

Technical Education on Capacity Expansion Software

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Scenario Analysis & Special Studies

TEAC Special Session - Order 1920

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 PJM uses Energy Exemplar's Plexos software for capacity expansion

• This presentation provides high-level education on use of the software using an illustrative example

 Further education on policy and resource adequacy modeling will be provided in a subsequent meeting





- Introduction
- Setting up the database
- Simulation setup
- Running capacity expansion
- Reports
- Illustrative East West example of PJM system
- Next steps

Introduction



- User Interface
 - System elements consist of various classes
 - Classes can be enabled/disabled using Config menu settings
 - Simulation elements consist of models and settings for running the models







Config menu on Home ribbon

| ØP | LEXOS | Hom | ie | Window | w Visu | alizer | Gen2-Tl | hermal | Ther | mes | | | | | | | | | | | |
|----------|-------|---------|-------|--------|-----------------|-----------------------|---------|----------|-----------------|---------|--------------|----------|--|----------------------|-----------|----------|----------------|---------------------|----------------|----------|----------------|
| H New | Copen | Connect | Cloud | Save | 🖌 Cut 📘 Copy | 💼 Paste 🤜 🚫 Cancel | Excel | T XML | Find Replace | Changes | Carve Out | Overview | <mark>iਵ</mark> Model Highlight▼ | Column Up Down | Selection | Property | Column Size | D Execute | A Build | Config S | 22 Settings |
| | | File | | | | Clipboa | rd | | | | Edi | t | | | Fill | | | Datak | oase | Opti | ions |

4

• Includes all classes and their properties

| ✓ 📁 E | lectric | • | | Property | Dynamic | Bands | Default | Validation | Units |
|----------------------------------|--------------------|---|--------------|--------------------------|--------------|-------|---------|------------|----------|
| • • • | Generator | | ^ (| Generators | | | | | |
| | Power Station | | \checkmark | Units | | | 0 | >=0 | - |
| • • | Fuel | | \checkmark | Max Capacity | | | 0 | | MW |
| • | Fuel Contract | | \checkmark | Min Stable Level | | 1 | 0 | >=0 | MW |
| • | Power2X | | \checkmark | Fuel Price | | | 0 | | \$/MMBtı |
| • 🗸 🍵 | Battery | | \checkmark | Heat Rate | | 1 | 0 | | Btu/kWh |
| • | Storage | | \checkmark | VO&M Charge | | | 0 | | \$/MWh |
| • 🗌 🎽 | 🖥 Waterway | | ~ | FO&M Charge | | | 0 | | \$/kW/yr |
| • 🗌 🏂 | Emission | | ~ | Rating Factor | \checkmark | | 100 | >=0 | % |
| • | Abatement | | | Initial Age | | | 0 | | yr |
| • | Physical Contract | | | Power Degradation | | | - | | % |
| ا أ | Purchaser | | ~ | Power Degradation | | | 0 | | |
| • 🗆 🐸 | Reserve | | \checkmark | Equity Charge | | | 0 | | Ş/kW/yr |
| • | Reliability | | \checkmark | Debt Charge | | | 0 | | \$/kW/yr |
| • 🗆 🖪 | Financial Contract | | \checkmark | Firm Capacity | \checkmark | 1 | 0 | | MW |
| • 🗆 🚽 | Cournot | | \checkmark | Firm Capacity Unit Count | \checkmark | 1 | 0 | | - |
| • | RSI | | \checkmark | Build Cost | | 1 | 0 | | \$/kW |



Introduction

Each element can have memberships and properties

- Memberships relate classes to one another
 - Example: Emission.Fuels or Emission.Generators

- Each element has a set of properties
 - Example: Generator MaxCap, Fuel price

Introduction



- Scenarios
 - Software terminology for tagging data properties
 - Each model consists of base data and data scenarios
 - You can tag data and properties using a scenario. Then use the scenarios to make changes to the base data or create multiple models

| | Collection | Parent Object | Child Object | Property | Value | Data File | U 🔺 | Band | Date From | Date To | Timeslice | Action | Expression | Scenario |
|---|------------|---------------|--------------|----------|-------|--------------|-----|------|-----------|---------|-----------|--------|------------|-----------|
| • | Fuels | System | NGHenry | Price | 0 | Fuel Price-H | \$/ | 1 | | | | = | | High Fuel |
| • | Fuels | System | NGHenry | Price | 0 | Fuel Price-L | \$/ | 1 | | | | = | | Low Fuel |



- LT Plan
 - LT Plan phase is used for long term capacity expansion
 - The objective is to minimize system cost
 - Fixed costs (Capital cost of new generation and FOM costs)
 - Production costs (Cost of operating the system given a set of existing generators and cost of unserved energy)
 - Decision variables are whether and when to build a generator candidate
 - Discount factors are used to represent all costs as present values



• LT Plan

| A Base | > > Hide Unused | - • |
|--|----------------------------------|--|
| LT Plan Transmission Production Competition Pe | rformance Diagnostic | |
| Step Size | Discounting | Transmission |
| Step Size (years): | Discount Rate (%): | Regional Ozonal Nodal |
| Overlap (years): | End Effects Method: | Heat Rate |
| Chronology | O None Perpetuity | O Detailed O Simple O Simplest |
| Partial | Discount/Expansion Period: | Storage |
| ◯ Fitted | ○ Month ○ Quarter ● Year | Restart each Expansion Period |
| ○ Sampled | Always Annualize Build Cost | Outages |
| One Duration Curve each: | Depreciation Method: | Use Effective Load Approach |
| ◯ Day ◯ Week ● Month ◯ Quarter ◯ Year | None O Straight-Line O Declining | Compute Reliability Indices |
| Blocks in each Duration Curve: 12 | lax kate (%): | Compute Multi-area Reliability Indices |
| Blocks in last curve in Horizon: 0 | Inflation Kate (%): | 10 Outage Increment (MW) |



Config menu for Generator Expansion

| 🖌 🖮 Expansion | | | |
|-------------------------------------|------------|----------|------------|
| 🗸 📥 Build Cost | Multi Band | \$/kW | 0 |
| 🗸 📥 Retirement Cost | | \$000 | 0 |
| 🗸 📥 One-time Cost | | \$000 | 0 |
| 🗸 📥 Lead Time | | уr | 0 |
| 🗸 📥 Project Start Date | | - | 1/1/2000 |
| 🗸 📥 Commission Date | | - | 12/31/1899 |
| 🗸 📥 Technical Life | | yr | 1E+30 |
| V 📥 WACC | | % | 10 |
| 🗸 📥 Levelized Capital Carrying Rate | | % | 0 |
| 🗸 📥 Economic Life | | уr | 30 |
| 🗸 📥 Max Units Built | | - | 0 |
| 🗸 📥 Max Units Retired | | - | 0 |
| 🗸 📥 Min Units Built | | - | 0 |
| 🗸 📥 Min Units Retired | | - | 0 |
| 🗸 📥 Max Units Built in Year | | - | 1E+30 |
| 🗸 📥 Max Units Retired in Year | | - | 1E+30 |
| 🗸 📥 Min Units Built in Year | | - | 0 |
| 🗸 📥 Min Units Retired in Year | | - | 0 |
| 🗸 🚨 Build Set Size | | - | 0 |
| 🗌 📥 Hint Units Built | | - | 0 |
| Capacity Price | | \$/kW/yr | 0 |

Setting up the database



- Capacity expansion candidates
 - Units
 - Max Capacity
 - Build Cost
 - Project Start Date

| Property | Value | Data File | Units |
|---------------------------------|----------|--------------------------------------|----------|
| Units | 0 | | - |
| Max Capacity | 150 | | MW |
| FO&M Charge | 33.41 | | \$/kW/yr |
| Rating Factor | | wk_OH-Mansfield_PV_1-Axis_SolarShape | % |
| Firm Capacity | 37.5 | | MW |
| Build Cost | | Build_Cost | \$/kW |
| Project Start Date | 1/1/2024 | | - |
| Levelized Capital Carrying Rate | 5.68 | | % |
| Economic Life | 30 | | yr |
| Max Units Built | 150 | | - |
| Max Units Built in Year | 5 | | - |

- Levelized Capital Carrying Rate
- Max Units Built/ Max Units Built in Year



Load forecast input using data files

| | Collection | Parent Object | Child Object | Property | Value | Data File | Inits | Band | Date From | Date To | Timeslice | Action |
|---|------------|---------------|--------------|----------|-------|-----------|-------|------|-----------|---------|-----------|--------|
| • | Regions | System | East | Load | | EAST | /w | 1 | | | | = |
| | Regions | System | West | Load | 0 | WEST | /W | 1 | | | | = |

– Data file

| Data File | Property 🔺 | Value | Filename | Units | Band | Date From | Date To | Timeslice | Action | Expressio |
|-----------|------------|-------|--|-------|------|-----------|------------|-----------|--------|-----------|
| EAST | Filename | - 0 | Load Forecasts\MH-East_2023-2039-new.csv | | 1 | 1/1/2023 | 12/31/2039 | | = | |
| WEST | Filename | 0 | Load Forecasts\MH-West_2023-2039-new.csv | | 1 | 1/1/2023 | 12/31/2039 | | = | |

– Source .csv file

| А | В | С | D | E | F | G | Н | | J | K | L | М | N | 0 | Р | Q |
|------|-------|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Year | Month | Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 2029 | 1 | . 1 | 54792 | 54564 | 54396 | 54716 | 55630 | 57724 | 61010 | 63883 | 64529 | 64566 | 64186 | 63173 | 62232 | 61242 |
| 2029 | 1 | . 2 | 54582 | 53879 | 53688 | 53858 | 54745 | 56997 | 60729 | 63577 | 63809 | 63119 | 62377 | 61247 | 60529 | 59549 |
| 2029 | 1 | . 3 | 56116 | 55552 | 55359 | 55591 | 56634 | 58998 | 63390 | 66494 | 66651 | 65854 | 65026 | 63291 | 62027 | 61038 |
| 2029 | 1 | . 4 | 55530 | 54802 | 54662 | 54901 | 55879 | 58348 | 62836 | 65950 | 65962 | 65173 | 64157 | 62884 | 61922 | 61034 |
| 2029 | 1 | . 5 | 55370 | 54585 | 54237 | 54287 | 55116 | 57277 | 60946 | 64081 | 64419 | 63973 | 63491 | 62507 | 61370 | 60471 |
| 2029 | 1 | . 6 | 54387 | 53685 | 53313 | 53307 | 53739 | 54838 | 56273 | 58031 | 59138 | 59877 | 59580 | 58797 | 57858 | 56883 |
| 2029 | 1 | . 7 | 54102 | 53466 | 53274 | 53398 | 53725 | 54612 | 55712 | 57419 | 58470 | 58659 | 57980 | 57102 | 56390 | 55504 |
| 2029 | 1 | . 8 | 55107 | 54963 | 54873 | 55385 | 56469 | 58899 | 63268 | 66500 | 67067 | 66824 | 66213 | 65120 | 64043 | 63017 |



Transmission links between zones

| Line | Property | Value | Data File | Units | Band | Date From | Date To | Timeslice | Action | Expression |
|--------------|----------|--------|-----------|-------|------|-----------|---------|-----------|--------|------------|
| East to West | Min Flow | -10000 | | MW | 1 | | | | = | |
| East to West | Max Flow | 10000 | | MW | 1 | | | | = | |

• Fuel input using data files

| | Collection | Parent Object | Child O | Property | Value | Data File | Units | Band | Date From | Date To | Timeslice | Action I |
|---|-----------------|---------------|---------|------------------|-------|---------------|----------|------|-----------|---------|-----------|----------|
| * | Fuels | System | NGHenry | Price | | MH-Fuel Price | \$/MMBtu | 1 | | | | = |
| | Generator.Fuels | Gen1-Thermal | NGHenry | Transport Charge | 0 | | \$/MMBtu | 1 | | | | = |
| | Generator.Fuels | Gen2-Thermal | NGHenry | Transport Charge | 0 | | \$/MMBtu | 1 | | | | = |

• Battery expansion candidates

| Collection | Parent Object | Child Object | Property | Value | Data File | Units I |
|------------|---------------|--------------|----------------------|-------|------------|----------|
| Batteries | System | BSEx1 | Units | 0 | | - |
| Batteries | System | BSEx1 | Capacity | 200 | | MWh |
| Batteries | System | BSEx1 | Max Power | 50 | | MW |
| Batteries | System | BSEx1 | Charge Efficiency | 80 | | % |
| Batteries | System | BSEx1 | Discharge Efficiency | 80 | | % |
| Batteries | System | BSEx1 | FO&M Charge | 30 | | \$/kW/yr |
| Batteries | System | BSEx1 | Max Units Built | 5000 | | - |
| Batteries | System | BSEx1 | Build Cost | | build cost | \$/kW |
| Batteries | System | BSEx1 | Economic Life | 30 | | yr |



Simulation setup

• Simulation Horizon

| | A | |
|-----------|------------------|-----------------------------|
| 2029-2039 | > $ $ $>$ $ $ | Hide Unused |
| | Planning Hori | zon |
| | Begin On: | Monday, January 1, 2029 |
| | Run for: | 11 + 0 (Year - |
| | End On: | Saturday, December 31, 2039 |
| | Interval Length: | 1 Hour 💌 |
| | Compression: | 1 🚔 |
| | Days Begin: | 12:00 AM 🔻 |
| | Years End: | (Automatic) 🔻 |
| | Weeks Begin: | (Automatic) 🔻 |



Simulation setup

• Reports

| Properties | s Field List | | | | | | | | | | | |
|------------|---|-----------------------|--|--|--|--|--|--|--|--|--|--|
| | Solution File Formats | | | | | | | | | | | |
| | Flat Files (.csv) | | | | | | | | | | | |
| | ✓ Compressed XML (.zip) | | | | | | | | | | | |
| | Compact Full | | | | | | | | | | | |
| | Period Types | | | | | | | | | | | |
| | Period (hour, 30-min., or 10-min. as in Horizon) | | | | | | | | | | | |
| | Hour | Month | | | | | | | | | | |
| | Day | Quarter | | | | | | | | | | |
| | Week | ✓ Year | | | | | | | | | | |
| | Stochastics Report Statistics Save Each Sample | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | Filters | | | | | | | | | | | |
| | ✓ Filter Objects (Interval) | | | | | | | | | | | |
| | ✓ Filter Objects (Summary) | | | | | | | | | | | |
| | Whole Years Only | | | | | | | | | | | |
| | Flat Files | | | | | | | | | | | |
| | Format: | Datetime 💌 | | | | | | | | | | |
| | Locale: | (default) | | | | | | | | | | |
| | Date Time Convention | | | | | | | | | | | |
| | Date Time Convention: | Beginning of Period 🔹 | | | | | | | | | | |
| | | | | | | | | | | | | |

| I Image: Second secon | > > | Hide U | - |
|--|---|---|---|
| Class <all></all> | Sort Ascending Reset Names | Tool Margaria Margaria Margaria Margaria | |
| Generator Fuel Battery Region | | | |
| X Node T Line Soconstraint ▼ | Max Capacity | V V MW V V MW | Maximum generating capacity of each unit Installed capacity (Max Capacity x Units) |
| Phase UT Plan ST Schedule | Rating Raw Rating Rated Capacity | | Rated capacity of units Rated output capacity of units without considering outages of Installed capacity accounting for [Rating] and [Rating Factor] |
| | A Rating Violation A Rating Violation Cost A Firm Capacity | MW (GWh) S (\$000) MW | Violation of Rating constraint Cost of Rating violation Contribution of the generator to capacity reserves |
| Synchronize Selections: Sync Lock LT Plan AND OR | A Net Firm Capacity Reliability Expansion | | Firm Capacity net of maintenance and degradation |
| | Units Built Units Retired Capacity Built | | Number of units built Number of units retired Capacity built (Max Capacity x Units Built) |
| | Capacity Retired | | Capacity retired (Max Capacity x Units Retired) Net Capacity (cumulative Max Capacity x (Units Built - Units Price received by the generator for capacity |
| | Capacity Revenue | <pre>\$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$</pre> | Revenue from capacity payments Cost of building a unit |



Running capacity expansion model

Select "Execute" from the ribbon

| ØP | LEXOS | Hon | ne | Window | w Visualizer | Comp | onents | Theme | S | | | | | | | | | | | |
|----------|-------|---------|-------|--------|---------------------|-----------|-----------|-----------------|----------|--------------|-----------|---------------------------------|-------|----------------------|-----------|--|----------------|-------------|----------|-----------------|
| H New | Open | Connect | Cloud | Save | ✓ Cut 		 Cut 		 Pa: | ncel | | Find Replace | Changes | Carve Out | Overview | Model Highlight • | | Column Jp Down | Selection | The property of the second sec | Column Size | Execute Bui | d Config | Settings |
| | | File | | | Clip | oboard | | | | Edi | t | | | | Fill | | | Database | Opt | ions |
| | | | | | | Models an | d Project | s selected | for next | Executi | ion: | | | | | | | | | |
| | | | | | | Class | Category | / Name | e Exe | cution (| Order Rur | n Solution Vie | ews | | | | | | | |
| | | | | | | Model | - | LT | 0 | | |] | | | | | | | | |
| | | | | | Add > | Model | - | LT No E | LCC 0 | | |] | | | | | | | | |
| | | | | | Remove < | Model | - | LT NoRF | o s | | |] | | | | | | | | |
| | | | | | Add All >> | | | | | | | | | | | | | | | |
| | | | | | Remove All << | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| | | L | | | Split Exe | ecution | Exec | ute in Par | allel | Exec | ute in Cl | oud | ecute | e in Co | nnect | Execu | te | Cancel | | |





Output Interface

| PLEXOS | Home | Window | Visu | alizer | Chart | Solut | tion Views | Themes | | | | | | | | | | | | | |
|--------------------------------|-------------------------------|---------|-----------------|-----------|-------|-------------------|------------------|---------------|--------|----------------|---------------------------|---------------------------------------|------------------------------------|------------|------------|------------|-------|---------|-------------|-----------|-------|
| H 🗃 New Open | Connect Cloud | Save | 🔶 Cut 📘 Copy | 🔋 Paste 🔹 | Excel | To Text Format | Standard Auto | Column Ex | kecute | esent 5.00% | Value | s SUM By Object Σ Aggreg | ▼ ○ Ca▼ | ncel | | | | | | - Cor | mpare |
| | File Clipboard Numeric Format | | | | | | | | | | Solution Solution Compare | | | | | | | | | | |
| 📋 Training | × 👩 LT N | lo ELCC | × | | | | | | | | | | | | | | | | | | |
| Phase | | | | | | | 🗸 🚯 System | | | | Dat | a Chart | | | | | | | | | |
| OLT Plan | | | | | | | - 🧺 Electric | | | | | List | Pro | Properties | | Names | | Periods | | Bands | |
| Period Type | a | | | | | | 🗸 🖌 🔚 Gene | rators | | | | Parent Name | Collection | Child Name | Category | Property | E | Band | Fiscal Year | Value | Units |
| Block | | | | | | | . 🖂 늘 Es | voancion | | | • | System | Generator | GenEx1-PV | Expansion | Capacity I | Built | 1 | 2029 | 0.00 | MW |
| Interval | | | | | | | · • • • • | kpansion | | | | System | Generator | GenEx1-PV | Expansion | Capacity I | Built | 1 | 2030 | 0.00 | MW |
| Fiscal Vear | | | | | | | 🕨 🗸 🔘 G | en1-PV | | | | System | Generator | GenEx1-PV | Expansion | Capacity I | Built | 1 | 2031 | 0.00 | MW |
| | | | | | | | 🕨 🗸 🌔 G | | | | System | Generator | GenEx1-PV | Expansion | Capacity B | Built | 1 | 2032 | 0.00 | MW | |
| Date Range | 2 | | _ | | | |) V 0 G | en1-W | | | | System | Generator | GenEx1-PV | Expansion | Capacity B | Built | 1 | 2033 | 0.00 | MW |
| 1/1/2029 | • | | 1: 12 | MA 00: | - 0 | | | | | | | System | Generator | GenEx1-PV | Expansion | Capacity E | Built | 1 | 2034 | 0.00 | MW |
| 11 🖨 Y | 'ear(s) 🔻 | Exte | nd Trend | 0 | | | 🕨 🗸 🚺 G | en2-PV | | | | System | Generator | GenEx1-PV | Expansion | Capacity I | Built | 1 | 2035 | 10,050.00 | MW |
| Primary Axis | s Secondar | y Axis | | | | | 🕨 🗸 🌔 G | en2-Thermal | | | | System | Generator | GenEx1-PV | Expansion | Capacity I | Built | 1 | 2036 | 1,350.00 | MW |
| Properties | ; | | | | (1/13 | | 🕨 🗸 🧿 G | en2-W | | | | System | Generator | GenEx1-PV | Expansion | Capacity I | Built | 1 | 2037 | 0.00 | MW |
| riopenae | Property | | Unit | Bands | -1× | | | | | | | System | Generator | GenEx1-PV | Expansion | Capacity E | Built | 1 | 2038 | 0.00 | MW |
| Generator | 1 | | | | | ľ | Batte | ries | | | | System | Generator | GenEx1-PV | Expansion | Capacity B | Built | 1 | 2039 | 0.00 | MW |
| Units | | | - | 1 | | | Transmission | n | | | | System | Generator | GenEx1-W | Expansion | Capacity E | Built | 1 | 2029 | 0.00 | MW |
| Generation | | | GWh | 1 | | | 🗸 🔚 Node | 25 | | | | System | Generator | GenEx1-W | Expansion | Capacity E | Built | 1 | 2030 | 0.00 | MW |
| Max Capacity | | | MW | 1 | | Ι, | 🗸 🔚 Lines | | | | | System | Generator | GenEx1-W | Expansion | Capacity I | Built | 1 | 2031 | 0.00 | MW |
| Installed Capa | city | | MW | 1 | | | Caparic | | | | | System | Generator | GenEx1-W | Expansion | Capacity E | Built | 1 | 2032 | 0.00 | MW |
| Units Built | | | - | 1 | | 11' | Generic | | | | | System | Generator | GenEx1-W | Expansion | Capacity F | Built | 1 | 2033 | 0.00 | MW |
| Units Retired | | | - | 1 | | • | 🗸 🔚 Const | traints | | | | System | Generator | GenEv1-W | Expansion | Canacity | Built | 1 | 2034 | 0.00 | MW |
| Capacity Built | | | MW | 1 | | | 🗸 🔚 Decis | ion Variables | | | | System | Generator | GenEv1-W | Expansion | Canacity | Built | 1 | 2035 | 0.00 | MM |
| Capacity Retire | ed | | MW | 1 | | | Data | | | | | System | Generator | GCHEXI-W | = . | cupacity t | ount | - | 2000 | 0.00 | 10100 |



Illustrative East – West example of PJM system

• Demo in Software





- Technical Education
 - Modeling Policies
 - Modeling Resource Adequacy





Presenter:

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Sources for Techno-Economic Inputs

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