Power System Equivalents

- Background
- Equivalencing in PowerWorld Simulator
- Deleting an External System
- Examples
  - small 7 bus case
  - 10,452 bus MAIN case
- Merging Systems

Introduction

- Equivalencing is a general technique for representing one system by a second system, in which the second system approximates the behavior of the original system.
- Practically every system used in power flow studies is an “equivalent.”

Properties

- Equivalent systems usually
  - are smaller and less detailed
    - solve quicker
    - require less storage
    - require less up-to-date data
  - contain fictitious elements
    - can make modeling/updating more difficult
  - only approximate the behavior of the original

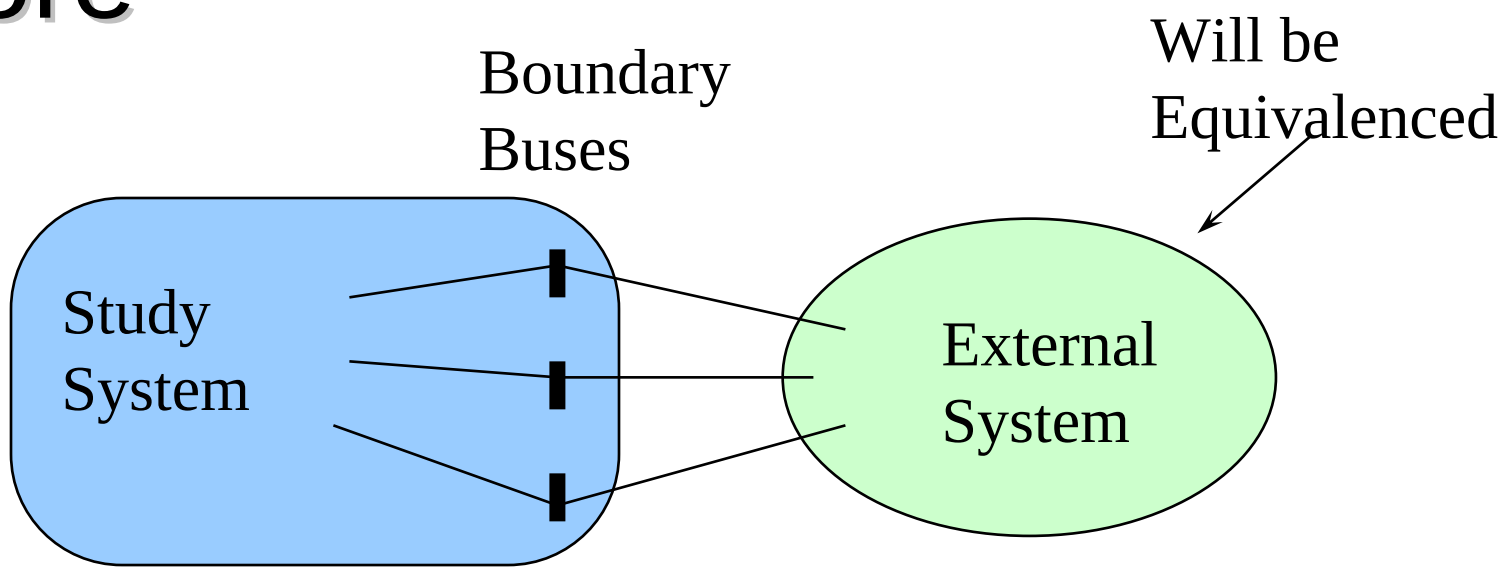
Modeling

- Equivalent systems need NOT correspond exactly to the actual power system
- Elements can be used to examine limits not typically considered in power flow analysis
  - transient stability limits
  - oscillatory stability limits
  - voltage stability limits

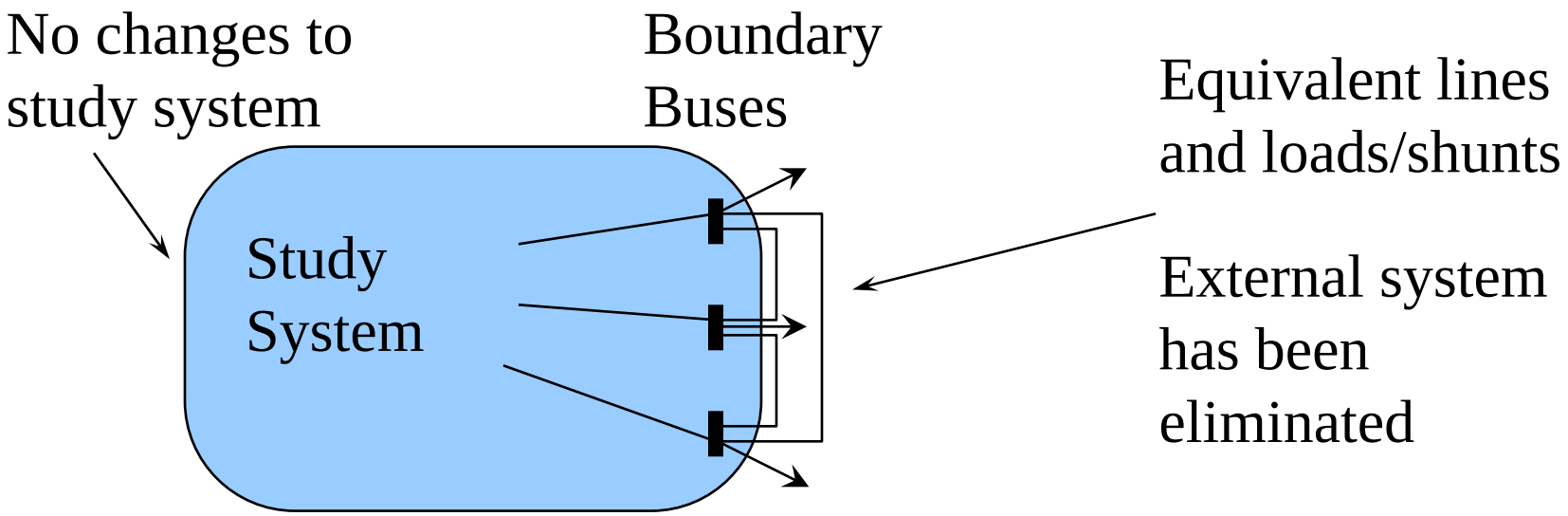
Study vs External Systems

- Typically broken up into two systems
  - study system represented in detail
  - external system represented by an equivalent
- Two systems are joined at boundary buses
- Boundary buses are the buses in the study system that connect to the external system

Before



After



The “Optimal” Equivalent

- It depends upon the application
- Requires engineering judgment between
  - size
  - accuracy
  - complexity

Equivalencing in PowerWorld

- Based on Ward Injection Method
- Generalization of Thevenin Equivalent
  - simple example is representing two parallel resistors by a single equivalent resistor
  - for linear single-port dc subsystem, the subsystem can be represented by a resistor in series with a voltage source
  - multi-port Thevenin equivalent

Ybus Reduction

- Partition bus admittance matrix (Ybus) into study and external systems

$$I = Y V$$

$$\begin{bmatrix} I_{Study} \\ I_{External} \end{bmatrix} = \begin{bmatrix} Y_{S,S} & Y_{S,E} \\ Y_{E,S} & Y_{E,E} \end{bmatrix} \begin{bmatrix} V_{Study} \\ V_{External} \end{bmatrix}$$

Ybus Reduction

- Eliminate the external buses

$$I_{Study} = (Y_{S,S} - Y_{S,E} Y_{E,E}^{-1} Y_{E,S}) V_{Study} + Y_{S,E} Y_{E,E}^{-1} I_{External}$$

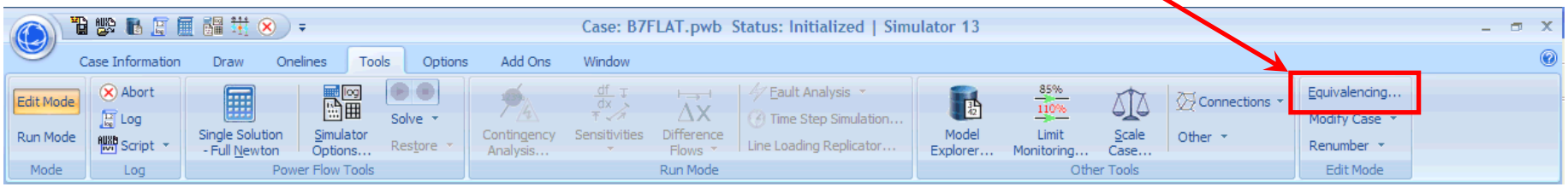
Ybus for the study system

Results in new equivalent lines joining the boundary buses and shunts at the boundary buses

Equivalent current at boundary buses

Equivalents Display

- Equivalencing in Simulator is done in the Edit Mode using the Power System Equivalent Display.
- To view select (in Edit Mode):
  - **Tools** ribbon tab → **Equivalencing**

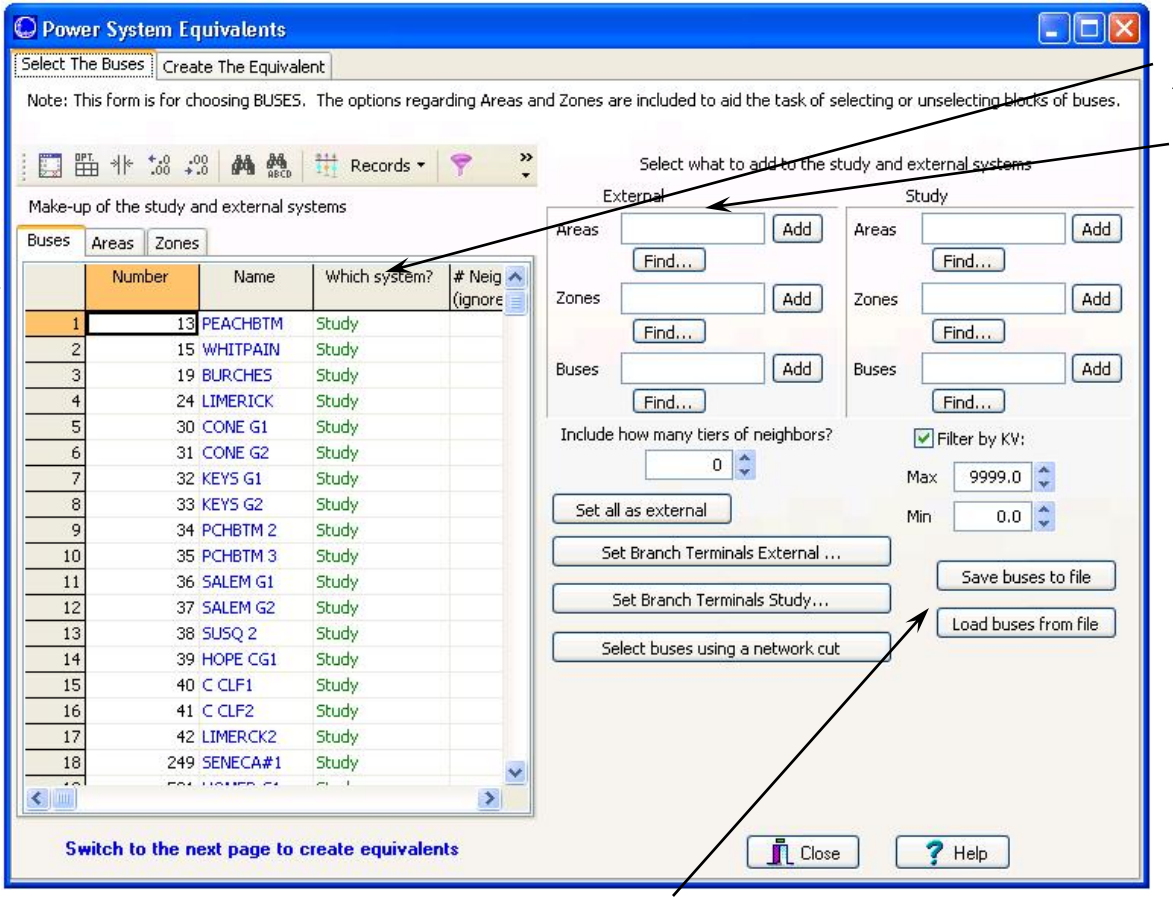


Equivalents Display

- This display is used to perform 4 tasks on 2 tabs
- Select the Buses Tab
  - partition system into the study and external systems (always must be done)
- Create The Equivalent Tab
  - create an equivalent (optional)
  - save the external system in a file (optional)
  - delete the external system, without creating an equivalent (optional)

Bus Selection

First partition system into the study subsystem and the external subsystem



Can set buses, areas or zones as part of the external subsystem

Allows saving and loading bus numbers of external system to a text file

Partitioning the System

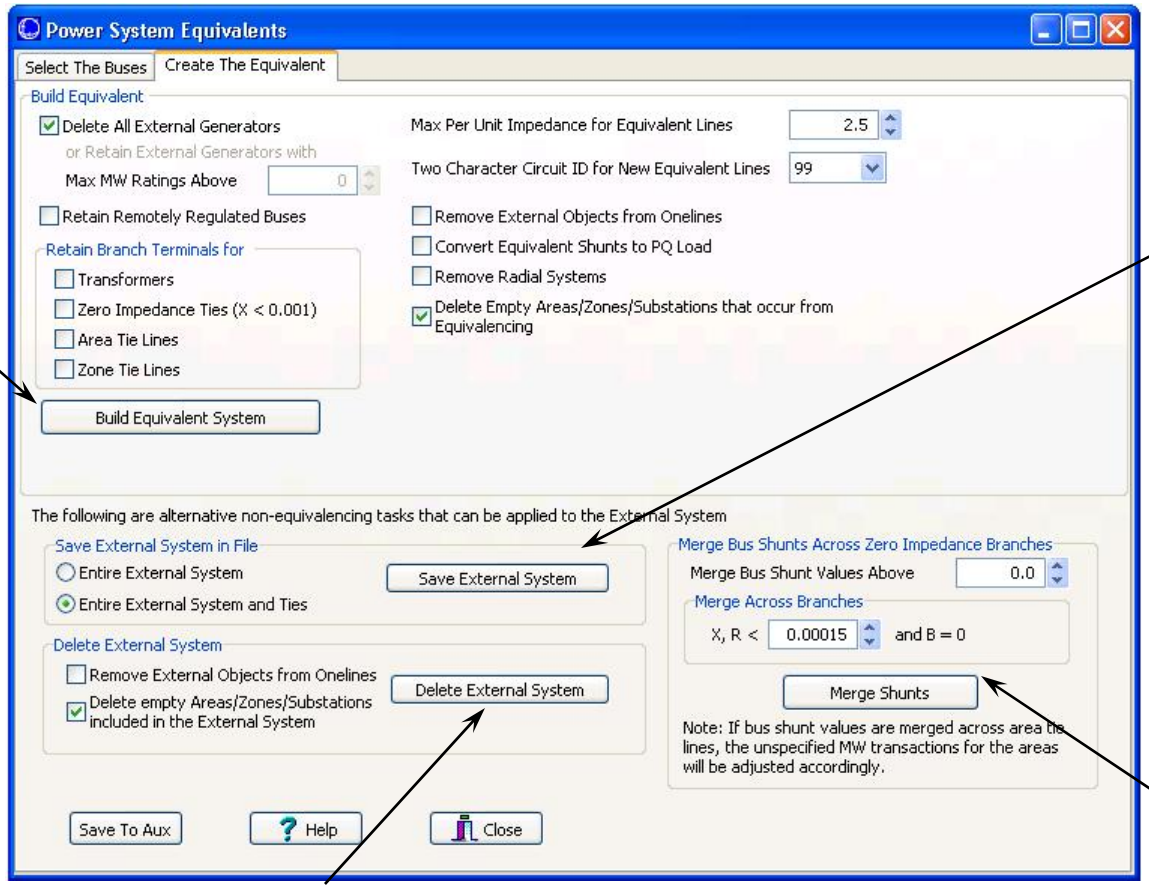
- Use Buses, Areas, and Zones tabs to change external/study status of buses or all the buses in an area.
- Use Add to Study System or External System to add ranges of buses/areas/zones to the appropriate system
- Include how many tiers of neighbors?
  - When a bus is selected to add to either the external or study system, this value indicates how many tiers of neighbors to include in the selection
- Filter by kV, Max, Min
  - If Filter by kV option is selected, only those buses selected to add having a nominal voltage between the specified Min and Max will be selected

Partitioning the System

- Set external or study buses by filtering branches and including the terminal buses of branches meeting the filter
- Select buses using a network cut
- Save Buses stores list of buses in study system in a file (one bus number per line); Load Buses loads this list.

Create Equivalent

Builds the equivalent system, removing the external subsystem



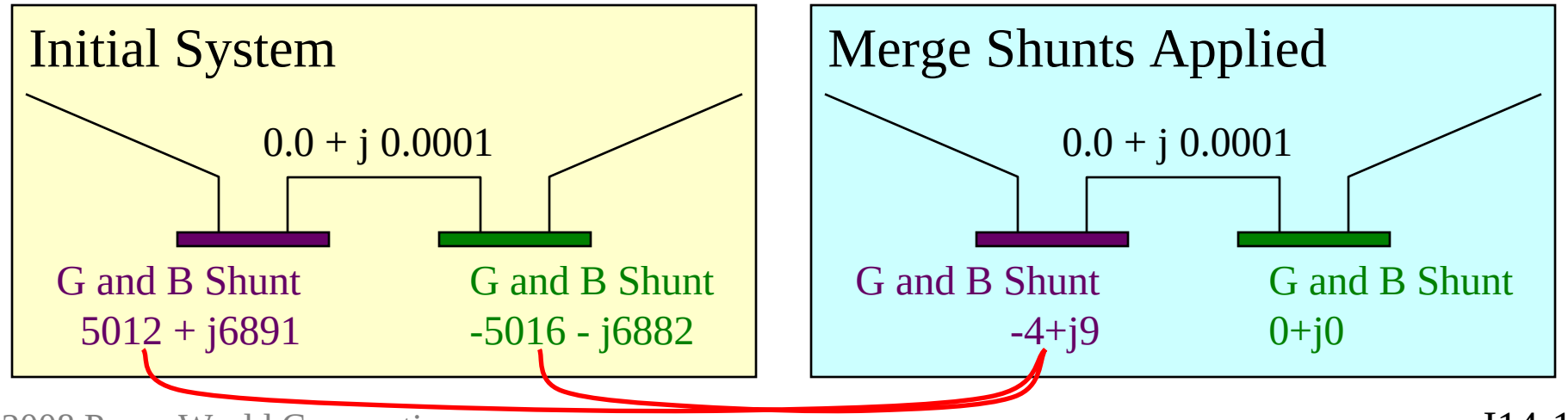
Allows saving external subsystem to a file

Merge Shunt fixes a data error seen in some models

Deletes external subsystem without building an equivalent

Merge Bus Shunts Across Zero-Impedance Branches

- Feature was added to help fix some problem cases PowerWorld has seen from clients
  - Very large Bus Shunt values were showing up across very low impedance branches
  - They essentially cancel each other out though so it seems to be a data error
  - Merge Shunts fixes this data error



Saving External System

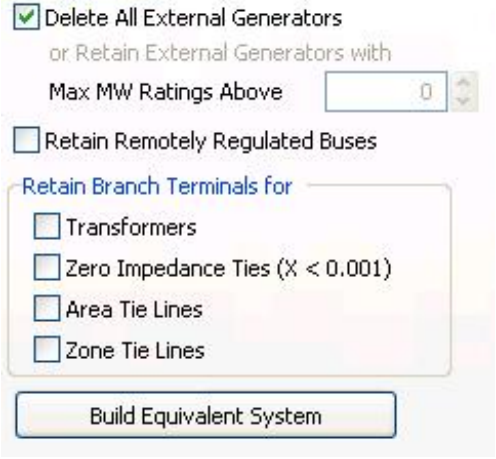
- Either just the external system, or the external system and its tie-lines to study system can be saved in a file.
- When used with **Tools** ribbon tab → **Modify Case** → **Append Case** this allows systems to be merged together.

Deleting External System

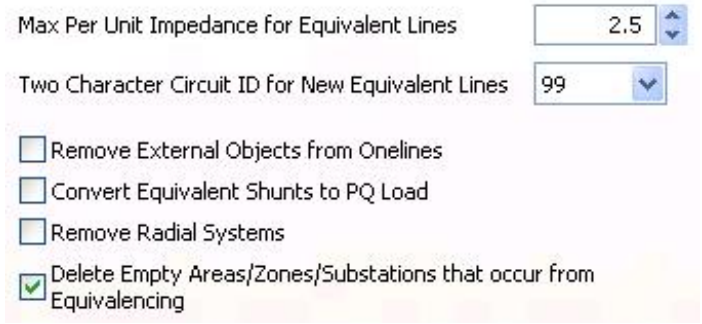
- Deletes the entire external system from the case, including any tie-lines.
- Again, when used with **Tools** ribbon tab → **Modify Case** → **Append Case** this allows systems to be merged together.
- Remove External Objects from Onelines deletes any objects referencing the external system from the open onelines.
- Empty Areas, Zones, and Substations in the external system can be deleted.

Build Equivalent

- Builds the Equivalent. This section has the following options:
  - Explicitly retain generators in the external system with maximum MW ratings above a user specified threshold.
  - Retain remotely regulated buses makes sure that buses that are being remotely regulated by devices in the study system are always retained.
  - Retain the branch terminals for transformers, zero impedance ties, area tie lines, and/or zone tie lines.



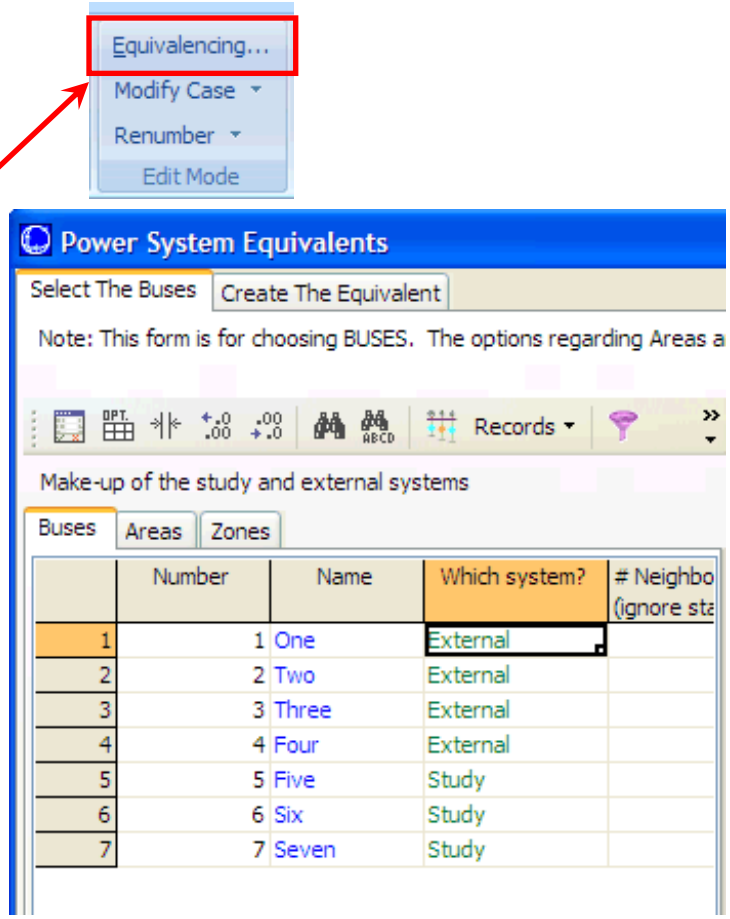
Build Equivalent



- Max Per Unit Impedance for Equivalent Lines field removes equivalent lines with impedances above this threshold value.
- Define the Two Character Circuit ID for New Equivalent Lines.
- Remove External Objects from Onelines deletes objects referencing the external system from the open onelines.
- Convert equivalent shunts into equivalent constant power loads.
- Remove Radial Systems results in all radial connections in the network being reduced to the nearest non-radial bus.
- Delete areas, zones, and substations that are completely emptied of any power system devices.

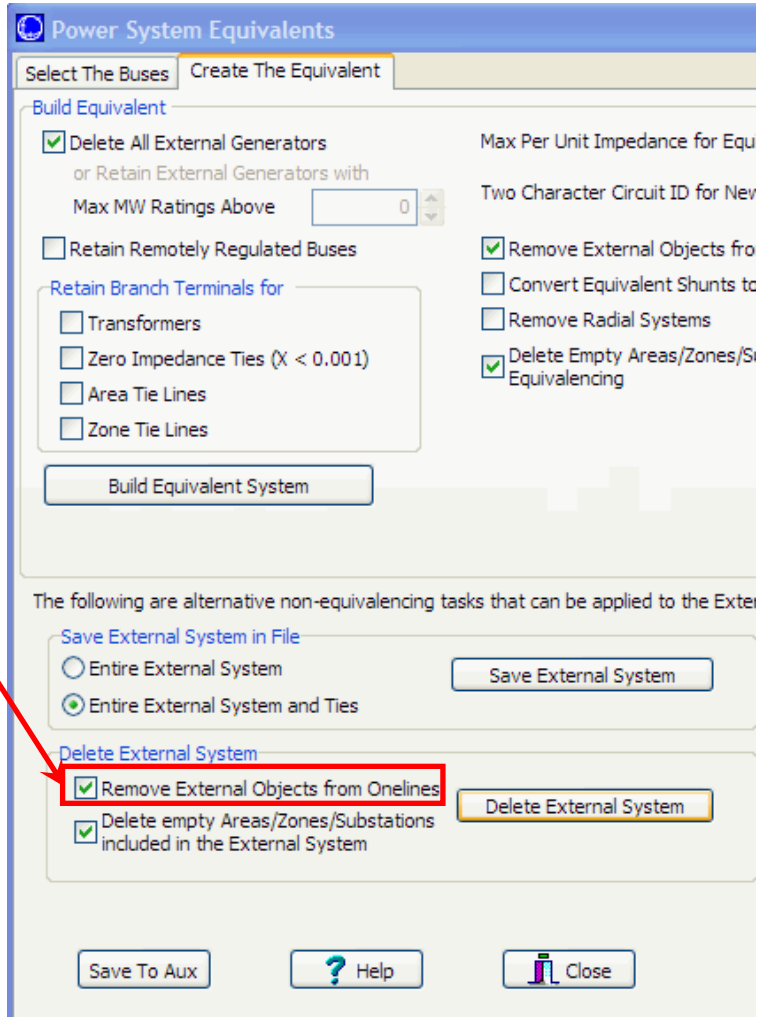
Seven Bus Example

- Open B7FLAT case and in Edit Mode use Tools ribbon tab → **Equivalencing** to open display.
  - Select buses 5, 6, and 7 as the study system; use Save Buses to File to save numbers to file.



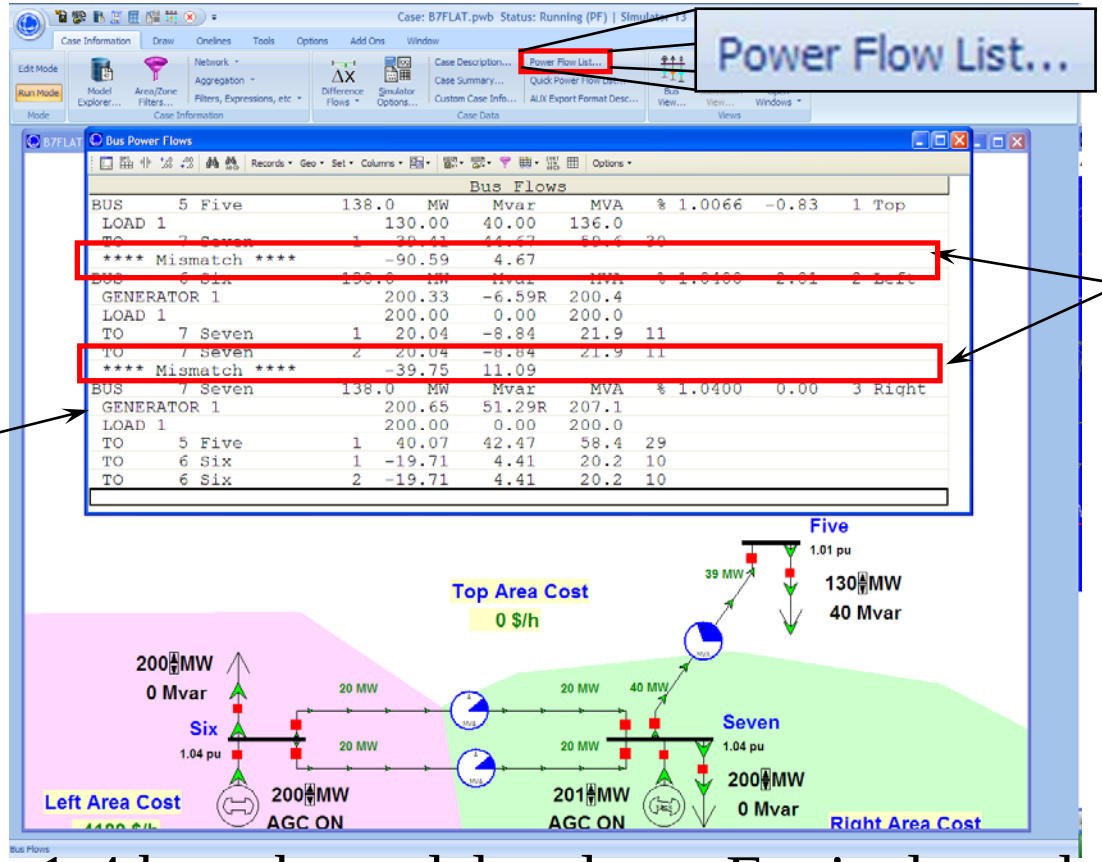
Delete External System Example

- Go to the Create The Equivalent Tab
  - Check the box **Remove External Objects from Onelines**
  - Click **Delete External System**.
    - Click **Yes** when asked "Are you sure ….?"
  - DO NOT SOLVE the case
  - DO NOT SAVE the case.



Deleting the External System

- On the **Case Information Ribbon Tab**, Click **Power Flow List…**



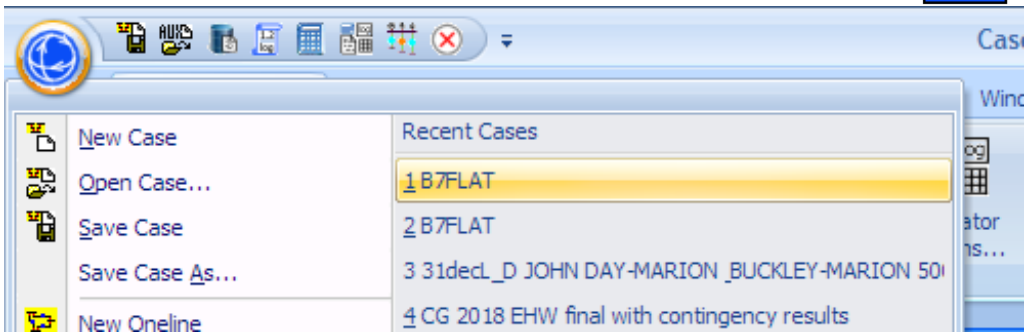
All objects referencing the external system have been removed

Initial mismatches at boundary buses

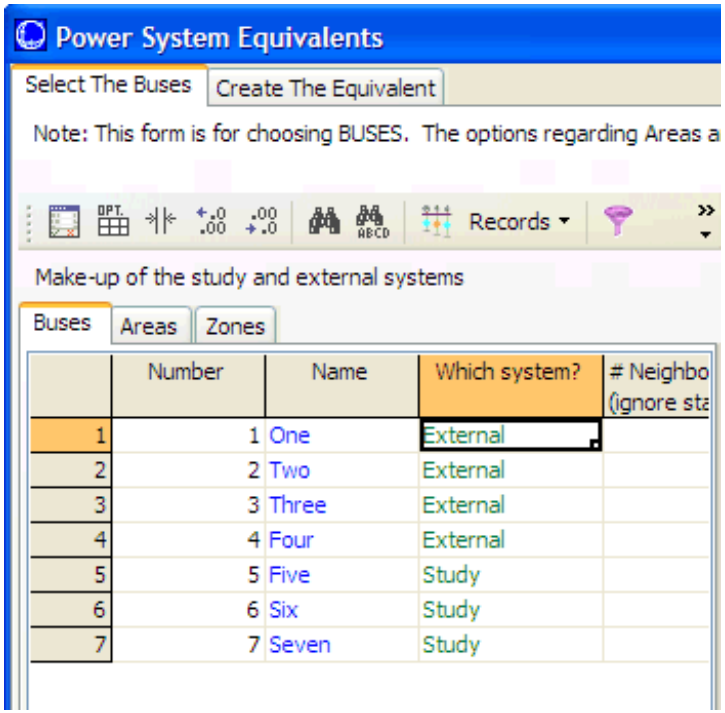
Buses 1-4 have been deleted, not Equivalenced. Hence no equivalent lines/shunts have been added.

Equivalencing External System

- Do NOT SAVE
- Reload B7FLAT



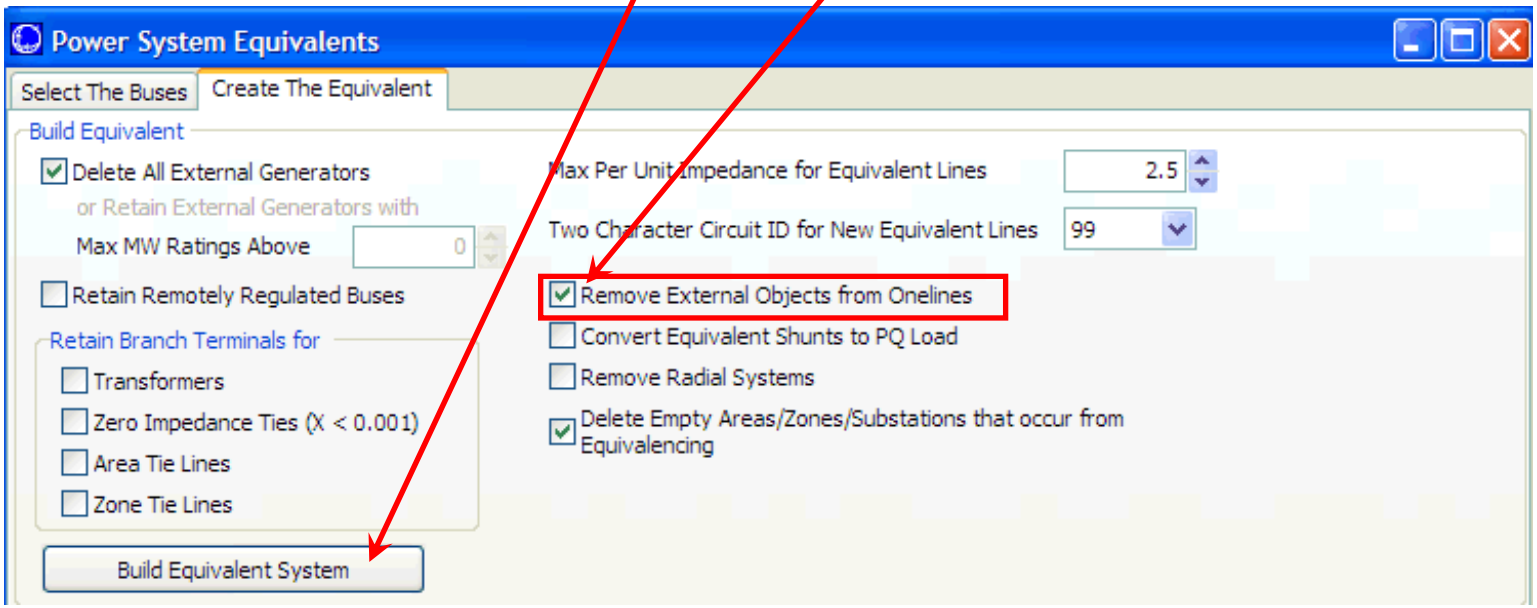
- Click **Equivalencing**



- Again Set buses 5-7 as the Study system.

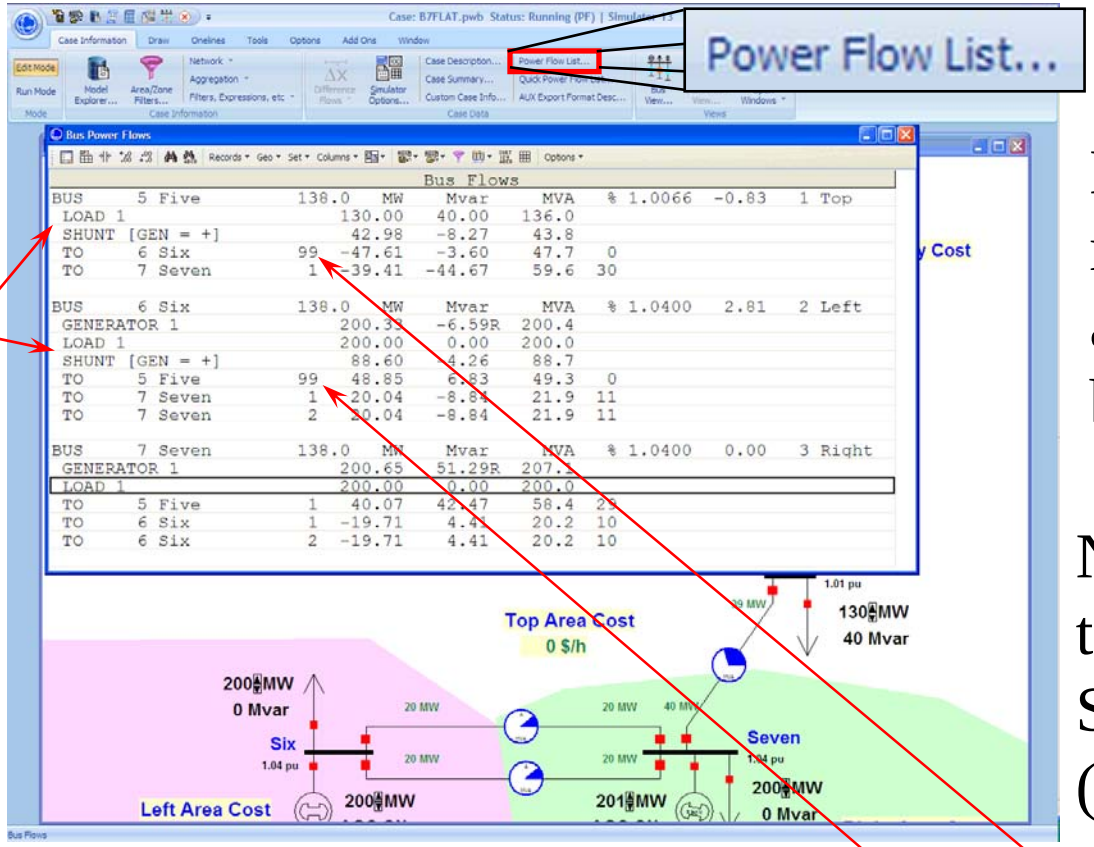
Build Equivalent System Example

- Go to the Create The Equivalent Tab
  - Check the box **Remove External Objects from Onelines**
  - Click **Build Equivalent System**
    - Click **Yes** when asked "Create an equivalent ….?"



Build Equivalent System Example

- On the **Case Information Ribbon Tab**, Click **Power Flow List…**



Bus Shunt has also been added at Bus 5 and 6

No Initial mismatches at boundary buses

No changes to internal Study system (bus 7)

New Branch between bus 5 and 6 has been added with Circuit ID of “99”

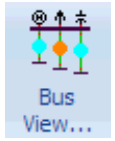
Equivalents and the Slack Bus

- Every system requires a slack bus.
- When creating an equivalent, sometimes the slack bus is “Equivalenced”.
- Simulator notifies user when this will occur.
- When this occurs, a new slack bus must be defined.

MAIN Example

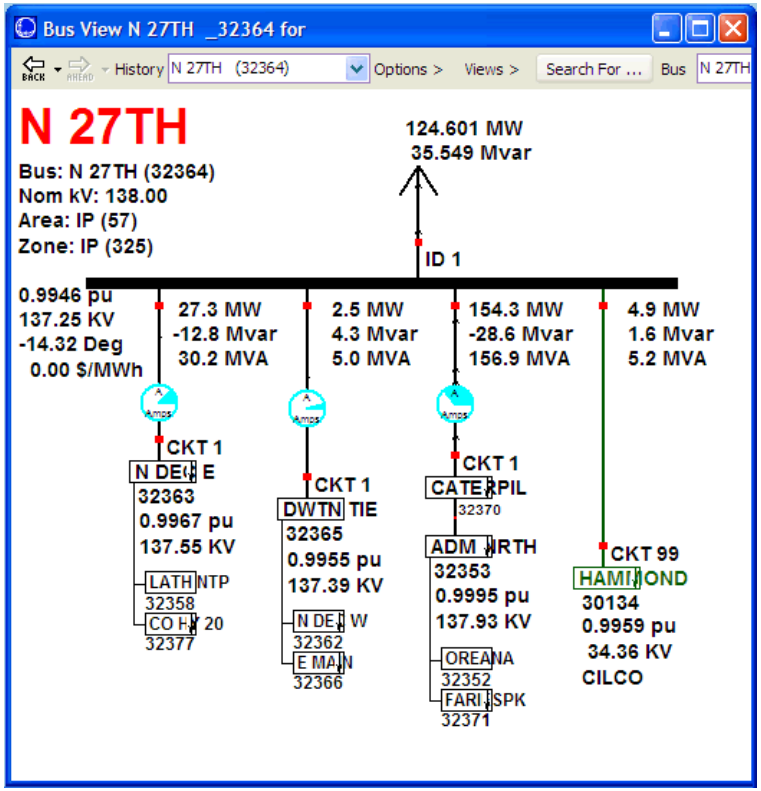
- Open Midwest.raw
- Click Single Solution
- Case has 10,452 buses in 35 control areas.
- In example we'll reduce this number substantially, looking at accuracy of results
  - requires studying contingent response of equivalent versus original system
  - wide variety of cases should be studied

Original System Contingency

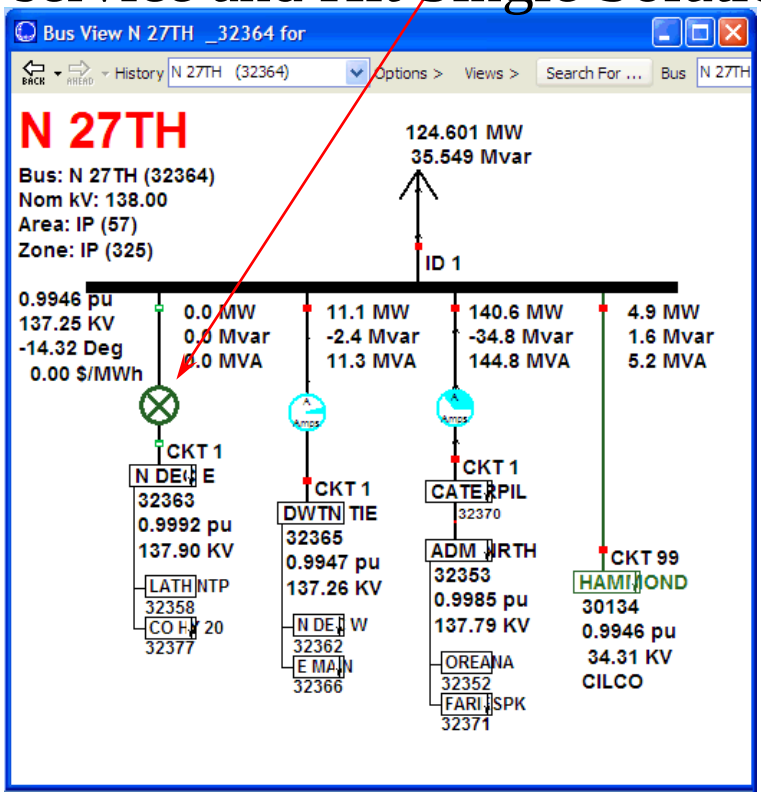
- Open the Bus View 

. Go to Bus 32364

Before Contingency



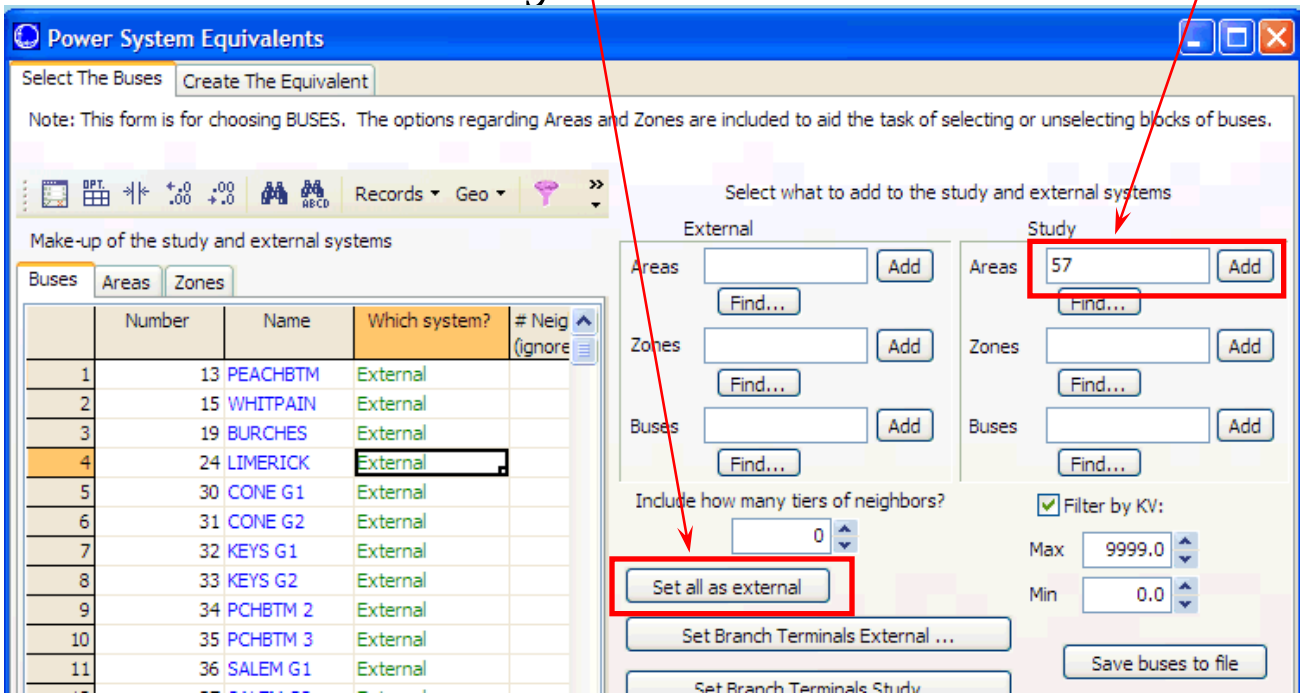
Take Line from 32364 – 32363 out of service and Hit Single Solution



Flow on 32364-32370 is 140.6 MW and -34.8 Mvar

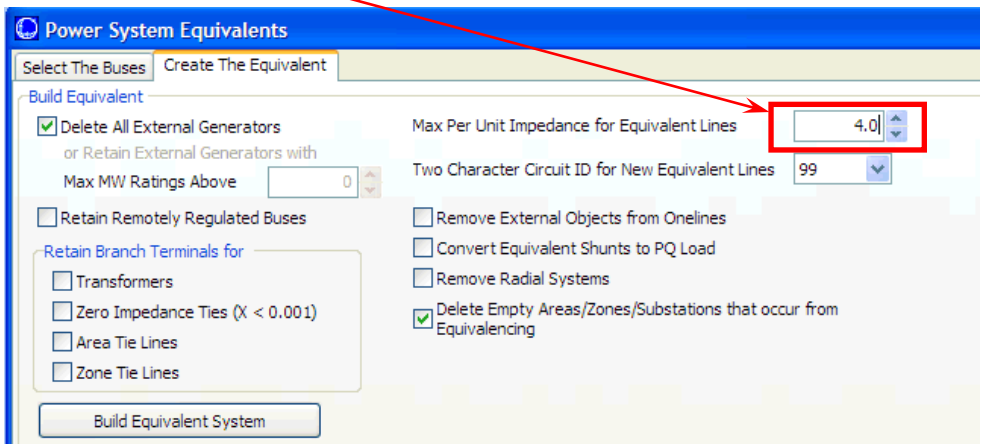
IP Area Equivalent

- Open **Equivalencing** agin
- Click **Set all as external**
- Enter 57 under Study Areas and Click **Add**



Build Equivalent System for IP

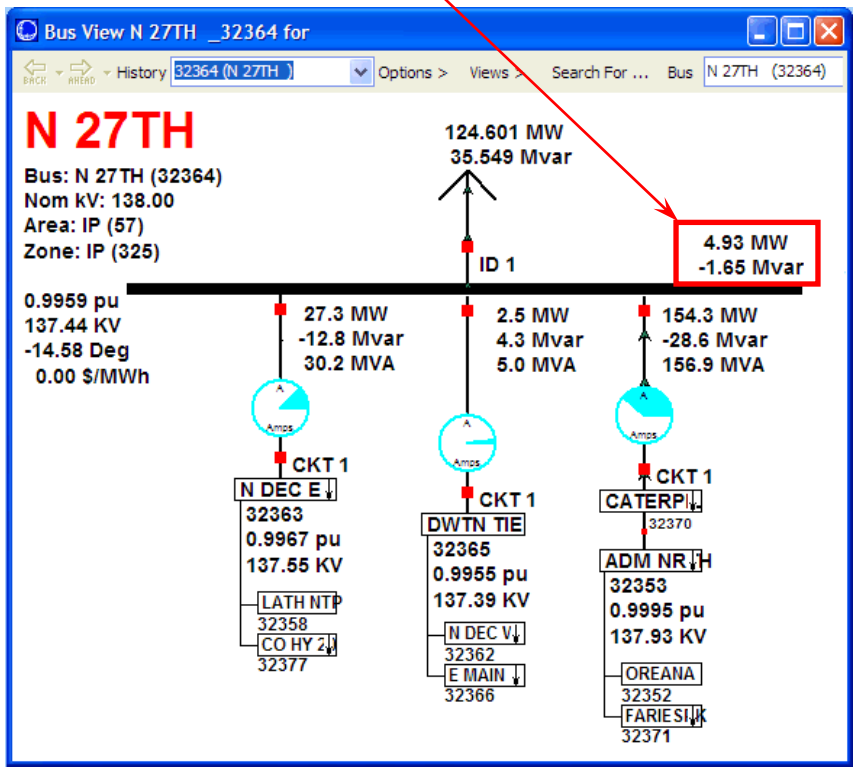
- Go to the Create The Equivalent Tab
  - Set Max Per Unit Impedance to 4.0 to eliminate high impedance equivalent branches
  - Make sure other check boxes



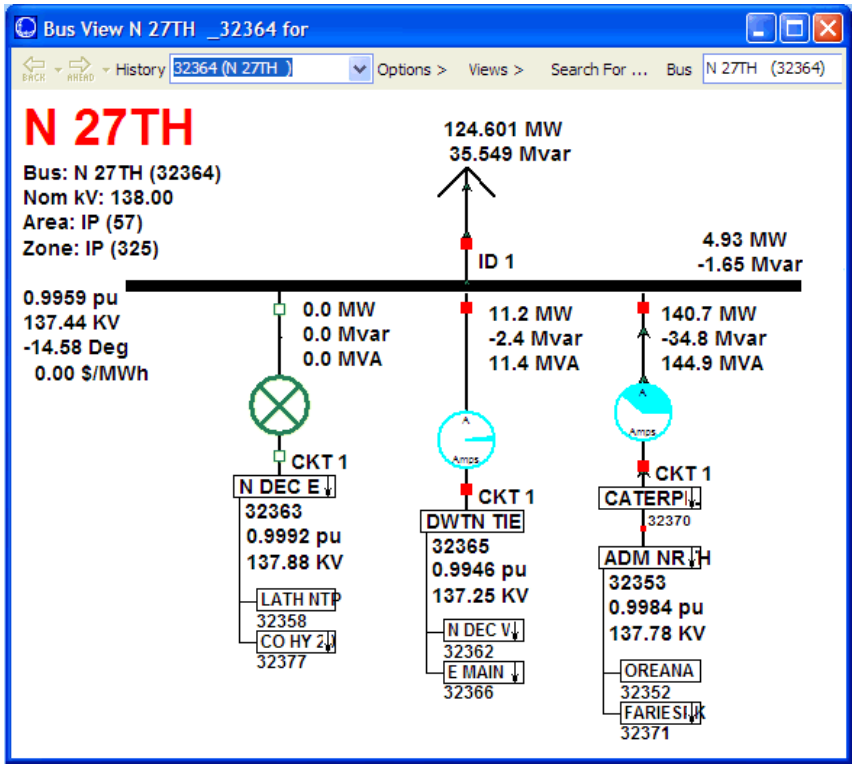
  - Click **Build Equivalent System**
  - Answer “Yes” to “Create an electrical equivalent, permanently removing 10281 buses, ….?”
- New Case has 171 buses now.
  - See this under **Case Summary…**

Contingency Result using the 171 bus equivalent

Shunt equivalent element has been added for tie line to Hammond



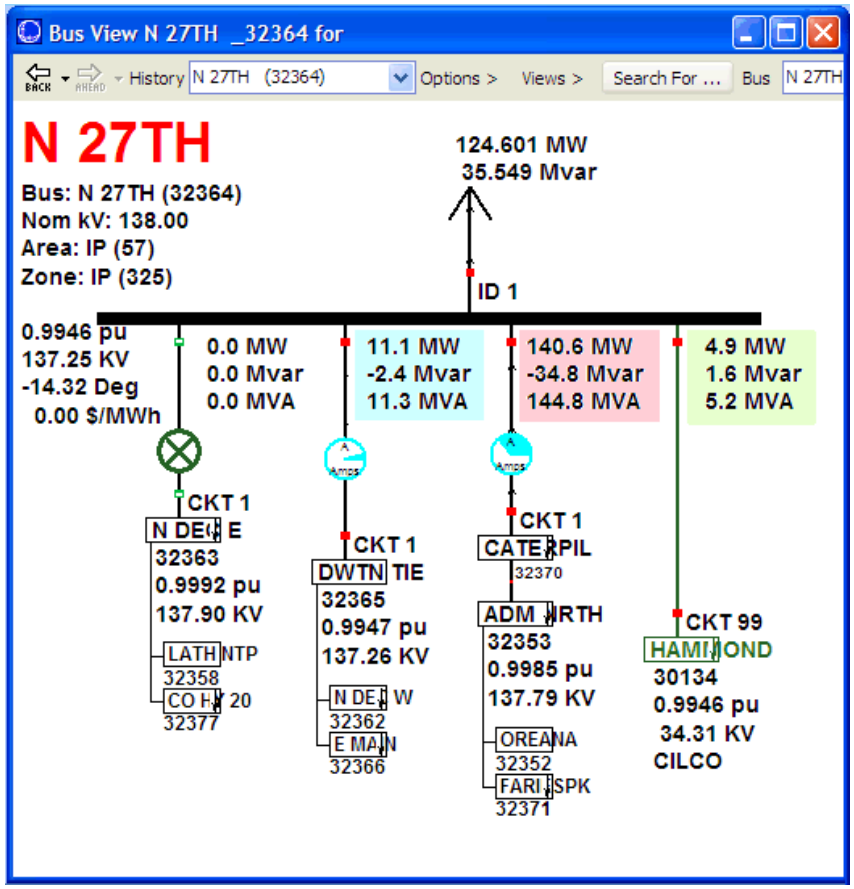
Take Line from 32364 – 32363 out of service and Hit Single Solution. Results are same as before!



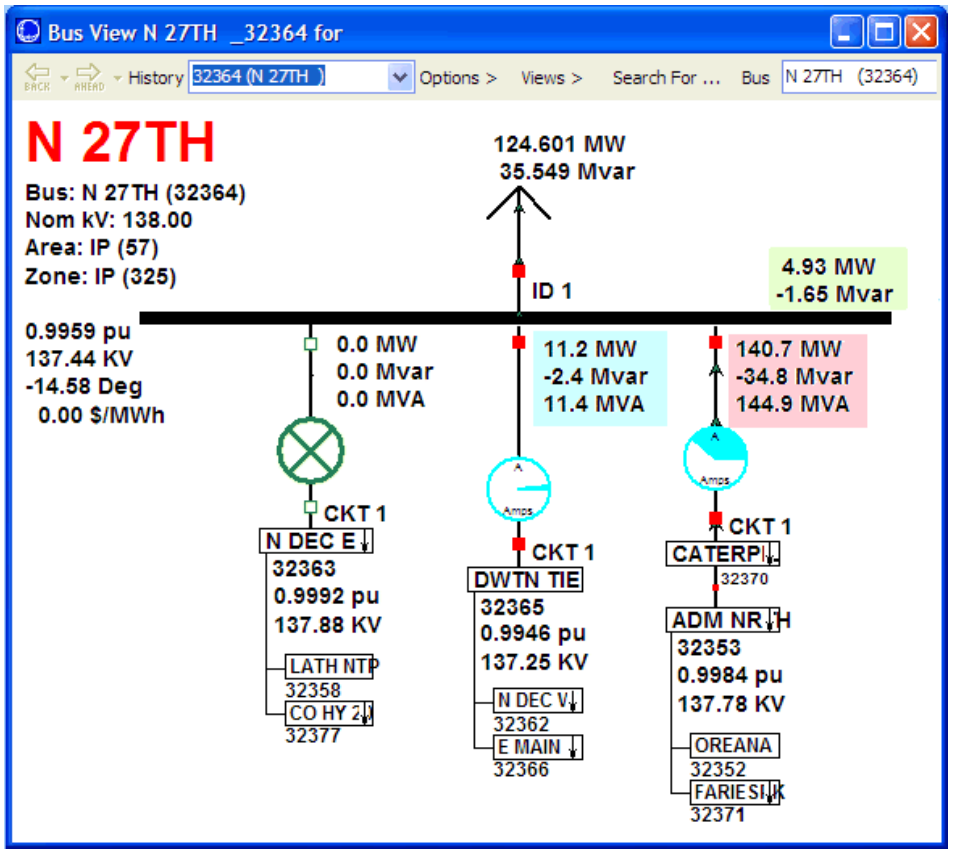
Flow on 32364-32370 is 140.7 MW and -34.8 Mvar

Compare Contingency Result

Full Model (10,452 buses)



Equivalent Model (171 buses)



Area Equivalent with a Few Buses

- Sometimes it is useful to retain an area, representing it by a few buses, or even a single bus
  - with total load and generation for the area
  - allows modeling of interchanges between areas
  - can explicitly retain key tie-lines between areas
- Select a few buses in area to retain. Usually these buses contain large generators or connect to important tie-lines
- Equivalence the rest
- Modify equivalent load/generation to match original load for the area

General Equivalencing Tips

- Tends to be a trial and error process
- Continually compare accuracy of equivalent versus original system
- Avoid equivalencing automatic controls close to area of interest
  - PV generators
  - LTC/Phase shifting transformers
  - DC transmission lines
  - Switched Shunts

Merging Systems

- The ability to merge several systems together is often important. For example, merging a detailed model of own system with a less detailed external system (e.g., the MAIN model).
- In Edit mode use **Tools** ribbon tab → **Modify Case → Append Case**
- Append command completely overwrites any duplicated records.

Merging Systems