PLEXOS OVERVIEW & TUTORIAL

1. Introduction

Before proceeding through these notes, it is recommended that you review the User Interface Guides. They are posted to the course website here: http://home.eng.iastate.edu/~jdm/ee552/ee552schedule.htm. In reading these guides, it is suggested that you read rather fast. Your main goal when reading is not necessarily to assimilate everything in these guides but rather to pick up central ideas and familiarize yourself with the structure of the guide and understand the type of information that is contained within each chapter. I would expect that you take about one hour in reading through these guides. In particular, pay attention to the definitions associated with Plexos' object-oriented software design; focus on gaining some understanding of the following terms: objects, classes, collections, categories, memberships (or relationships), and properties.

2. Accessing Plexos

In accessing Plexos, it is assumed you are using a Windows machine. If you are not, then some of the access procedures you will need may differ from those described below.

To access Plexos, use "remote desktop" (for Windows 10, remote desktop is found under "Windows Accessories" from your "apps" list; for older operating systems, remote desktop is found from your "Start" button in the lower left-hand-side of your Windows screen) to access the server "plexos.ece.iastate.edu". The remote desktop process will ask you for login information – use your ISU net-id and password. All EE 552 students should have access; if you do not, please send email to mshambli@iastate.edu with cc to jdm@iastate.edu. Once you log in to this server, you will see an icon in the left-hand-corner called "PLEXOS 7.1 x64 Edition." Double click on this icon, and the Plexos interface with come up. You are now into the Plexos program.

In the upper left-hand corner of the interface, just above the "new," "open," and "connect" buttons, you will find three small rectangular buttons. The one farthest to the right is the "Help" button. Single click on this button to open the "Plexos Guide" window.

The "Plexos Guide" window is split into two subscreens: the menu subscreen on the left and the text subscreen on the right. In the menu subscreen, click on the "+" sign just to the left of the "User Interface Guides" folder. This will show the contents of the "User Interface Guides" folder. (I have uploaded an older User Interface Guide called "PLEXOS 6 User Interface Guides" to the course webpage

which you can browse for now.) There is a sub-folder called "How to…" – click the "+" sign to the left of this subfolder to open its contents. You will see 12 different files, beginning with "Change Settings for PLEXOS" and ending with "Change a Model Setting." Click on each of these files and inspect its contents. Again, there is no reason to assimilate all of this information; your objective at this point is just to obtain a high-level overview of central concepts together with knowledge of where information is which you can return to later as necessary.

Another folder within the menu screen of the Plexos Guide window is called "Modelling Guide." Click on the "+" sign to the left of this folder. A file called "Concise Modelling Guide" will appear in the menu screen. Click on it and review it quickly. Pay particular attention to Section 2.5.

Within this same folder ("Modelling Guide"), you will see a subfolder called "Simulation." It will already be partly expanded, but click on its "+" sign anyway. It will expand to 5 files; click on the one that says "LT Plan" and quickly review its contents.

3. High-level description

Plexos is a simulation tool based on optimization. It is capable of
- Production costing:
    - Running optimal power flow,

- o Running short-term, medium-term, or long-term unit commitment;
- Expansion planning:
  - o Determining optimal size and timing of new investments,
  - o Valuing generation and transmission assets, including mixed hydro-thermal systems,
  - o Projecting short, medium, and long-term capacity adequacy,
  - o Calculating stranded-asset cost;
  - o Assessing the impact of security-of-supply constraints, and environmental constraints,
- Maintenance: Optimizing the timing and duration of maintenance outages;
- Market assessment:
  - o Performing market benefit analysis for transmission and generation assets,
  - o Calculating market outcomes that account for both fixed and variable cost components,
  - o Calculating optimal trading strategies for a portfolio of generation and transmission assets including entrepreneurial interconnectors,
  - o Projecting pool prices under various scenarios of load growth and new entry,
  - o Determining the impact of market design decisions, and rule changes,
  - o As a real-time market-clearing engine,

o Analyzing generation and transmission constraints and calculating rents;

There are four different simulation options within Plexos.

- LT Plan: This performs the long-term expansion planning function. The purpose of the LT Plan model is to find the optimal combination of generation new builds and retirements and transmission upgrades (and retirements) that minimizes the net present value of the total costs of the system over a long-term planning horizon. That is, it simultaneously solves a generation and transmission capacity expansion problem and a dispatch problem from a central planning, long-term perspective. Planning horizons for the LT Plan model are user-defined and are typically expected to be in the range of 10 to 30 years. LT Plan appropriately deals with discounting and end-year effects. The following types of expansion/retirements and features are supported:
  o Building new generating plant
  o Retiring existing generating plant
  o Multi-stage projects
  o Building new DC transmission lines
  o Retiring existing DC transmission lines
  o Multi-stage transmission projects
  o Expanding the capacity on existing transmission interfaces
  o Taking up new physical generation contracts
  o Taking up new physical load contracts

- o Chronological or load duration curves
- o Deterministic or stochastic optimization
- PASA: This stands for "projected assessment of system adequacy." It produces output such as the projected capacity reserves (capacity in excess of reserve) and LOLP on a region-by-region basis. It distributes and optimizes available generation capacity between regions.
- MT Schedule: This model addresses medium-to-long-term power system decisions while respecting constraints on hydro storage, fuel supply and emissions. This is basically a hydro-thermal coordination and fuel-scheduling application. MT Schedule can be run on a week-by-week or month-by-month basis. Important modeling features include
  - o reducing the number of simulated periods by combining together dispatch intervals in the horizon into 'blocks';
  - o modeling the transmission network only to the region or zone level; and
  - o replacing the Optimal Power Flow with a transportation model; and
  - o simplifying the detail used to model Generator efficiency.
- ST Schedule: This is essentially a production-cost simulation tool, i.e., it simulates electricity markets by one hour time steps or by 5-minute time steps. It is

designed to emulate the dispatch and pricing of real market-clearing engines.

4. Object-oriented design

Plexos uses an object-oriented programming design. If you are familiar with object-oriented programming, then you have a head start. If not, then it is OK, but you will need to become comfortable with a few concepts:

- Class: A set of rules and definitions that specify how objects of that class behave and what data can be defined on those objects. A class encapsulates data and operations that belong together, and it controls the visibility of both data and operations. Class behavior specifies what collections objects are allowed to belong to, what collections they must belong to, and how those objects interact with other objects of the same and other types. The class Dog would consist of traits shared by all dogs, such as breed and fur color (characteristics), and the ability to bark and sit (behaviors). Examples of Plexos classes include System, Company, Region, Zone, Node, Line, Transformer, Contingency, Fuel, Emission, Generator, and Data File.
- Object: A pattern (exemplar) of a class. The class Dog defines all possible dogs by listing the characteristics and behaviors they can have; the object Lassie is one particular dog, with particular versions of the characteristics. A Dog has fur; Lassie has brown-and-

white fur. We may therefore speak of a "class of an object."

- File: A file (.xml) is a single System object, which represents the power system being studied. This is the root object to which all other objects belong.
- Collection: The System has a set of collections, one for each class of objects. All other objects belong primarily to these System collections e.g. Companies, Generators, Fuels, Storages, etc. Here are some examples:
  - To define a generator, one adds a new Generator object to the System's Generators collection. To represent ownership of a generator by a company, one adds the Generator object to the Generators collection of the Company object that owns it.
  - Generator G injects at node N: Generator object G belongs to Node N Generators collection
  - Generator G uses fuel F: Fuel object F belongs to Generator G Fuels collection
  - Transmission line A-B flows between nodes A and B: Both Node objects A and B belong to the Nodes collection of Line A-B

  A collection is defined by the Parent Class, Child Class, and Collections fields.
- Memberships: A membership to a collection is defined by Parent Class, Child Class, Collections, Parent Name, and Child Name.

- Properties: Properties are defined on memberships, and therefore require the five fields, plus Property, Period Type, Band and Value.

5.Step-by-step example

1. **Remote login to Plexos machine and Start Plexos**: If you have not already done so, use the remote desktop connection to access the plexos server and then start Plexos, as described in Section 2 of these notes.
2. **Create a new file**: Click "Home" from top left-hand menu. Then click on the "Save" icon above the word "Save" on the top left-hand menu. Choose a directory to save to, and name your file "3Node.xml".
3. **Observe**:
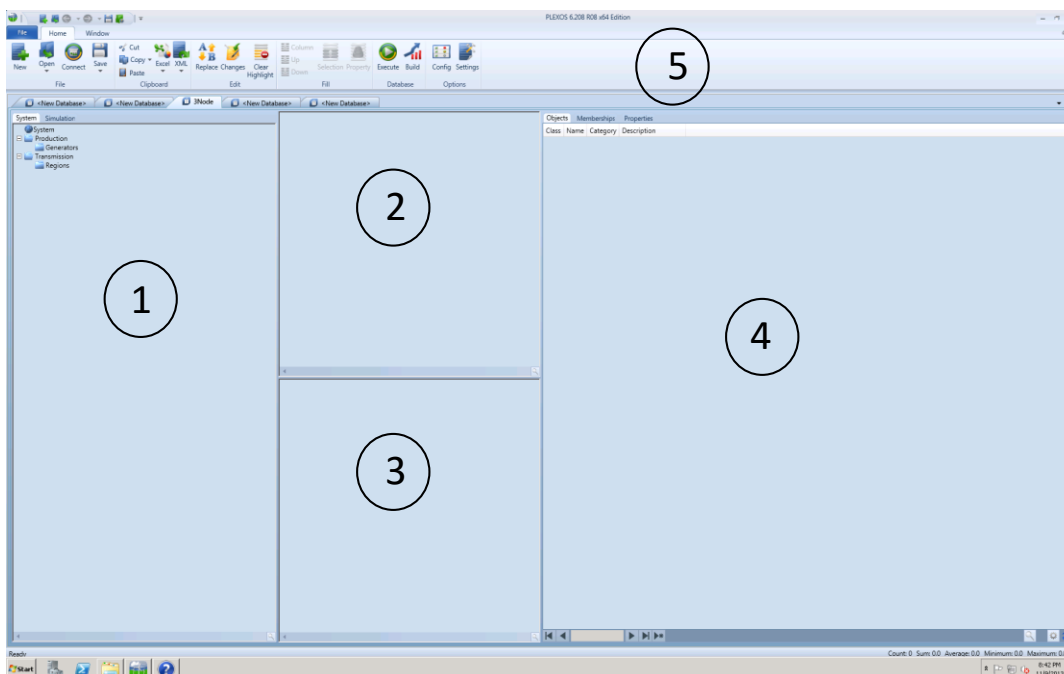
The numbers 1-5 above refer to

1. The Main Tree

    This tree shows you all the *Objects* in the database organized into *Collections* shown as folders. This tree is your primary means of navigating the data in the system. The other interface elements respond to your selections in this tree.

2. The Membership Tree

    Shows the relationships (called *Memberships*) between objects. The contents of this tree change according to your selection in the Main Tree.

3. The Properties Tree:

    Lists the properties available for the type of objects selected in the Main Tree.

4. The Data Grid

    There are three tabs for the grid (Objects, Memberships, Properties). Each presents a standard Access datasheet where you can edit/add/delete data. You can also use the standard Access filtering and sorting commands to organize the data presented.

5. The Menu Bar

    Provides the action commands for PLEXOS such as Execute to begin execution of a simulation.

Now we are going to create the following power system.

Gen_11
300MW
$32.00/MWh

Gen_12
700MW
$40/MWh

Gen_3
300MW
$48/MWh

L1-2
Max flow 1000
Max flow back 1000

L2-3
Max flow 1000
Max flow back 1000

L1-3
Max flow 1000
Max flow back 1000
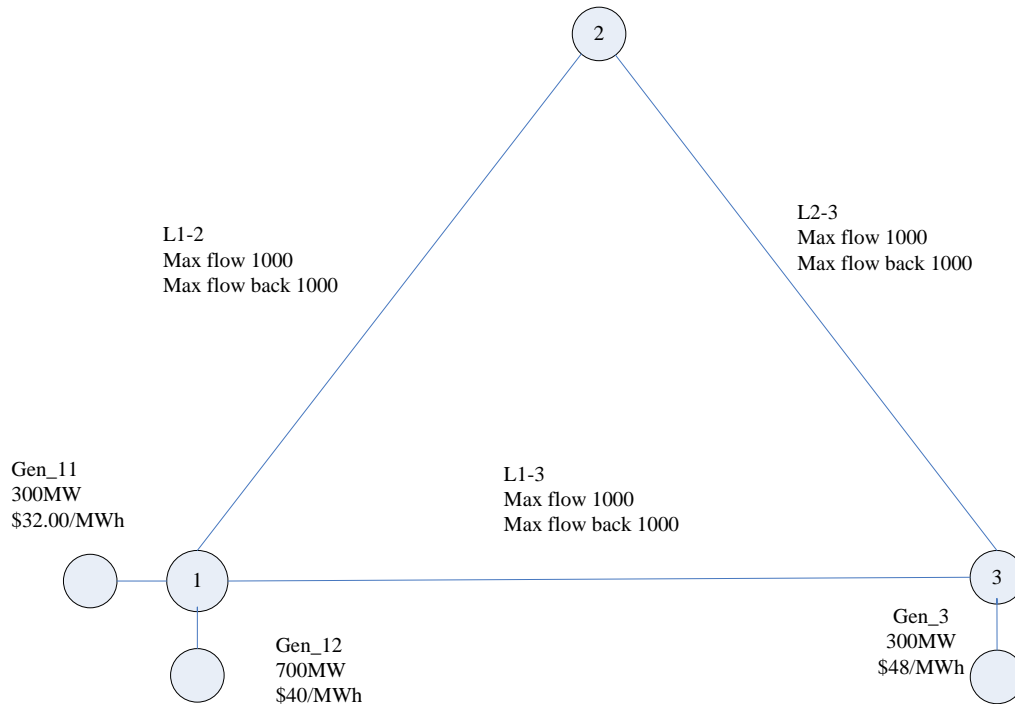
We will do seven types of operations:
- Set configuration

- Create objects (regions, nodes, lines, generators)
- Add objects to collections
- Set properties
- Set memberships
- Execute
- Examine solution
4. **Set configuration**: Click on "Configuration" in the menu bar.
   a. Click on the "+" sign beside "Region" under the "Transmission" category in the left-hand-side of the screen. Click on the check-box next to enable "Region.Reference Node."
   b. Click on the check-box besides "Node" under the "Transmission" category in the left-hand-side of the screen. Now click on the "+" sign to the left of the "Node" check-box you just checked. You will see three sub-folders: "Settings", "Production," and "Pass-through." (The "Production" folder will already be checked and you can leave it that way.). Click on the "Settings" folder (but do not check it). You will see four options below it. Click on "Is Slack Bus."
   c. Click on the check-box besides "Line" under the "Transmission" category in the left-hand-side of the screen. Now click on the "+" sign to the left of the "Line" check-box you just checked. You will see about 10 or 11 sub-folders. Click on the "+" sign

next to the "Line" subfolder. Click on the "Capacity" subfolder.

d. Under the "Production" category in the left-hand-side of the screen, click on the "+" sign to the left of the "Generator" icon. You will see a bunch of sub-folders appear. Click on the "+" sign next to "Generator" subfolder. You will see 5 sub-folders. Click on the check-box next to the "Capacity" sub-folder and next to the "Expansion" subfolder.

e. Under the "Data" category in the left-hand-side of the screen, click the "+" sign to the left of the "Data File" subfolder. Click on the "+" sign beside the "Attributes" sub-subfolder. Click to enable the following functions: "Enabled," "Growth Period," "Method," "Relative growth at min," and "Decimal places."

f. Click on "OK" at the bottom right-hand-corner of the screen.

g. Click on "Settings" in the menu bar. Click on "Imperial" at the bottom left-hand-corner of the screen.

h. Click on "OK" at the bottom right-hand-corner of the screen.

5. **Create a region**: Right click on "Region" (from main tree) and select "New Region."
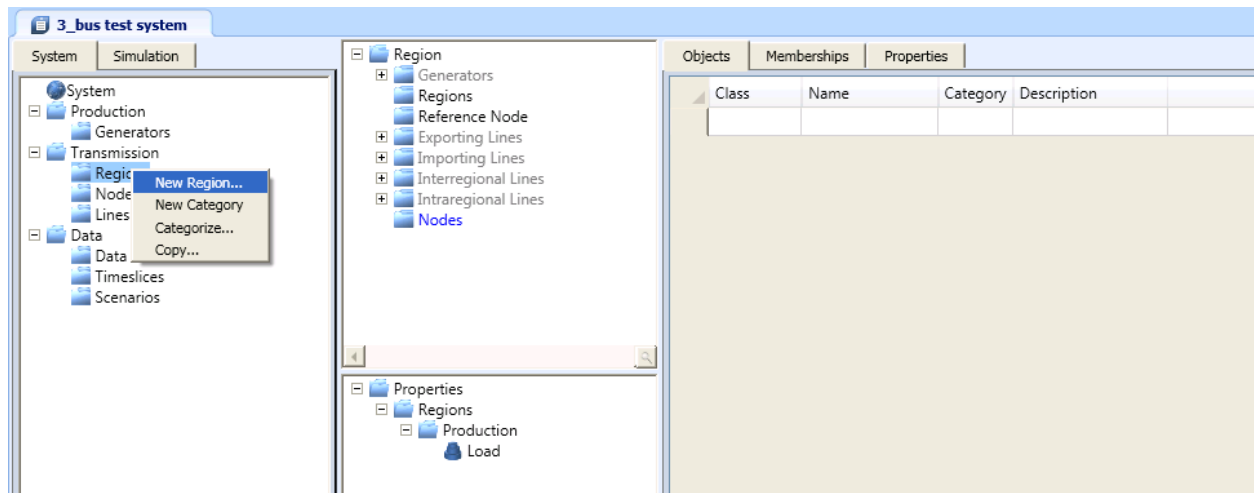
A dialog box will appear where you will need to provide your new region with a name. I will assume in what follows the new region name given is "3node." Click "OK," and a "3node" Properties window will appear. Click "OK" at the bottom right-hand corner of this window.

6. **Create node 1**: Right click on "Nodes" from main tree and select "New node."
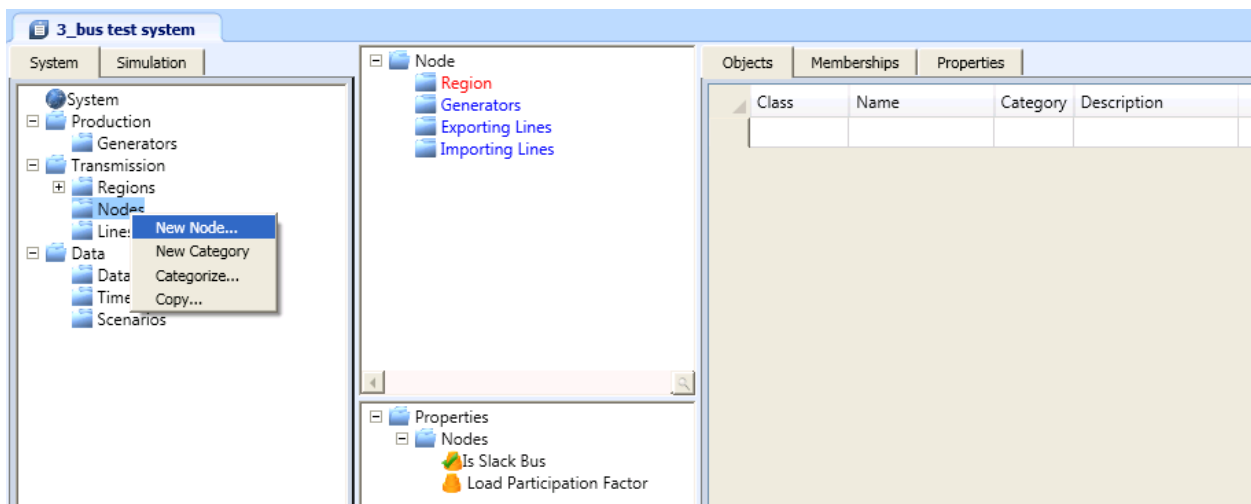
A dialog box will appear, where you will need to provide your new node with a name. I will assume in what follows the new node name given is "1." Click "OK,"

and a "1" Properties window will appear. Click "OK" at the bottom right-hand corner of this window.

7. **Create node 2**: Repeat step 6 except name the new node "2".

8. **Create node 3**: Repeat step 6 except name the new node "3".

9. **Create Lines**: Right click on "Lines" from main tree and select "New line." A dialog box will appear, where you will need to provide your new line with a name. Name your new line "L12." Click "OK," and a "L12" Properties window will appear. Click "OK" at the bottom right-hand corner of this window. Repeat this process to create lines L13 and L23.

10. **Create generators**: Right click on "Generators" from main tree and select "New generator." A dialog box will appear, where you will need to provide your new generator with a name. Name your new generator "Gen_11". Click "OK," and a "Gen_11" Properties window will appear. Click "OK" at the bottom right-hand corner of this window. Repeat this process to create generators Gen_12, and Gen_3.

11. **Add nodes 1, 2, 3 to node collection of region**:
    a. Left click on "Regions" in main tree.
    b. Left click on "Nodes" in membership tree.
    c. Left click beneath the "Collection" column in data grid. When you do this, you will see a drop-down menu appear on the right-side of the cell. Select "Node.Region".

d. Left click on the "Parent Name" column, and select "1". Left click on the "Child Name" column, and select "3node".

e. Left click on "Nodes" within the membership tree. Then repeat steps c and d except use row 2, selecting "2" and "3node" for the "Parent Name" and "Child Name" columns, respectively.
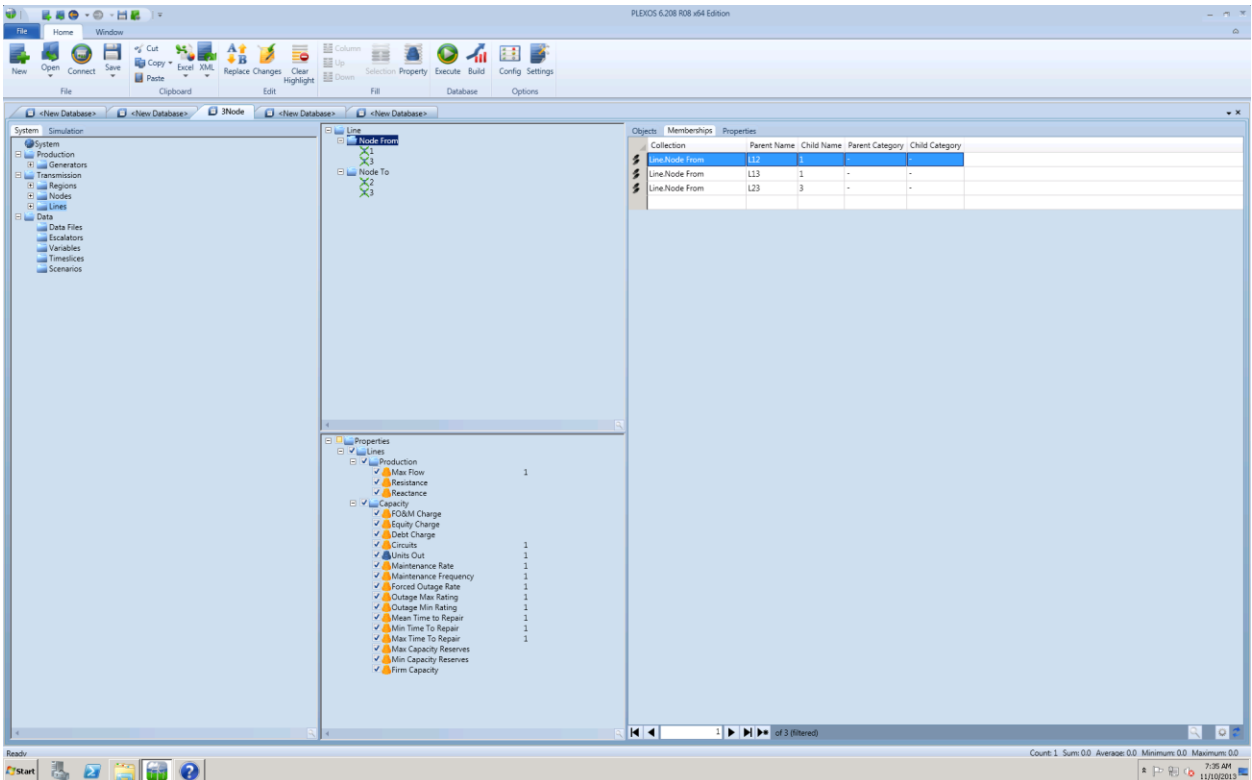
f. Left click on "Nodes" within the membership tree. Then repeat steps c and d except use row 3, selecting "3" and "3node" for the "Parent Name" and "Child Name" columns, respectively.

The screen should appear as below.
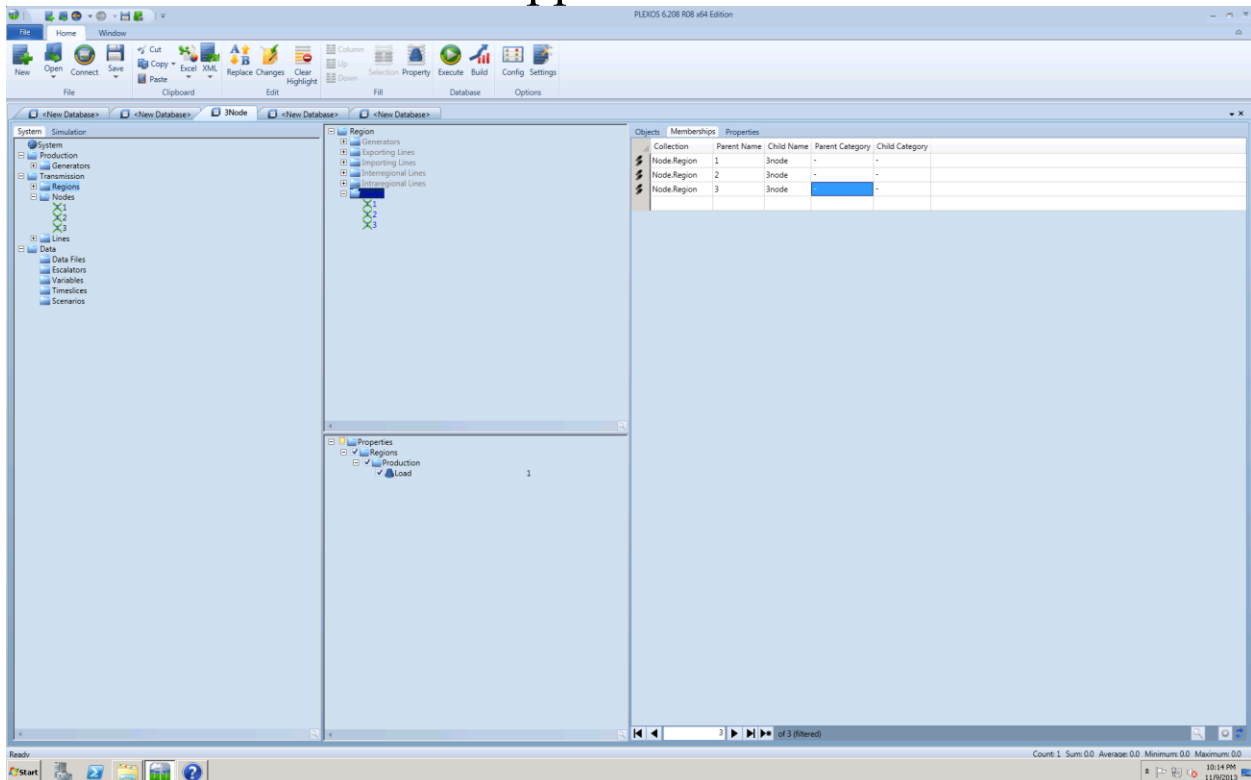
12. **Add node 3 to collection of reference node collection of region**:

a. Left click on "Regions" in main tree.

b. Left click on "Reference node" in membership tree.

c. Left click in first row of "Collection" column in data grid. When you do this, you will see a drop-down menu appear on the right-side of the cell. Left-click on it, and select "Region.Reference Node". The first row of the "Parent Name" column will automatically show "3node".

d. Left click in the first row of the "Child Name" column in data grid. When you do this, you will see a drop-down menu appear on the right-side of the cell. Left click on it, and select "3".

The screen should appear as below.
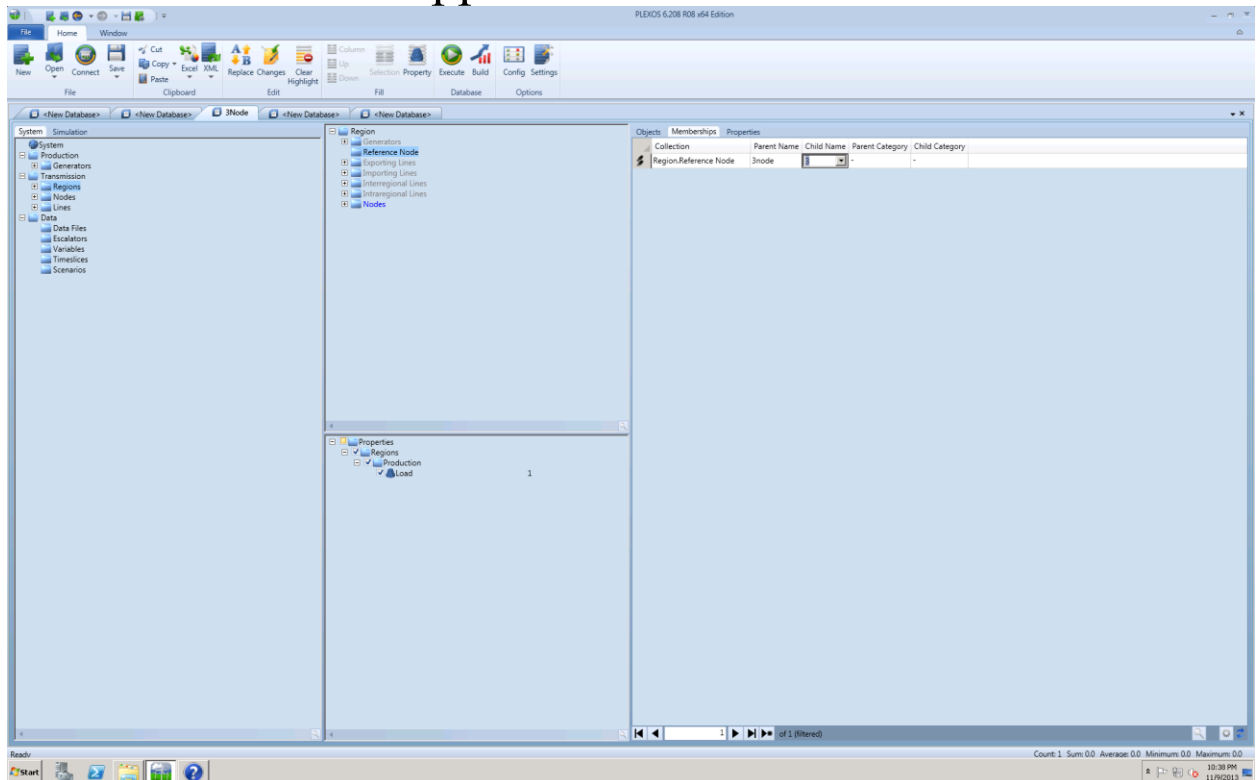

13. **Add node 1 to line L12's from node collection**:

a. Left click on "Lines" in the main tree.

b. Left click on "Node From" in the membership tree.

c. Left click in first row of "Collection" column in data grid. When you do this, you will see a drop-down menu appear on the right-side of the cell. Left-click on it, and select "Line.Node From".

d. Left click in first row of "Parent Name" column in data grid. When you do this, you will see a drop-down menu appear on the right-side of the cell. Left-click on it, and select "L12".

e. Left click in the first row of the "Child Name" column in data grid. When you do this, you will see a drop-down menu appear on the right-side of the cell. Left-click on it, and select "1".

14. **Add node 2 to line L23's from node collection**: Repeat steps 13-b, 13-c, 13-d, and 13-e, except select L23 in step 13-d and select "2" in step 13-e.

15. **Add node 1 to line L13's from node collection**: Repeat steps 14-d and e, except select L13 in step 14-d and select "1" in step 14-e.

The screen should appear as below (except without the "To-bus" list of nodes in the membership tree).

16. **Add node 2 to line L12's to node collection**:
    a. Left click on "Lines" in the main tree.
    b. Left click on "Node To" in the membership tree.
    c. Left click in first row of "Collection" column in data grid. When you do this, you will see a drop-down menu appear on the right-side of the cell. Left-click on it, and select "Line.Node To".
    d. Left click in first row of "Parent Name" column in data grid. When you do this, you will see a drop-down menu appear on the right-side of the cell. Left-click on it, and select "L12".
    e. Left click in the first row of the "Child Name" column in data grid. When you do this, you will see

a drop-down menu appear on the right-side of the cell. Left-click on it, and select "2".

17. **Add node 3 to line L23's to node collection**: Repeat steps 16-e and e, except select L23 in step 16-d and select "3" in step 17-e.

18. **Add node 3 to line L13's to node collection**: Repeat steps 16-d and e, except select L13 in step 16-d and select "3" in step 16-e.

After steps 16, 17 and 18, the screen should appear as below (make sure you click on the "properties" tab in the datagrid).
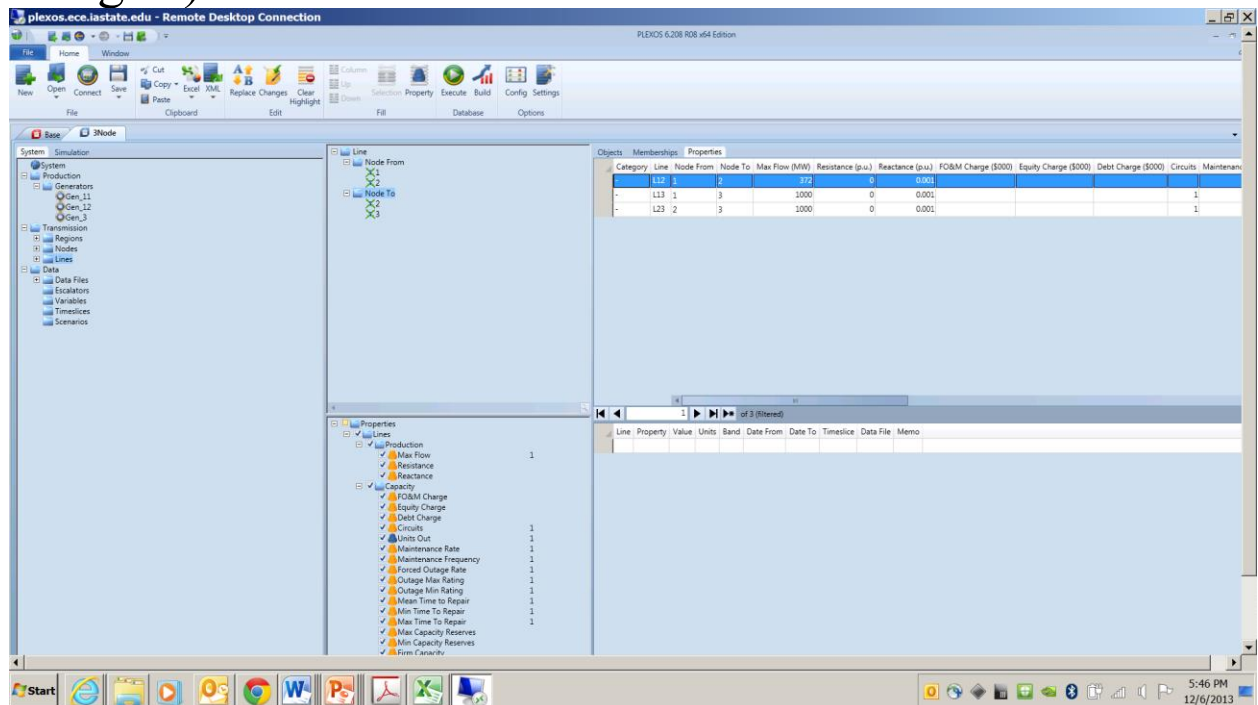
19. **Set node properties**:
   a. Left-click on "Nodes" in the main tree. You will see "Properties" of the nodes in the data grid. Click in the node 3 row under the "Is slack bus" column. When you do this, you will see a drop-down menu

appear on the right-side of the cell. Left-click on it, and select "Yes". You have now identified bus 3 as the system slack bus.

b. Click in the node 1 row under the "Load participation factor" column in the data grid. Type 0.3 Repeat for the node 2 row, except type 0.4 for the load participation factor. Repeat for the node 3 row except type 0.3. This indicates that the total system load will be split between nodes 1, 2, and 3 according to these fractions (the below shows the participation factors as 0,0,1, but they should be 0.3, 0.4, 0.3).
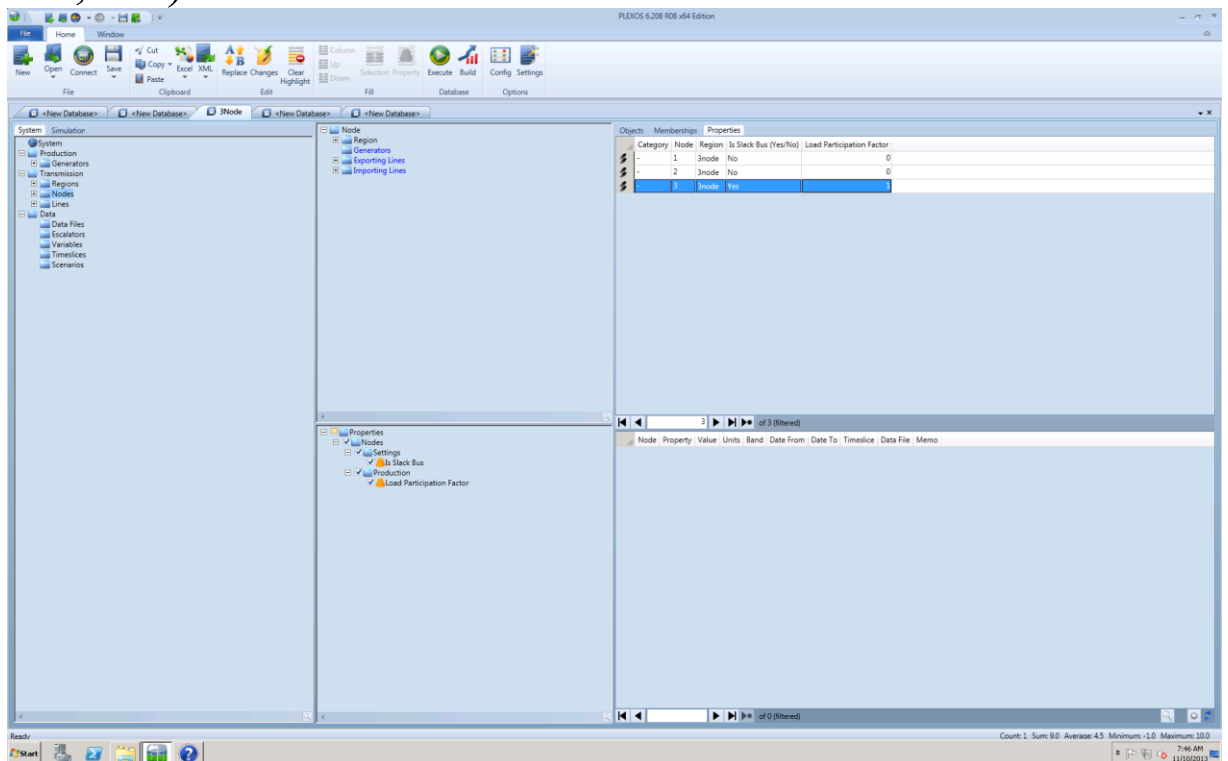
20. **Set line properties**: Left-click on "Lines" in the main tree. You will see "Properties" of the lines in the data

grid. For all three lines, set Max Flow=1000 MW, R=0, and X=0.001.
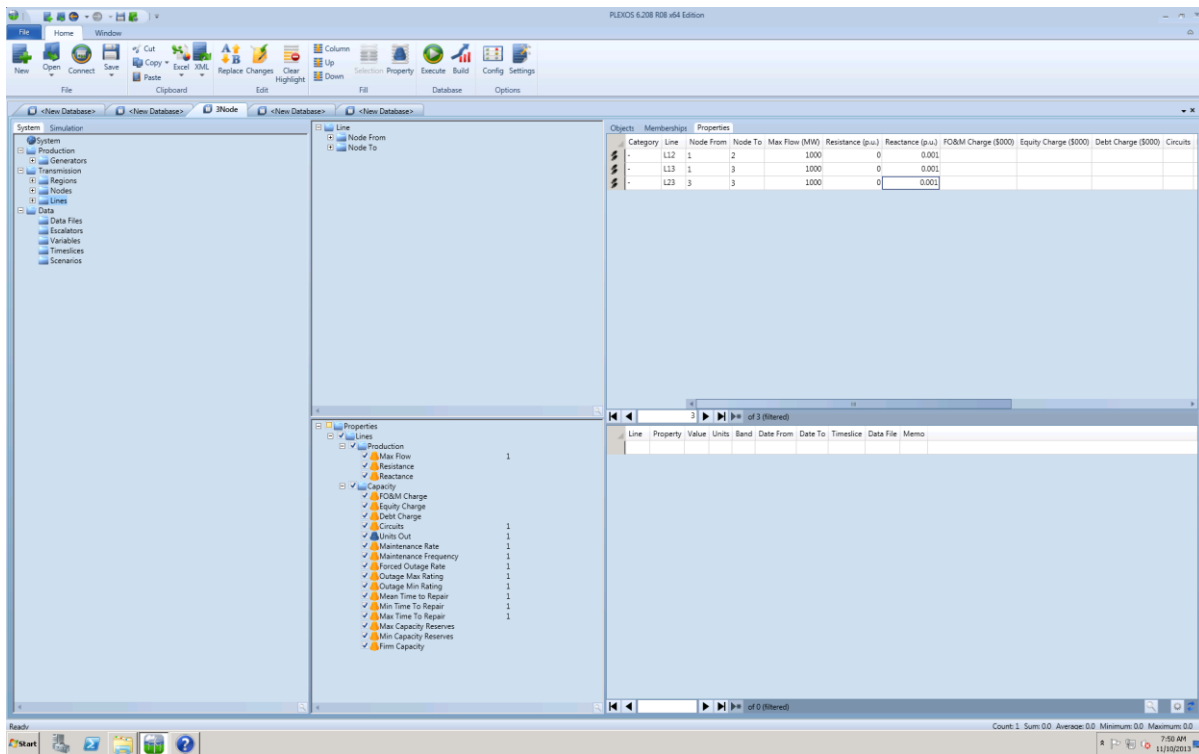
21. **Set generator properties**: Left-click on "Generators" in the main tree. You will see "Properties" of the generators in the data grid. Enter the following data.

Category	Generator	Nodes	Units	Max Capacity (MW)	Min Stable Level (MW)	Fuel Price ($/MMBTU)	Heat Rate (BTU/kWh)	FO&M Charge ($/kW/year)	Equity Charge ($/kW/year)	Debt Charge ($/kW/year)	Firm Capacity (MW)	Maintenance Rate (%)	Maintenance Frequency
-	Gen_11	1	1	300	0	4	8000	0	0	0	300	0	0
-	Gen_12	1	1	700	0	4	10000	0	0	0	700	0	0
-	Gen_3	3	1	300	0	4	12000	0	0	0	300	0	0

		Forced Outage Rate (%)	Outage Rating (MW)	Outage Pump Load (MW)	Mean Time to Repair (hrs)	Min Time To Repair (hrs)	Max Time To Repair (hrs)	Repair Time Shape	Repair Time Scale	Build Cost ($/kW)	Retirement Cost ($000)	
-	Gen_11	1	0	0	40							
-	Gen_12	5	0	0	100							
-	Gen_3	2	0	0	80							

		Project Start Date	Commission Date	Technical Life (years)	WACC (%)	Economic Life (years)	Max Units Built	Max Units Retired	Min Units Built	Min Units Retired	Capacity Price ($/kW/year)	Build Non-anticipativity ($/MW)	Retire Non-anticipativity ($/MW)
-	Gen_11				7								
-	Gen_12				7								
-	Gen_3				7								

What are the $/MWhr costs of the three units? These can be computed as the product of the fuel price and the heat rate, given as $32/MWh, $40/MWh, and $48/MWh.

It is of interest that the outage data provided above enables one to compute MTTF via

$$\text{FOR} = \frac{\text{MTTR}}{\text{MTTF} + \text{MTTR}} \rightarrow \text{MTTF} = \frac{\text{MTTR}}{\text{FOR}} - \text{MTTR}$$

For example, Gen_11 would have MTTF of

$$\text{MTTF} = \frac{100}{0.05} - 100 = 1900\text{hrs}$$

from which we can also obtain transition rates λ, μ from

$$\lambda = \frac{1}{MTTF} = \frac{1}{1900hrs} = 0.00052632/hr$$

$$\mu = \frac{1}{MTTR} = \frac{1}{100hrs} = 0.01/hr$$

22. **Set generator memberships**: After entering all above data under "Properties," click on the "Memberships" tag at the top of the data grid.

   a. Click in the "Collection" column of the first row. When you do this, you will see a drop-down menu appear on the right-side of the cell. Left-click on it, and select "Generator.Nodes".

   b. Click in the second column called "Parent Name" and select "Gen_11".

   c. Click in the third column called "Child Name" and select "1".

   Repeat the above steps to identify Gen_12 with node 1. Repeat again to identify Gen_3 with node 3.
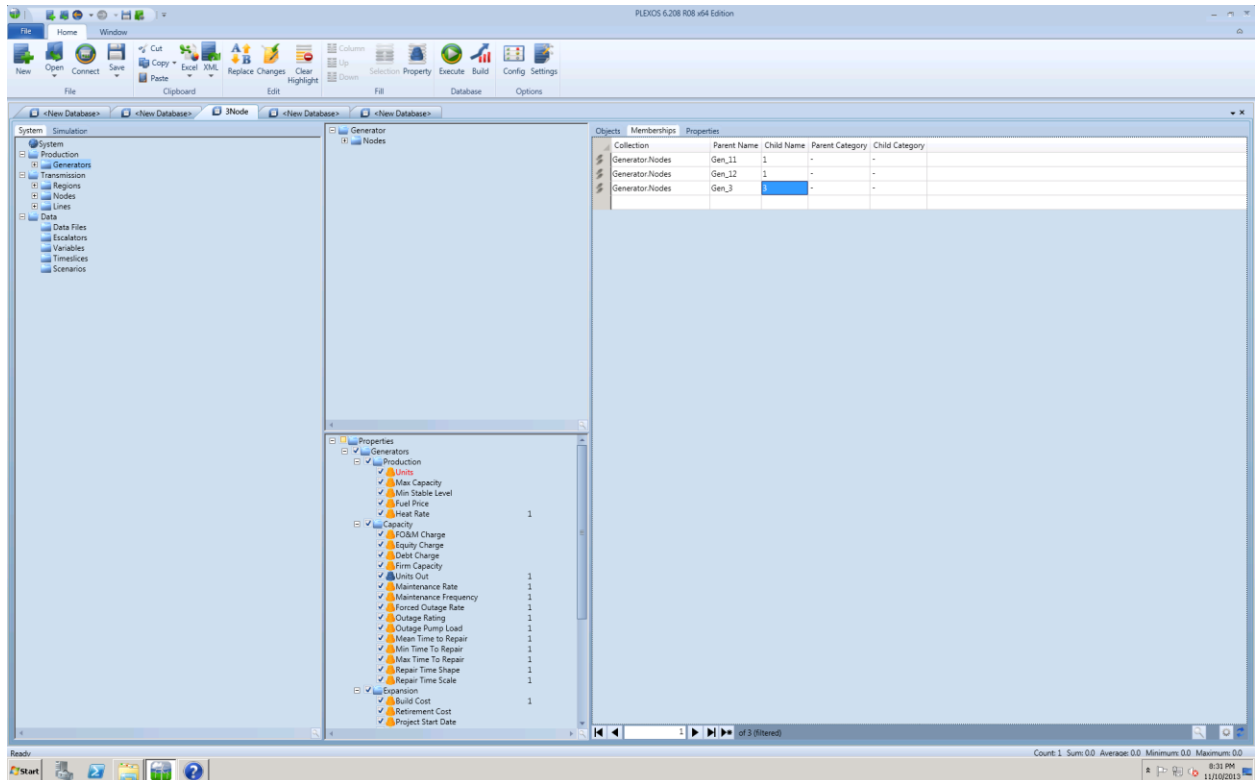
23. **Create or obtain a load data file**: To create a load data file, use Excel and create a .csv file having the following format:

Year	Month	Day	1	2	3	4	...	24
2016	11	1	1105	1086	1088	1090	...	1107
2016	11	2	1105	1086	1088	1090	...	1107

The load data, in MW, is specified one 24 hour day per row. It is possible to model as many days as desired.

In what follows, I will assume you have created a load data file for 18 days as above, with the hourly load identical on each day according to the following:

hr1:1105   hr2:1086   hr3:1088   hr4:1090
hr5:1092   hr6:1098   hr7:1120   hr8:1145

hr9:1175	hr10:1195	hr11:1210	hr12:1214
hr13:1207	hr14:1212	hr15:1220	hr16:1230
hr17:1200	hr18:1210	hr19:1180	hr20:1150
hr21:1140	hr22:1130	hr23:1110	hr24:1107

24. **Create a data file object**: Right click on "Data Files" (from main tree) and select "New Data File."
A dialog box will appear, and you will need to provide your new datafile with a name. In the example here, it is "Load_18Days". Click "OK" in the dialog box.

26. **Set data file properties:** Left click on "Data Files" in the main tree to edit the properties in the data grid. You may need to click on the "Properties" tag in the upper section of the datagrid.

a. In the lower section of the datagrid, click in the first row under the "Property" column and select "Filename" in the drop-down menu.

b. In the first row under "Filename" column, enter the full path filename of the load file. You should save it to a local folder, e.g., U:\PLEXOS\LoadData3-Node.csv.
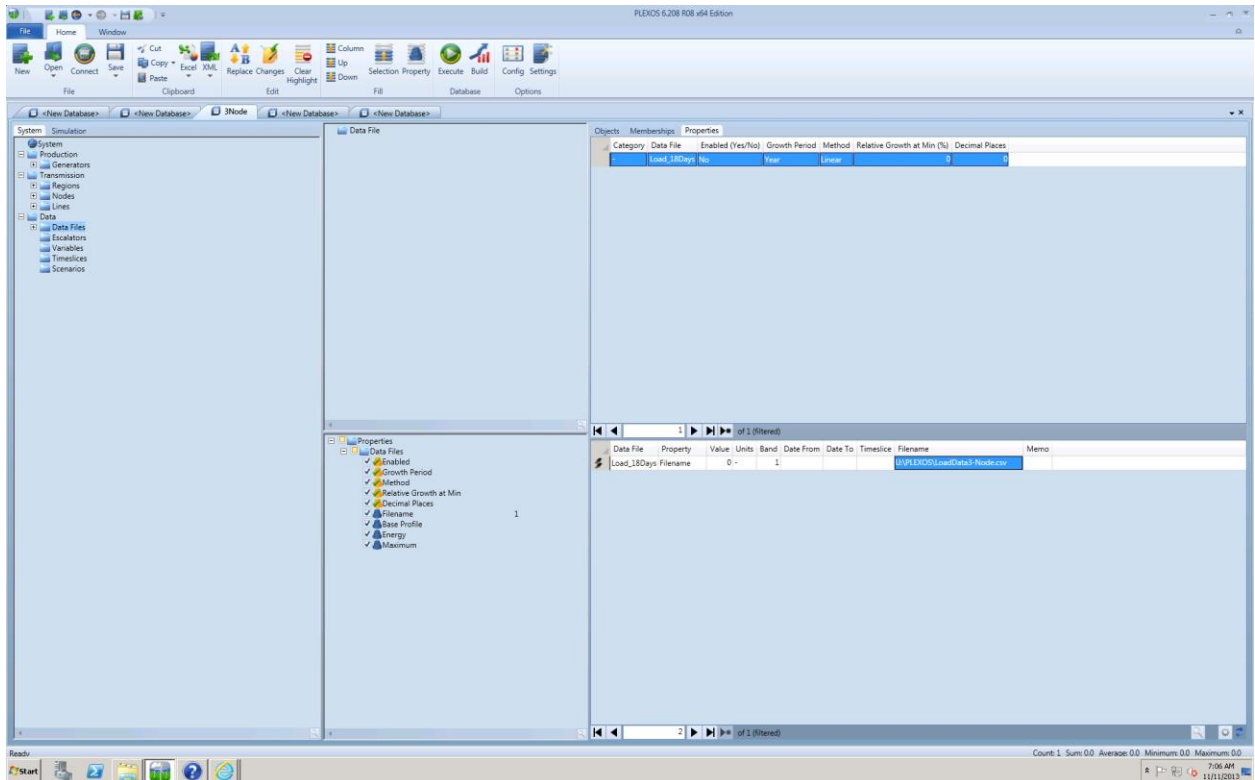
27. **Set load properties within region:** Left click on "Regions" in the main tree to edit the properties in the data grid. You may need to click on the "Properties" tag in the upper section of the datagrid.

   a. In the lower section of the datagrid, click in the first row under the "Region" column. A drop-down menu will appear in the right of the cell. Click it and select your region (should only be one, in this example, it is "3node").

   b. In the lower section of the datagrid, click in the first row under the "Property" column. A drop-down menu will appear in the right of the cell. Click it and select "load".

c. In the lower section of the datagrid, click in the first row under the "Data File" column. A drop-down menu will appear in the right of the cell. Click it and select your load file (should only be one, in this example, it is "Load_18Days").
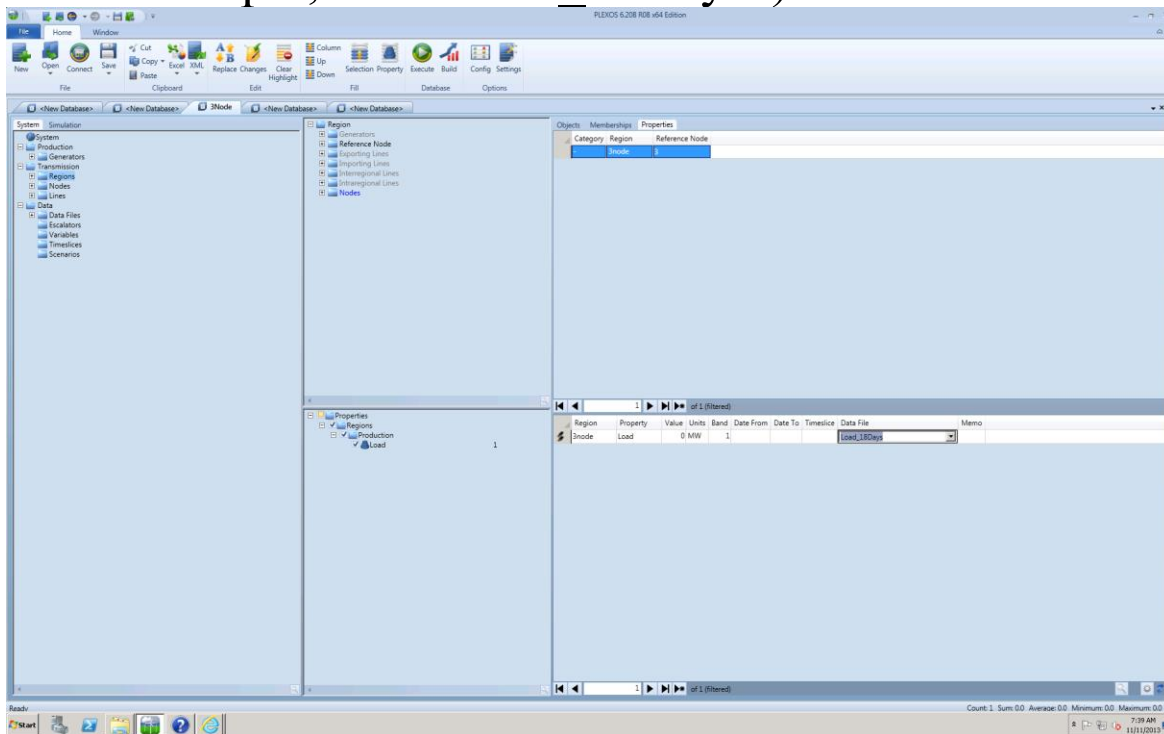
28. **Set Planning horizon:** Left click "Simulation" at the top of main tree, and then left-click on the "Horizons" subfolder under the "Simulation" folder of the main tree. You will see the "Horizon" folder and two subfolders in the membership tree. Left-click on the "+" sign beside the "Models" subfolder in the membership tree. You will then see a "Base" icon beneath the "Models" subfolder. Right click on the "Base" icon, and a selection box will pop up. Left-click on "Properties" in the selection box. A properties screen will appear. Left-click on the "Horizon" menu tab. In the upper part of the panel, set the "Planning

Horizon" information to be consistent with your load data. In the case of this example, set the "Begin on:" date to be, for example, November 1, 2013 (or April 18, 2016), and set the "Run for" number to be 18 days. You will see some additional section items just after the "Planning Horizon" box. Make sure that the "interval length" is "1 hour" and the "day begins" at "12:00 AM." In the "Chronological Phase" box at the bottom, click on "Synchronize to Planning Horizon." Left-click on the "OK" button at the bottom right-hand corner of the window.
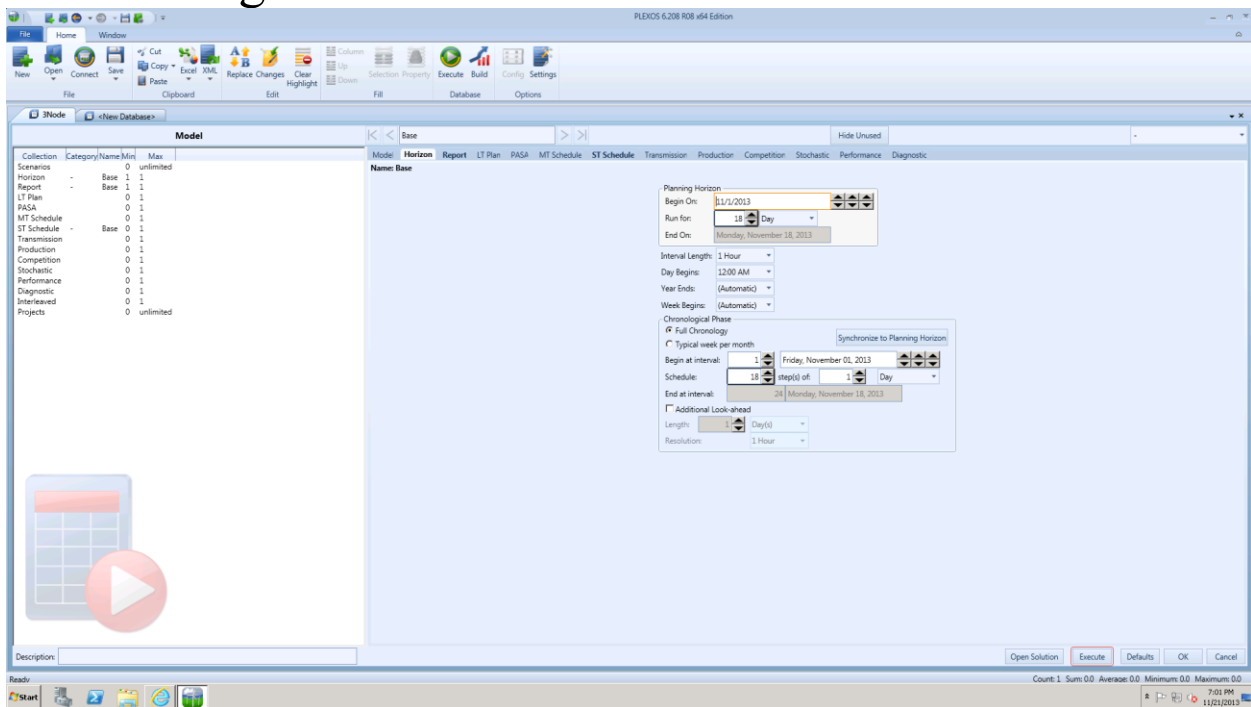
29. **End case construction**: You have completed constructing the case. Left-click on the "System" menu tab at the top of the main tree, and then Left-click on the "System" icon at the top of the main tree. Then click on

the "Objects" tab at the top of the data grid. It should appear as below.
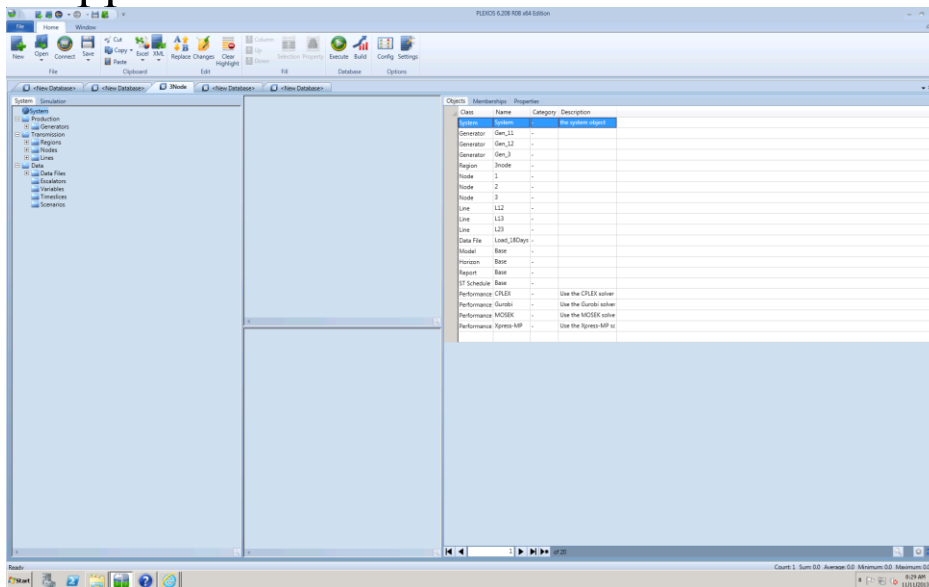
30. **Save**: You should have a good, working Plexos case at this point. Save the case from "File" on the menu bar.

31. **Prepare simulation:** Click on the "Simulation" tab at the top of the main tree.
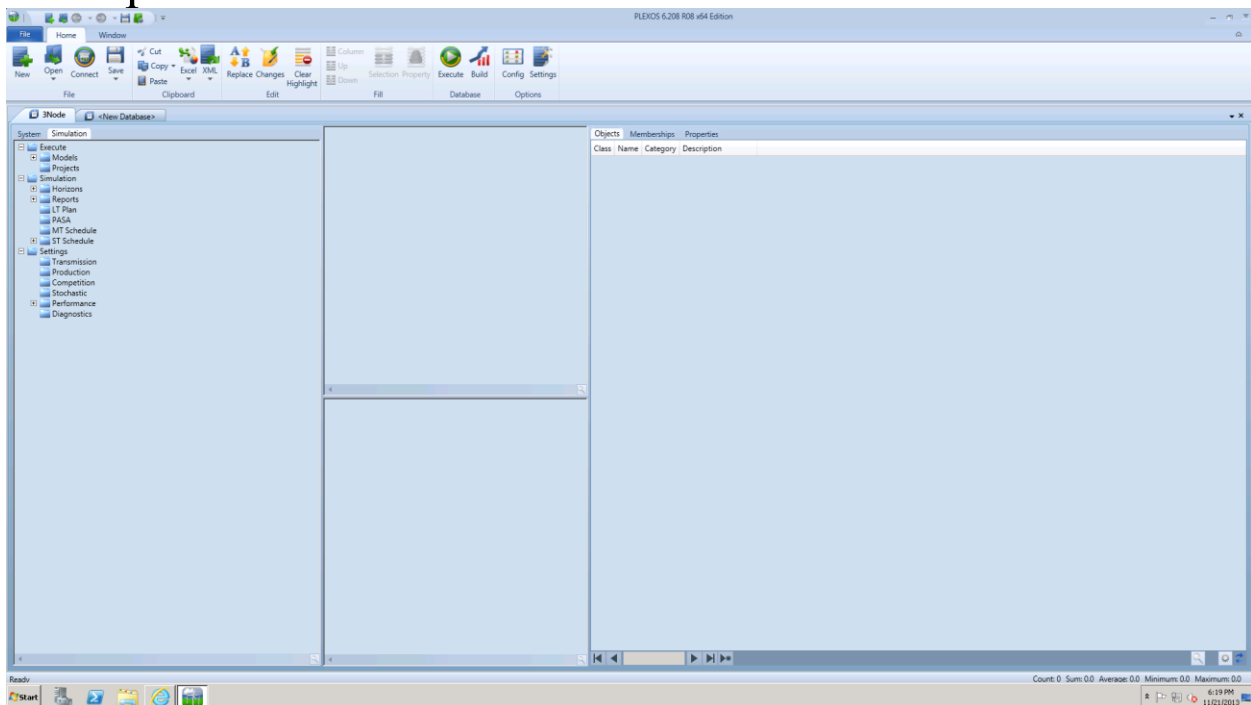
31. **Execute**: Execution at this point will result in a so-called "ST Schedule" solution, which is the default solution method for the software. The "ST" is for "Short-term." Essentially, the program runs a unit commitment over the time period. One may go to the help facility of the Plexos program (click on "Help" icon at the very top of the screen, and search on "ST Schedule") to learn more about this solution method. Here is some information (yellow shading is added to highlight some statements).

6. Short Term (ST) Schedule

Main Trail Page | Class Reference | ST Schedule Class

Description: ST Schedule simulation phase
Detail:

1. ST Schedule

ST Schedule is mixed-integer programming (MIP) based chronological optimization. It can emulate the dispatch and pricing of real market-clearing engines, but it provides a wealth of additional functionality to deal with:

    unit commitment;
    constraint modeling;
    financial/portfolio optimization; and
    Monte Carlo simulation.

Emulation of real market-clearing engines involves clearing generator offers against forecast load accounting for transmission and other constraints to produce a dispatch and pricing outcome. ST Schedule can do this but PLEXOS extends this basic functionality by allowing you to specify fundamental data such as generator start costs and constraints, heat-rate curves, fuel costs, *etc.* as well as or in addition to market data such as generator offers, and the dynamic formulation engine in the AMMO software at the heart of PLEXOS tailors the representation of each

simulation element, such as a generator, at runtime and on a case-by-case basis. This allows you to seamlessly mix market data with fundamental data as desired – relying on PLEXOS to compute the appropriate market representation at runtime, and maximize simulation efficiency.

2. ST Schedule Chronology

ST Schedule provides two methods for modeling the chronology:

Full Chronology

Every trading period inside the ST Schedule horizon is modeled explicitly.

Typical Week

One week is modeled each per month in the horizon and results are applied to the other weeks.

2.1. Full Chronology

In this mode, ST Schedule runs every trading period and maintains chronological consistency across the horizon. For example it can model generator start ups and shutdowns and track the status of units across time. The Horizon options allow you to select either the whole or only a subset of the planning horizon for execution with ST Schedule.

When selecting the planning horizon, the step type is chosen from years, months, weeks, or days. But the ST Schedule Step Type must be either weeks, days, hours, or minutes. The reason for this is related to the way in which PLEXOS sets up and solves the ST Schedule problem. At runtime PLEXOS:

dynamically constructs a mathematical programming problem to represent the first step of the ST Schedule; and then

as each step is evaluated, the same problem is simply modified to represent the next step, and so on until the required horizon has been evaluated.

The length of each ST step is controlled by the ST Schedule At a Time property. In general the longer each step of the ST Schedule is, the greater the execution time will be for each of those steps, but there is some overhead is switching from one step to the next. You should experiment with these settings to find the best combination for their models.

Note further, that the outcome of the simulation can be influenced by the size of the ST step when there are significant intertemporal aspects. This is because the state of the system, *e.g.* generator unit commitment, is recorded and carried over from one step to the next, but each step does not look-ahead to the next. Hence unless the model has no intertemporal elements, *e.g.* when performing a pure market-clearing emulation, it is recommended that the ST be run in steps of no less than one day at a time.

To further improve the optimization of unit commitment decisions you can configure ST Schedule to use a look-ahead period ahead of each step. This allows the step size of ST Schedule to be kept small (*e.g.* a day at a time) but sufficient look-ahead maintained for unit commitment decisions.

2.2. Typical Week

When ST Schedule is run in typical week mode, the horizon options are simplified. The simulation will always run across the whole planning horizon, and the only option to chose is the size of each step of the ST Schedule *i.e.* how many trading periods should be 'solved' at once. Typically, large models should be run in daily or evenly hourly steps, smaller models can run in weekly steps.

Running in this mode reduces the amount of simulation work for ST Schedule by more than a factor of four, but PASA and MT Schedule are still run in exactly the same manner.

Note that solution data for the typical week is written into the solution database, and the PLEXOS interface will explode those data out so that a full chronology can be viewed. This means that the size of the solution database is also reduced when ST Schedule is run in this mode. Summary data (daily, weekly, monthly, annual) are all calculated based on the mapping of typical weeks to trading periods i.e. the daily data for a day that was not part of a typical week, is taken from the day of the same type in the typical week that was run. Thus, summary data are complete, but may not match input data such as total energy, and peak demand.

The selection of week inside the month is controlled by the option Typical Week. The beginning day of week is set by the Week Beginning option. When set to automatic, the week begins on the same day of week as the first day of the planning horizon.

Execution is performed by clicking on the "Execute" button in the main menu. A "Models and Projects Selected for next Execution" window will pop up. Click on "Execute" in the bottom right-hand corner of this window. Plexos will run, generating the solver code which it ports to the solver. This sequence is logged to a black screen that you will see as the execution continues. This sequence will also be logged in a tex file in a subdirectory within the directory where the input database resides. The log file will appear on the screen as below.

32. Explore solution
The solution file called "Model base Solution.zip" will be available in the folder of the same solution file name in the directory where your 3Node case resides. To access it,

Left-click on "File" on the menu bar. A drop-down menu will appear; Left-click on "Open" in this menu. You will see a folder called "Model Base Solution;" Double click on it, and the program will open to the "Solutions Viewer" as illustrated below.
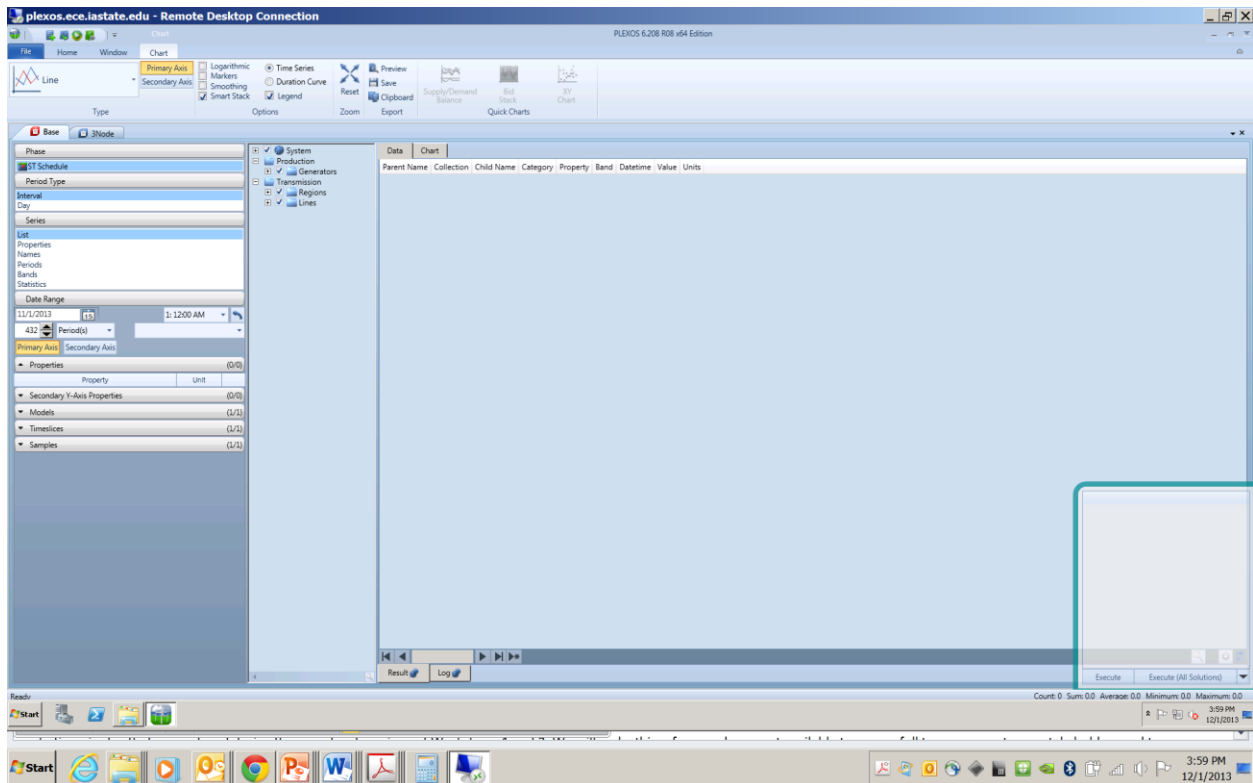

If your Plexos window is not already expanded, you may need to expand it now in order that the data grid (where data and charts will be shown) is not covered by the reporting screen in the lower right-hand corner of the data grid.

Note that Plexos can either show the data by table or by chart. There are two buttons ("Data" and "Chart") on the top of the data grid to switch between these two modes.

Let's view the generation levels. In the membership tree (middle screen), expand the "Generators" folder to ensure all three units are in fact there (if one or more is not, then you have erred in the previous instructions). Left-click on the "Generators" folder. Then expand the "Properties" menu in the main tree (left-most screen). You should see a list of generator properties there. Left-click on the "Generation   MW" row to select it. Then click on "Home" in the main menu (top left-hand corner of the Plexos screen), and the execute button will appear on the right-hand-side of the main menu. Left-click the execute button. The result will be shown in the data grid. If you are in the "data" mode, then switch to "chart" mode by clicking on the appropriate button at the top left-hand-corner of the data grid. You should see the following.
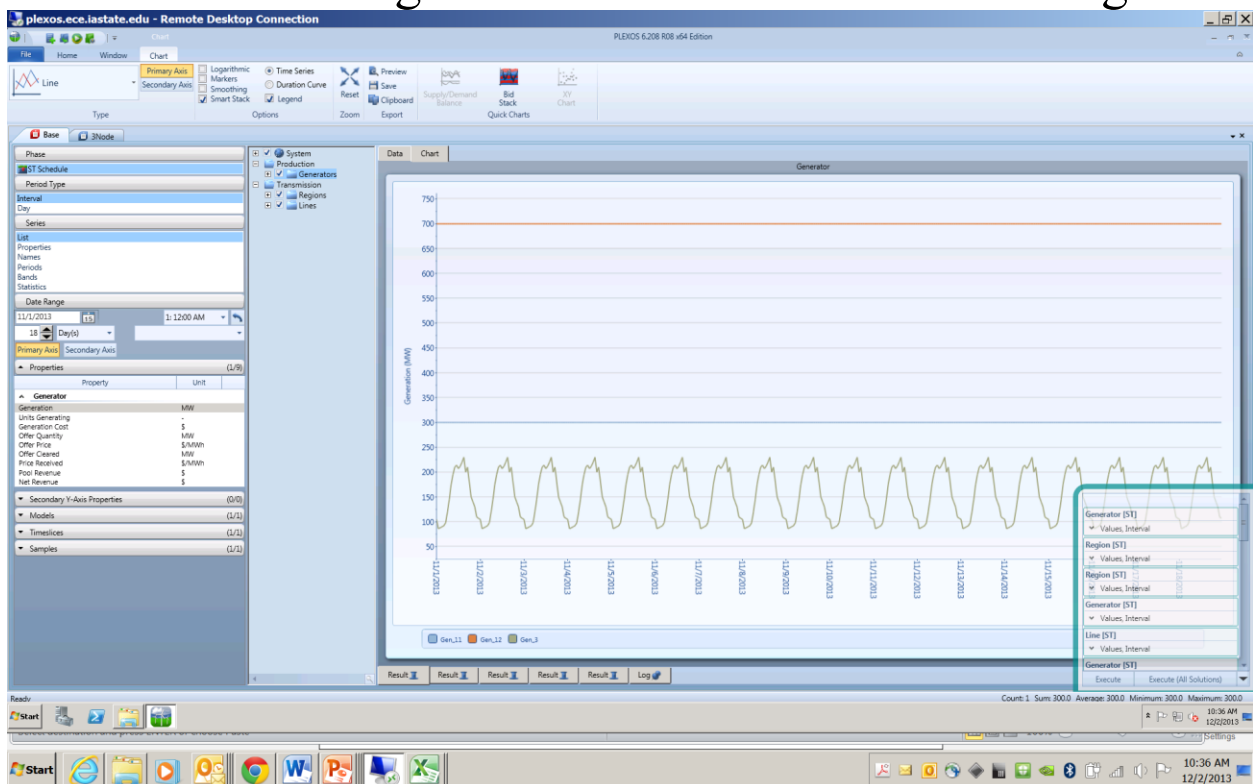
Now let's look at offer price. While keeping the "Generators" folder selected in the membership tree (middle screen), click on "Offer Price $/MWh" in the main tree (left-hand screen). Then click on "Home" in the main menu (top left-hand corner of the Plexos screen), and the execute button will appear on the right-hand-side of the main menu. Left-click the execute button. The result will be shown in the data grid. You should see the following. Observe that the three offer prices are the same as the unit energy costs in Step 21: $32/MWh, $40/MWh, and $48/MWh.
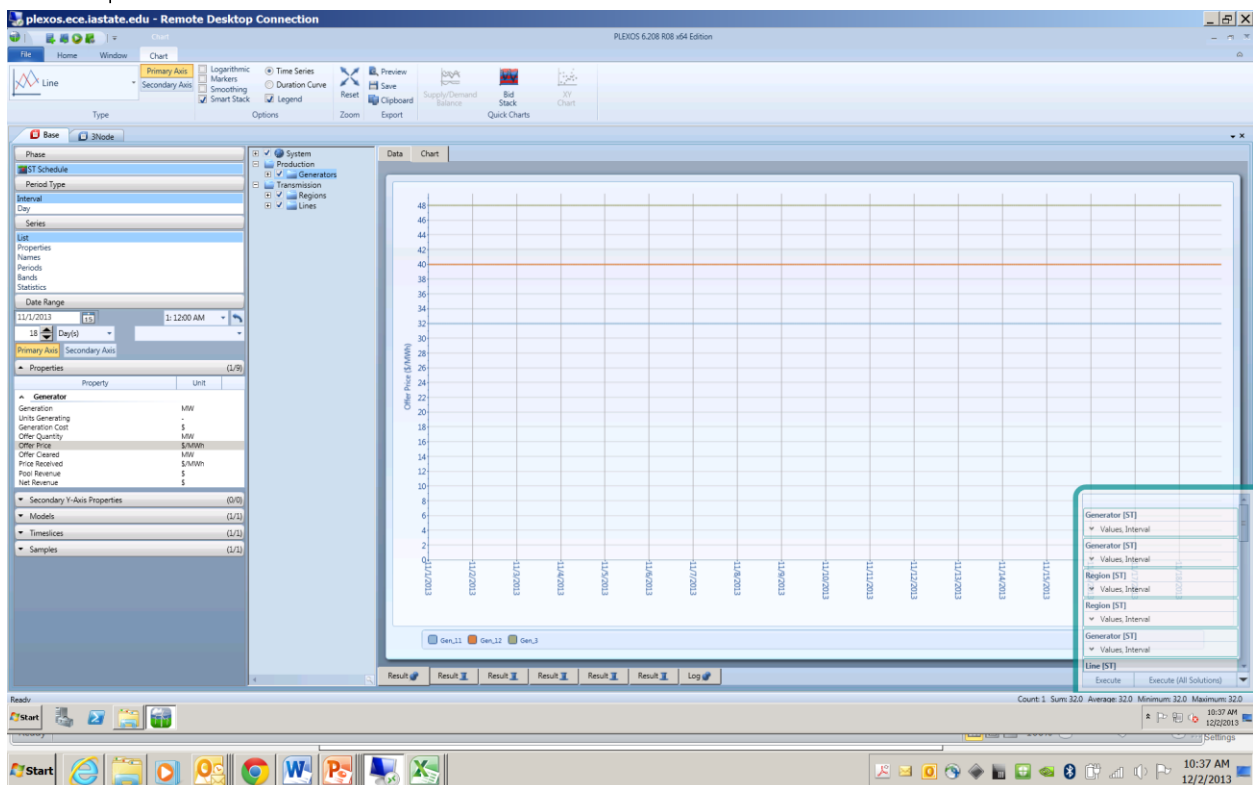
Now look at "Price Received." While keeping the "Generators" folder selected in the membership tree (middle screen), click on "Price received $/MWh" in the

main tree (left-hand screen). Then click on "Home" in the main menu (top left-hand corner of the Plexos screen), and the execute button will appear on the right-hand-side of the main menu. Left-click the execute button. The result will be shown in the data grid, as shown below. Observe that the price received by all three generators is the same: $48/MWh. This means that G_3 is the marginal unit, i.e., it is setting the price, which is consistent with the fact that its generation varies with time as indicated in the generation figure seen previously.
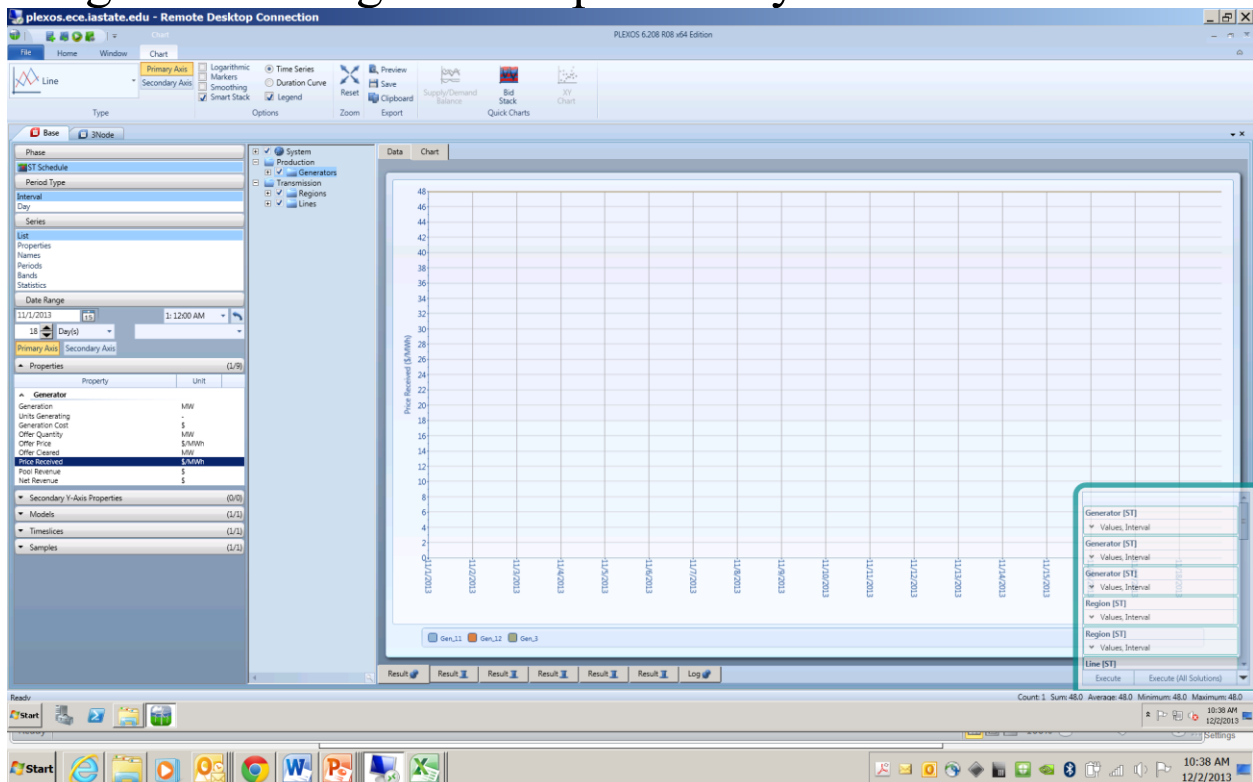
Now inspect the system load. Left-click on the "Regions" folder under the "Transmission" folder in the membership tree (middle screen). Then select "Load" under the region properties in the main screen (left-hand screen). Then

click on "Home" in the main menu (top left-hand corner of the Plexos screen), and the execute button will appear on the right-hand-side of the main menu. Left-click the execute button. The result will be shown in the data grid, as shown below.
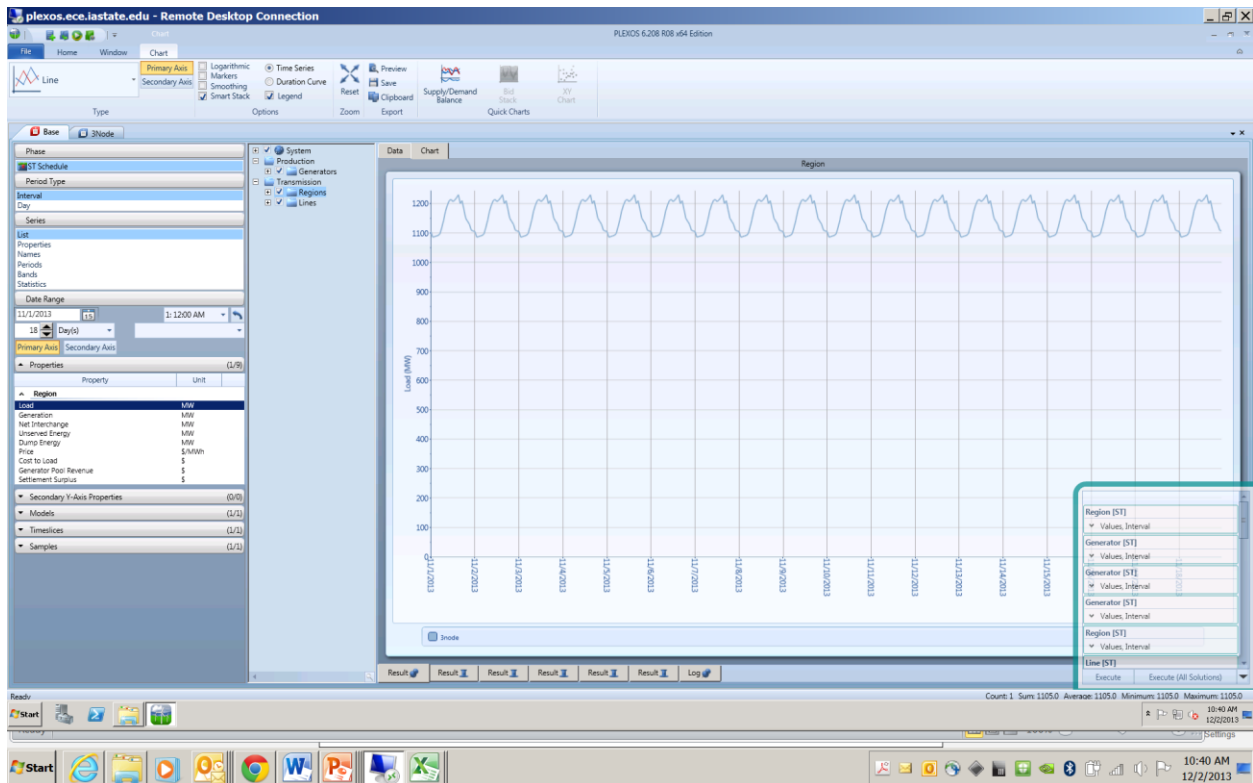

Now inspect the line flows. Left-click on the "Lines" folder in the membership tree (middle screen). Then select "Flow" under the Line properties in the main screen (left-hand screen). Then click on "Home" in the main menu (top left-hand corner of the Plexos screen), and the execute button will appear on the right-hand-side of the main menu. Left-click the execute button. The result will be shown in the data grid, as shown below.
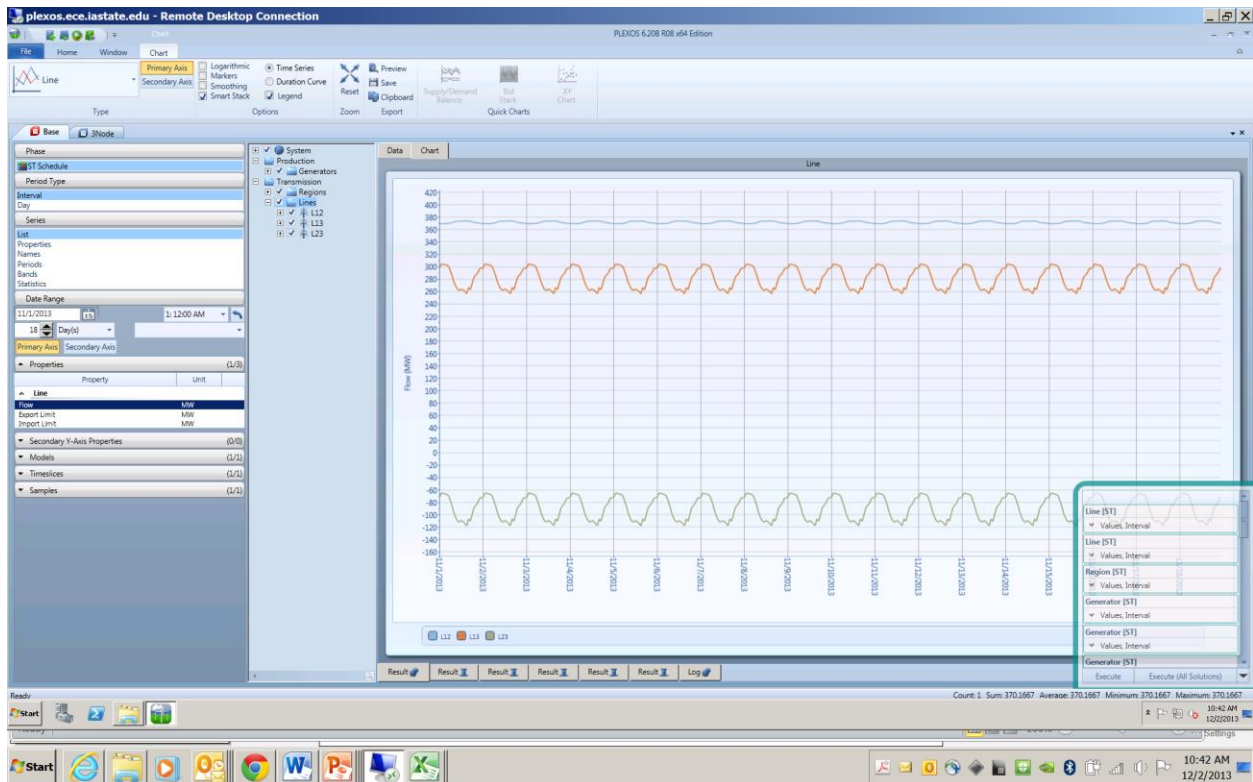
Now click on the "3Node" tab at the top of the main screen, expand the "Lines" folder (under the "Transmission" folder) and Left-click on "L12." In the data grid, you will see L12 properties. Change the "Max Flow" property of L12 from 1000MW to 372MW. You should be able to tell from the previous line-flow plot that this will cause L12 to be congested for a few hours per day.

Click on the "Base" tab at the top of the main screen. You will get a dialogue box giving you four options. Select "Refresh queries." The same line-flow plot that had should re-appear, except the L12 plot should now be

clipped a very small amount to satisfy the new 372MW limit, as shown below.
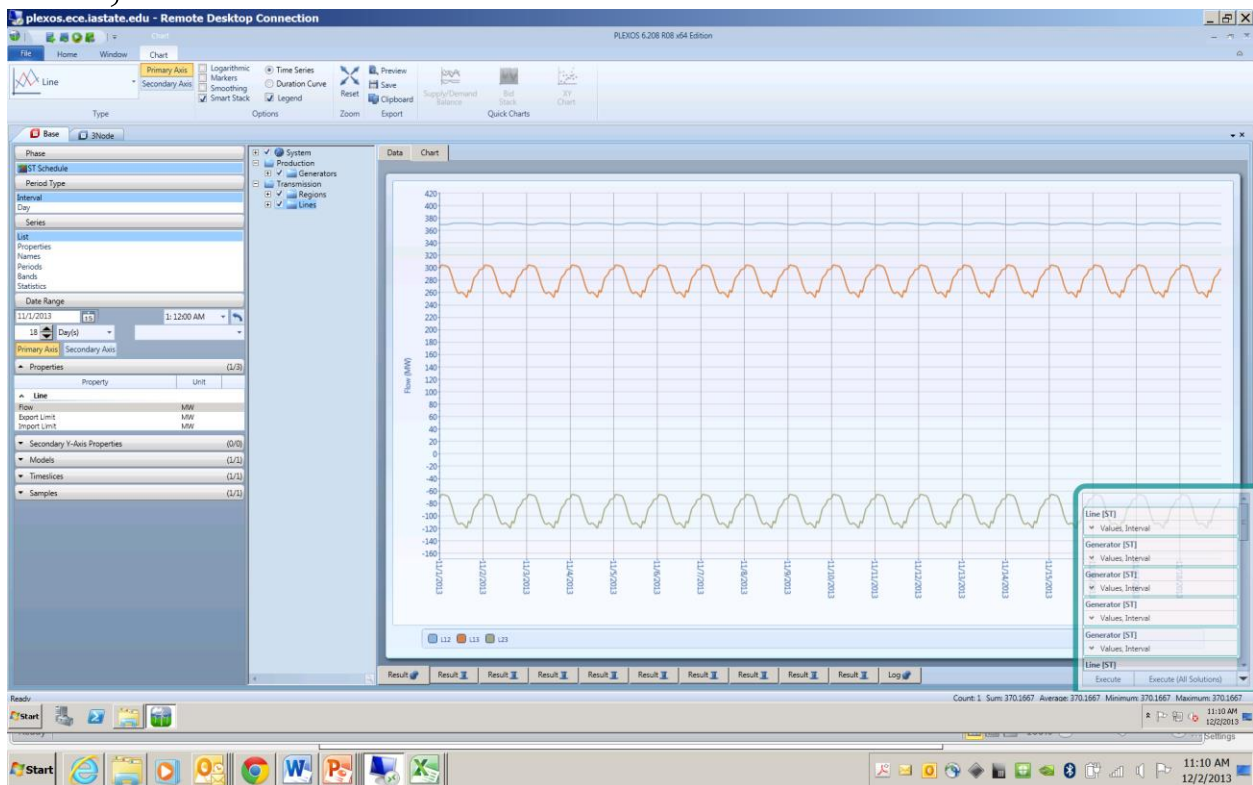
View the three generation levels again, and you should observe that Gen_12 (the 700MW unit) is coming off of its limit. This happens when L12 becomes congested; Gen_12 (selling at $40/MWh) backs down in order for Gen_3 (selling at $48/MWh) to turn up, in order to supply the load at bus 2 while satisfying the L12 constraint.
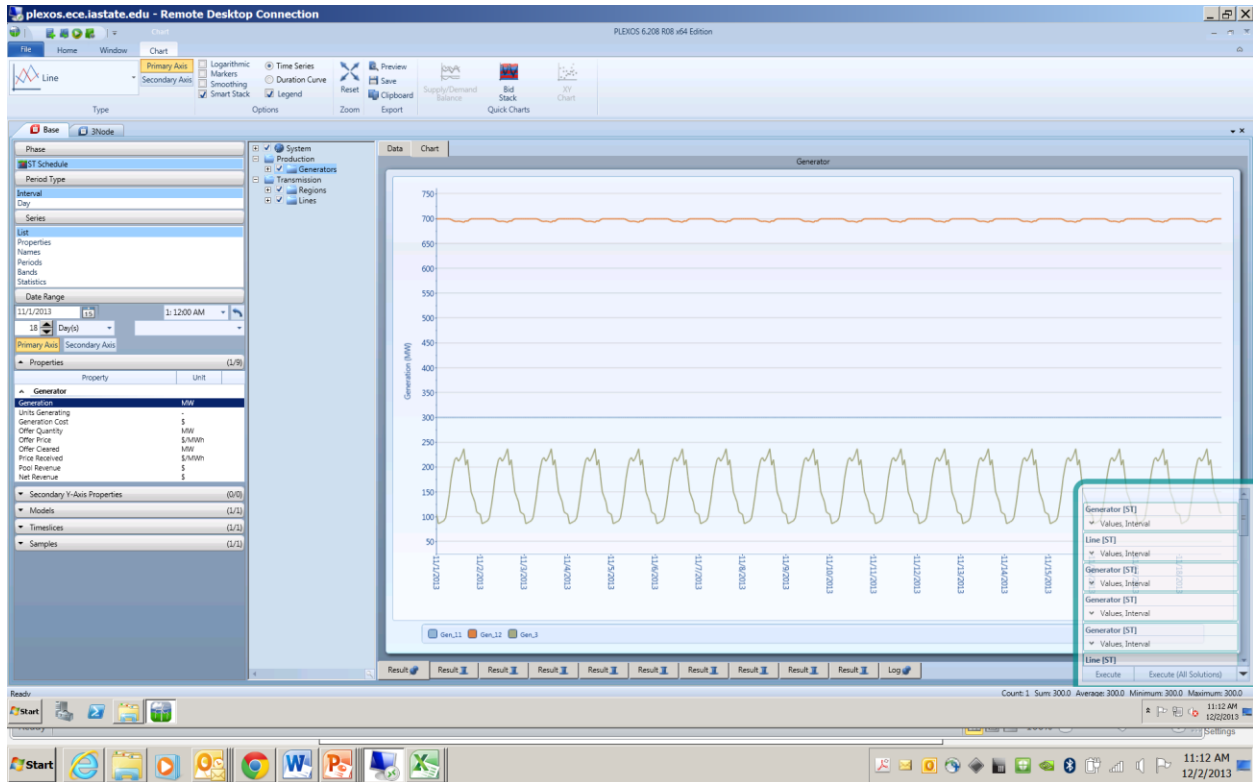
When we observe the "price received" of the three
generators, we see below that Gen_11 and Gen_12
receive $40/MWh whereas Gen_3 receives $48/MWh.
This reflects that any additional load at bus 1 would be
served by Gen_12 (the 700MW unit) at $40/MWh, and
any additional load at bus 3 would be served by Gen_3_
(the 300 MW unit) at $48/MWh). I could not determine
how to observe the bus 2 price, but it will be higher due to
the congestion rent associated with the L12 constraint.
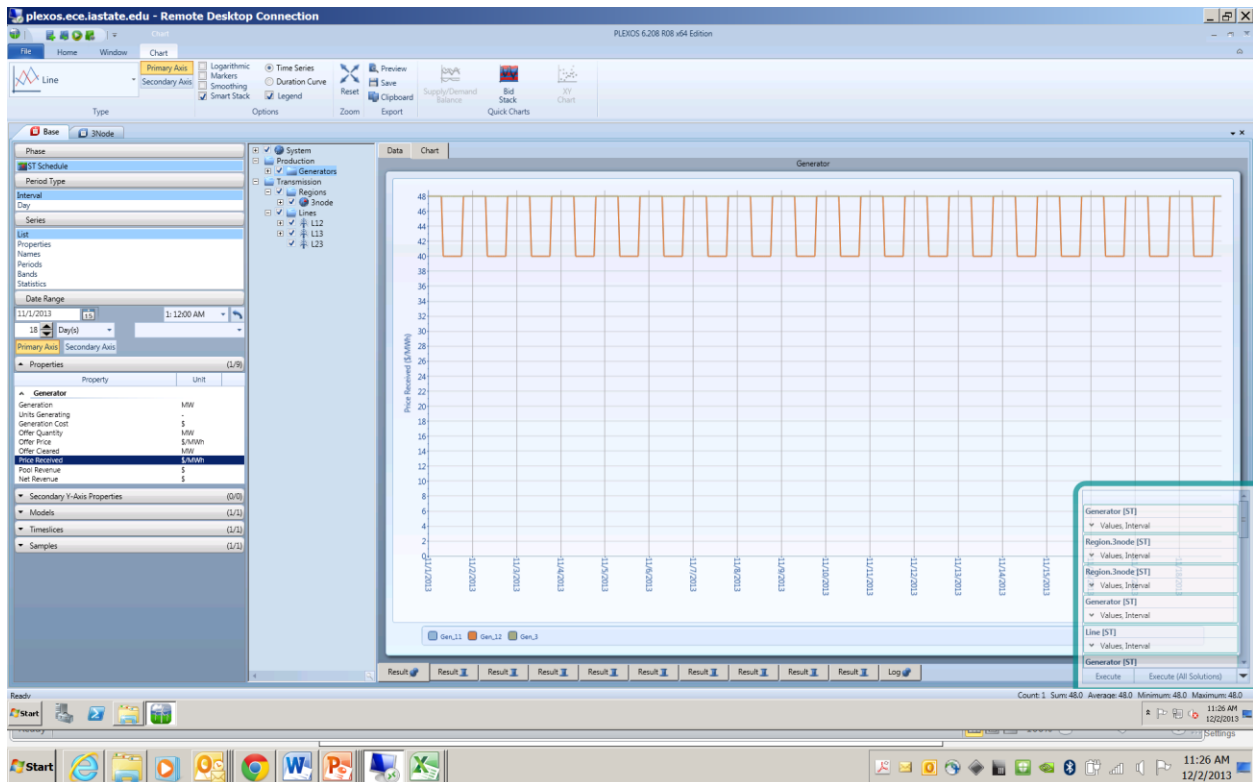
Assignment:

Perform a generation expansion planning (GEP) exercise using the 3 node system that you have built. To get started, do the following:

1. Starting with the 3 node system you have built, save it using "File" and "Save As" to another file name. You will use this new file name to perform the GEP.

2. Be sure to reset all line flow constraints to 1000 MW.

3. Develop an Excel spreadsheet in comma-delimited format containing the following load data for every 7 days, beginning with Wednesday January 1, 2016, and ending on December 31, 2016. You can call the datafile "LoadYear.csv" and its object name "LoadYear."

Year	Month	Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2014	1	1	1105	1086	1088	1090	1092	1098	1120	1145	1175	1195	1210	1214	1207	1212	1220	1230	1200	1210	1180	1150	1140	1130	1110	1107
2014	1	2	1105	1086	1088	1090	1092	1098	1120	1145	1175	1195	1210	1214	1207	1212	1220	1230	1200	1210	1180	1150	1140	1130	1110	1107
2014	1	3	1105	1086	1088	1090	1092	1098	1120	1145	1175	1195	1210	1214	1207	1212	1220	1230	1200	1210	1180	1150	1140	1130	1110	1107
2014	1	4	1105	1086	1088	1090	1092	1093	1100	1110	1130	1140	1150	1154	1152	1158	1160	1150	1145	1140	1135	1115	1110	1109	1107	1106
2014	1	5	1105	1086	1088	1090	1092	1093	1100	1110	1130	1140	1150	1154	1152	1158	1160	1150	1145	1140	1135	1115	1110	1109	1107	1106
2014	1	6	1105	1086	1088	1090	1092	1098	1120	1145	1175	1195	1210	1214	1207	1212	1220	1230	1200	1210	1180	1150	1140	1130	1110	1107
2014	1	7	1105	1086	1088	1090	1092	1098	1120	1145	1175	1195	1210	1214	1207	1212	1220	1230	1200	1210	1180	1150	1140	1130	1110	1107

4. Enter the load data similar to Steps 23-27.

5. Now repeat steps 24-27 to create a datafile object called "LoadForecast.csv" in the same folder that contains your load data. We are going to use Plexos to build a 10-yr dataset based on the one year of data contained in "LoadYear." Use the following steps:

   a. With the main tree in "System" view (left-click on the "System" tab at the top of the main tree), you should see the "Data" folder, a subfolder called "Data Files" and the two data file names LoadYear and LoadForecast. Left-click on the subfolder "Data Files."

   b. The datagrid will split between an upper and lower screen. You need to enter four different types of information in the lower screen.

      i. One row to identify the Loadforecast location and time duration.

      ii. One row to identify the Base Profile location and time duration.

      iii. 11 rows to identify the total energy demanded for each year 2014-2024. This yearly energy is a forecast characteristic.

      iv. 11 rows to identify the maximum hourly energy demanded in any one year. This maximum hourly energy is another forecast characteristic.

When you are done, your screen should appear
as below. (I show it twice to capture all of rows).

c. Now Left-click on the "Build" function on the right-hand-side of the main menu. You will see a split screen with your two datafiles named in the left-hand-screen. Left-click on the file "LoadForecast" in the left-hand-screen, and then use the "Add>" button in the middle of the screen to "Add" the file "LoadForecast" to the right-hand screen.

d. In the bottom right-hand corner of the screen, you will find three buttons: View, Build, and Close. Left-click on "Build." After a few seconds, you will see the following:
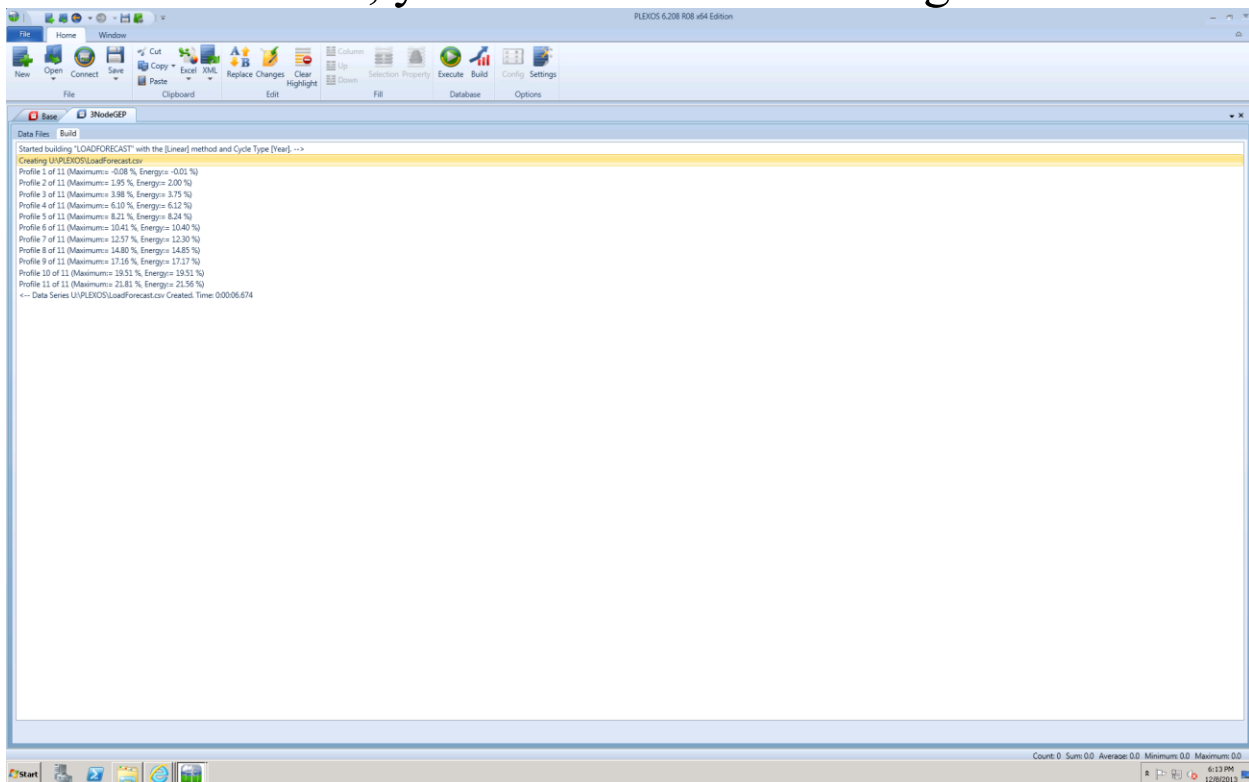

e. Left-click on the "Data Files" tab in the top-left-hand corner of this screen to take you back to the split screen with the three buttons in the lower

right-hand-corner. Left-click on "View." You will see the following plot of your forecasted load data.

f. Left-click on "Close" at the bottom right-hand-corner of this screen. This will take you back to the split screen with the three buttons at the lower-right-hand-corner of this screen. Left-click on "Close" again. You have now built your load forecast datafile, and it is stored in the Excel comma-delimited file that you named "LoadForecast.csv."

6. Modify the "Regions" object to use your new load data as follows. Left-click on "System" in the maintree and then left-click on the folder "Regions" in the maintree. In the lower half of the datagrid,

modify the "Date From" and "Date To" to be 1/1/2016 and 12/31/2026, respectively. Also use the drop-down menu in the "Data File" cell to select the new load file (called "LoadForecast"). To verify you have completed this step, double-click on the "3node" icon under the "Regions" subfolder in the maintree. You should see the below screen.
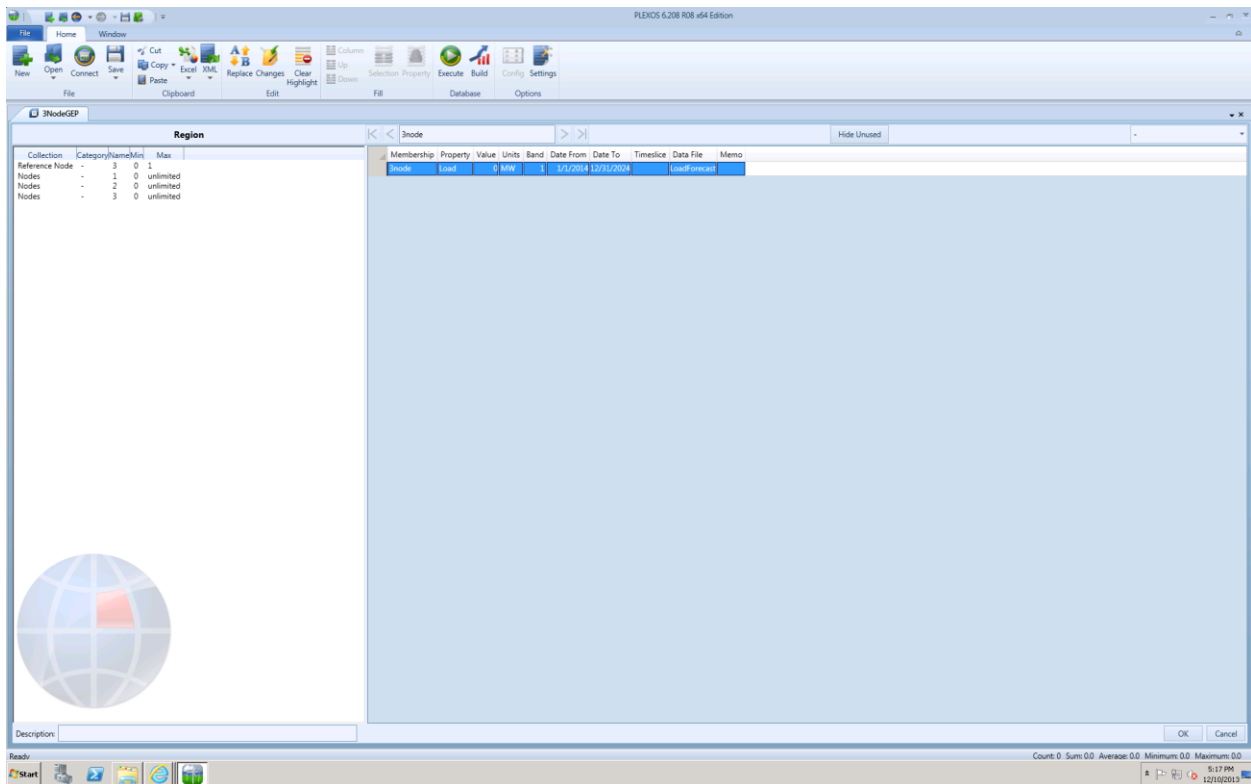
7. Add three candidate generators to the model, as described in Steps 10, 21, and 22 above. Adjust the settings of these candidate generators according to the data in the following table.

Category	Generator	Nodes	Units	Max Capacity (MW)	Min Stable Level (MW)	Fuel Price ($/MMBTU)	Heat Rate (BTU/kWh)	FO&M Charge ($/kW/year)	Equity Charge ($/kW/year)	Debt Charge ($/kW/year)	Firm Capacity (MW)	Maintenance Rate (%)	Maintenance Frequency
-	Gen_13-NGCC	1	1	100	0	4	8000	0	0	0	100	0	0
-	Gen_21-CT	2	1	100	0	4	11000	0	0	0	100	0	0
-	Gen_22-PV	2	1	200	0	2	10000	0	0	0	200	0	0

		Forced Outage Rate (%)	Outage Rating (MW)	Outage Pump Load (MW)	Mean Time to Repair (hrs)	Min Time To Repair (hrs)	Max Time To Repair (hrs)	Repair Time Shape	Repair Time Scale	Build Cost ($/kW)	Retirement Cost ($000)
-	Gen_13-NGCC	2	0	0	40					1100	0
-	Gen_21-CT	2	0	0	20					800	0
-	Gen_22-PV	2	0	0	80					1400	0

		Project Start Date	Commission Date	Technical Life (years)	WACC (%)	Economic Life (years)	Max Units Built	Max Units Retired	Min Units Built	Min Units Retired	Capacity Price ($/kW/year)	Build Non-anticipativity ($/MW)	Retire Non-anticipativity ($/MW)
-	Gen_13-NGCC				7	35	3						
-	Gen_21-CT				7	35	3						
-	Gen_22-PV				7	35	3						

8. You will also need to provide additional generator data for all six units (the 3 existing units and the 3 candidate units). To do this, begin by clicking on the "System" tab at the top of the main tree and then left-click on the "Generators" subfolder. If you performed the previous step (step 6) correctly, then you should see the list of six generators and their properties in the top half of the data grid. In the bottom half of the data grid, click in the first cell (i.e., the first column, under "Generator." You will see the list of generators in the drop-down menu within the cell. Select one of the existing generators, and then enter the following additional data:

    a. Under "Property," select "Units Out."

    b. Under "Value," select "0"

Select the second existing generator and repeat (a) and (b). Select the third existing generator and repeat (a) and (b). Repeat for the three candidate generators, except in (b), select "1" for "Value." This indicates that the candidate generator is not in service.

9. Left-Click on "Simulation" in the maintree, and then right-click on the "LT-Plan" folder in the maintree. A dialogue box will pop up asking you to name your long-term plan. Name it "GEP." When you hit carriage return, you will go to a screen named "For LT-Plan (name of your plan)," asking you to select the set of models that run this LT-Plan. Select the "Model-Base" by clicking on it and then clicking on the "Add" button in the middle of the screen. Click on "Close" at the right-hand-bottom of the screen. This will take you to a set of selections to be made in running LT-Plan that appear as below.
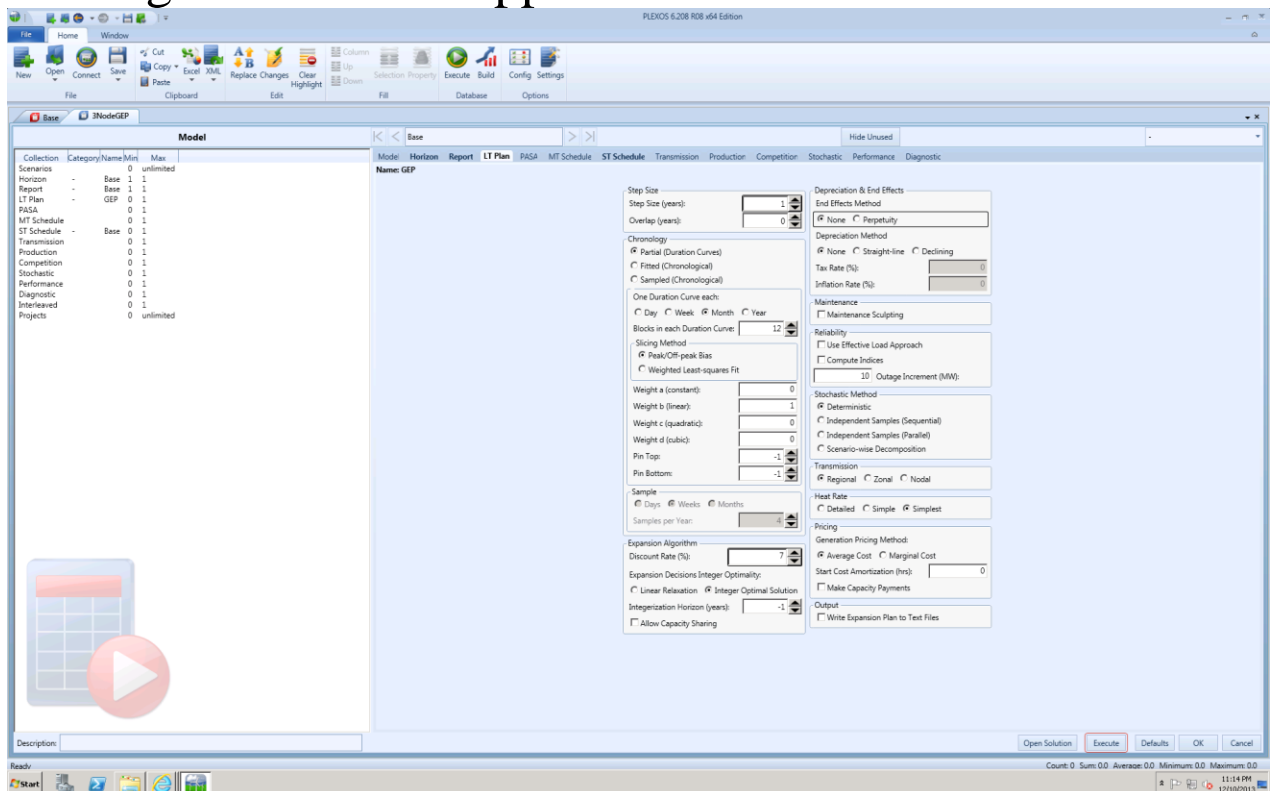

Make the following selections:

Step size (years): Select "1"

Chronology: Select "Partial (Duration curves)"

End effects method: Select "none"
Then press "Execute" at the bottom right-hand-corner of the screen.

10. You will see a black screen pop up which logs the program's execution. It will run for a few minutes. When execution is complete, it will say on the black screen "Press any key to close this window." Place your cursor anywhere in the black screen and press any key to make it disappear.

11. Then click on "Open solution" at the bottom right-hand corner of the screen. A dialogue box will pop up with four selections. Left-click on "Reopen file." After a few seconds, a screen will appear that will allow you to explore the solution.

   a. At the top left-hand corner of this screen, observe the "Phase" selections of "LT Plan" and "ST Plan." Left-click on "LT Plan." Then Left-click on the "Generators" subfolder in the middle screen. Then Left-click on "Capacity Built" under the "Properties" button in the left-hand-screen. Left-click on the "Home" tab on the main menu (at the top left-hand corner of the screen). Then Left-click on the "Execute" button on the main menu. After it completes, Left-click on the "Chart" tab at the top of the datagrid, and you should observe the following:
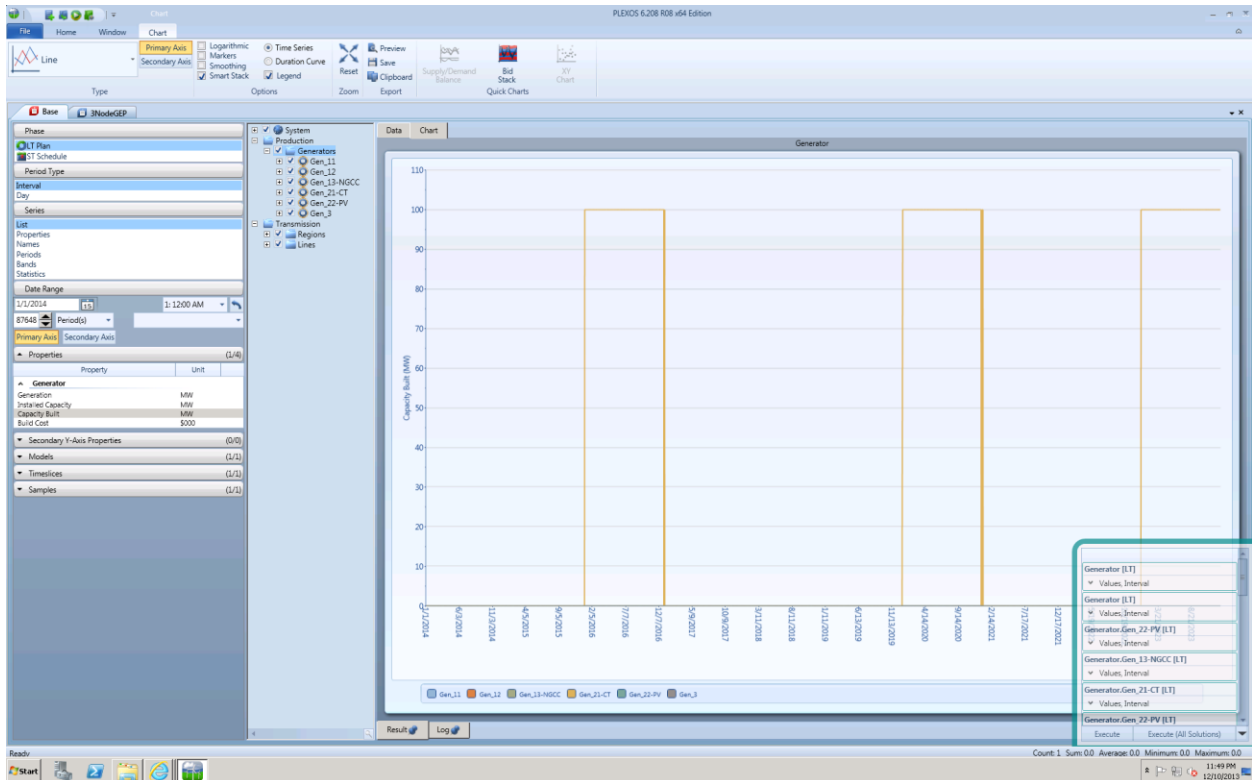
Identify which generator is getting built, how much capacity is getting built, and when that capacity is getting built. Inspect the data for the candidate units and explain:

- Why is this generator getting built as opposed to the other two candidate generators?
- Why is the amount of generation getting built at the particular years it is getting built?

b. Left-click on the "ST Plan" under the "Phase" menu, Left-click on the "Generation" under the "Property" menu, and finally, Left-click on the "Gen_21-CT" unit in the middle pane. Then Left-click on "Home", and Left-click on

"Execute". You should see the plot below which confirms the identity of the unit which was built.
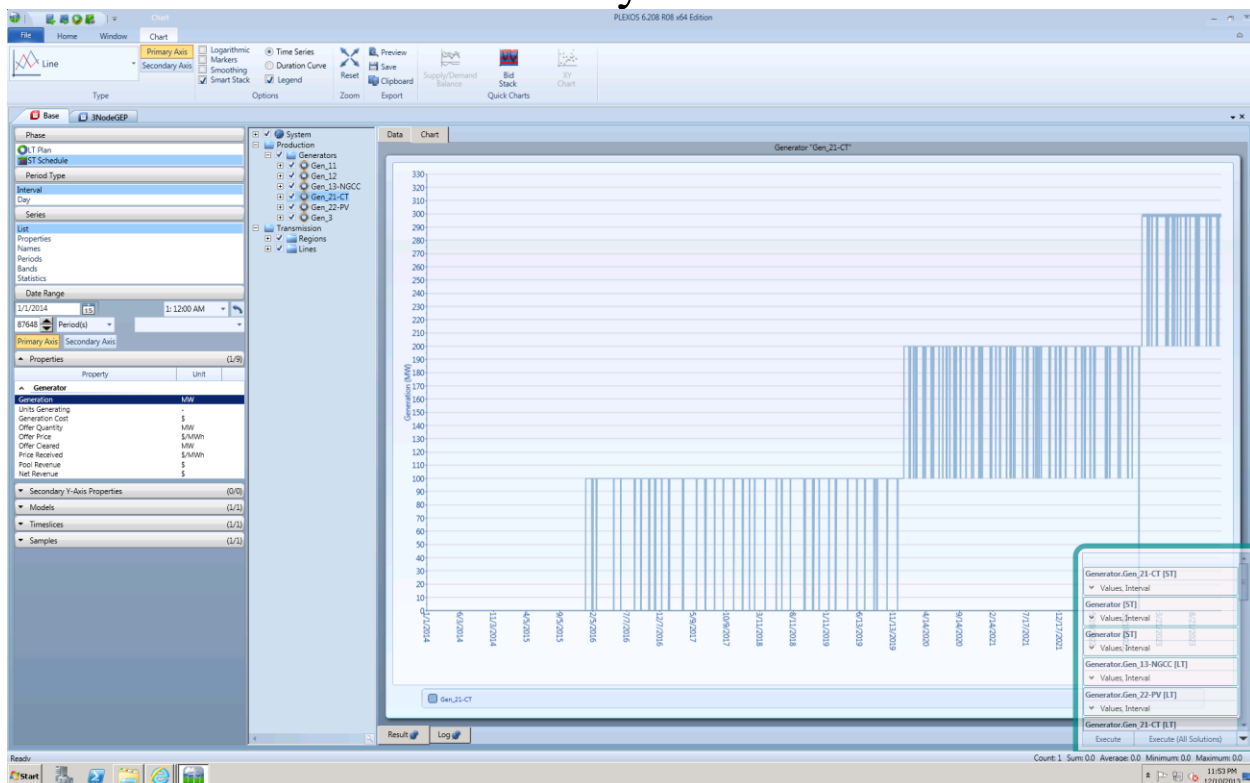
12. Run the following "experiments" and identify the effect on which unit is built.

 a. Change the generation build cost of Gen_21-CT from $800/kW to $1600/kW.

 b. With the generation build cost of Gen_21-CT back to $800/kw, change the fuel price of Gen_21-CT and Gen_13-NGCC from $4/MBTU to $12/MBTU.

In performing these experiments, observe that you can get back to the "LT Plan" screen by Left-clicking on the "Simulation" tab in the main tree, Left-clicking on the "LT-Plan" subfolder (under the "Simulation" folder), expanding the "Models" subfolder in the membership tree

(the middle pane), and double clicking on the "Base" icon under the "Models" subfolder. This will take to a screen that has a series of tabs at the top. Select the "LT Plan" tab. Then you can Left-click on the "Execute" button on the bottom right-hand side of the screen to run the program again. Then repeat steps 10 and 11 above.