tr>
<td>West</td>
<td>Intercooled Aero SCCT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>194</td>
<td>194</td>
</tr>
<tr>
<td></td>
<td>CCCT 2x1 - Dry Cooling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>469</td>
<td>469</td>
</tr>
<tr>
<td></td>
<td>CCCT 2x1 - Dry Cooling / Duct Firing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>117</td>
<td>117</td>
</tr>
<tr>
<td></td>
<td>Res./Small Comm’l Air Conditioner Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Irrigation Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>44</td>
</tr>
<tr>
<td></td>
<td><strong>Totals</strong></td>
<td>0</td>
<td>0</td>
<td>44</td>
<td>525</td>
<td>176</td>
<td>575</td>
<td>325</td>
<td>586</td>
<td>174</td>
<td>525</td>
<td>2,930</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>Brownfield Pulverized Coal (PC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>575</td>
<td></td>
<td>575</td>
</tr>
<tr>
<td></td>
<td>Intercooled Aero SCCT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>87</td>
<td>87</td>
<td>261</td>
<td>348</td>
<td>261</td>
<td>522</td>
<td>1,914</td>
</tr>
<tr>
<td></td>
<td>CCCT 2x1 - Dry Cooling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>420</td>
<td>420</td>
<td>420</td>
<td>420</td>
<td>420</td>
<td>3,780</td>
</tr>
<tr>
<td></td>
<td>CCCT 2x1 - Dry Cooling / Duct Firing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>210</td>
<td>105</td>
<td>105</td>
<td>945</td>
</tr>
<tr>
<td></td>
<td>Commercial Cooling Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Irrigation Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>44</td>
</tr>
<tr>
<td>West</td>
<td>Intercooled Aero SCCT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>194</td>
<td></td>
<td>194</td>
</tr>
<tr>
<td></td>
<td>CCCT 2x1 - Dry Cooling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>469</td>
<td></td>
<td>469</td>
</tr>
<tr>
<td></td>
<td>CCCT 2x1 - Dry Cooling / Duct Firing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>117</td>
<td></td>
<td>117</td>
</tr>
<tr>
<td></td>
<td>Res./Small Comm’l Air Conditioner Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>45</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Irrigation Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>44</td>
</tr>
<tr>
<td></td>
<td><strong>Totals</strong></td>
<td>0</td>
<td>0</td>
<td>87</td>
<td>612</td>
<td>1,111</td>
<td>786</td>
<td>2,570</td>
<td>1,111</td>
<td>786</td>
<td>522</td>
<td>10,515</td>
</tr>
</tbody>
</table>
Model Status - Conclusions

» CEM is not currently ready for full implementation
  • Third phase of validation must be completed
    ⇒ Match PVRRs of CEM to PROSYM
  • User-friendly interface and reporting module must be received and understood
    ⇒ Inputs are difficult to make
    ⇒ Outputs are difficult to interpret

» Can generate preliminary portfolios
  • Informs the manual build process
Model Status - Next Steps

» Continue validation
  • PVRR validation

» Further develop preliminary portfolios

» Receive interface to the model
  • Incorporate into MarketSym

» Receive enhancements to model
  • Reporting capability

» Goals for next year
  • Have user-friendly interface
  • Fully validated
  • Become primary capacity expansion methodology