

Introduction to PowerWorld Simulator: Interface and Common Tools



I14: Equivalents



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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

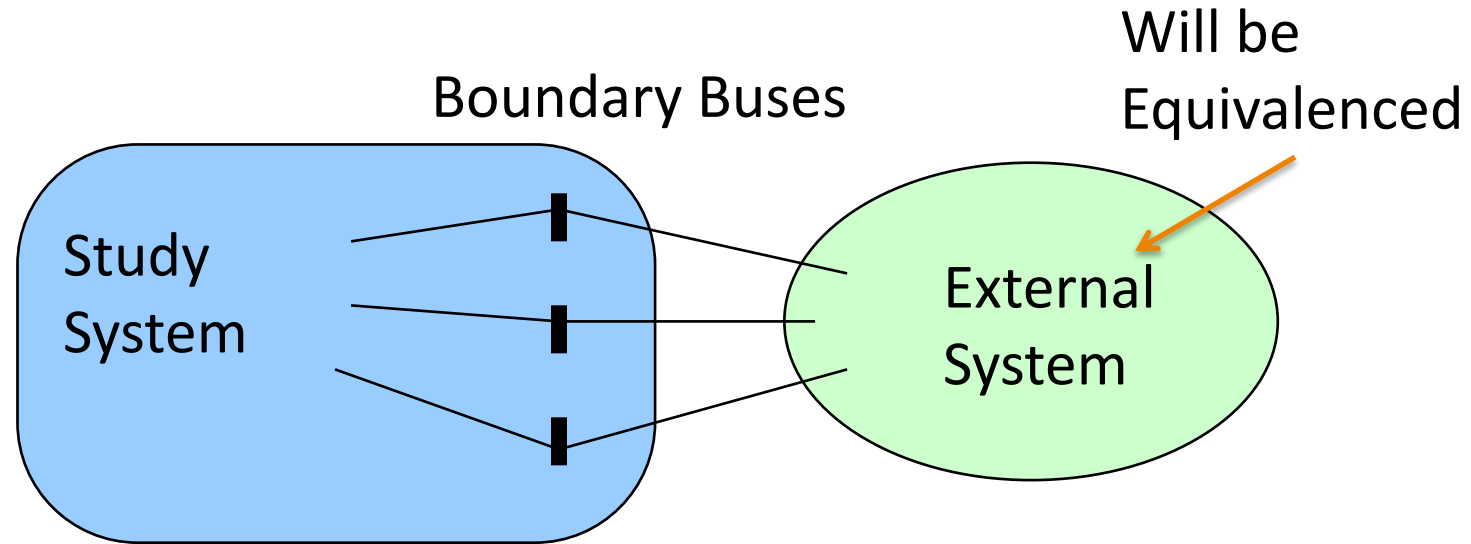


- Typically broken up into two systems
 - study system represented in detail
 - external system represented by an equivalent
- Two systems are joined at boundary buses
- Boundary buses are the buses in the study system that connect to the external system

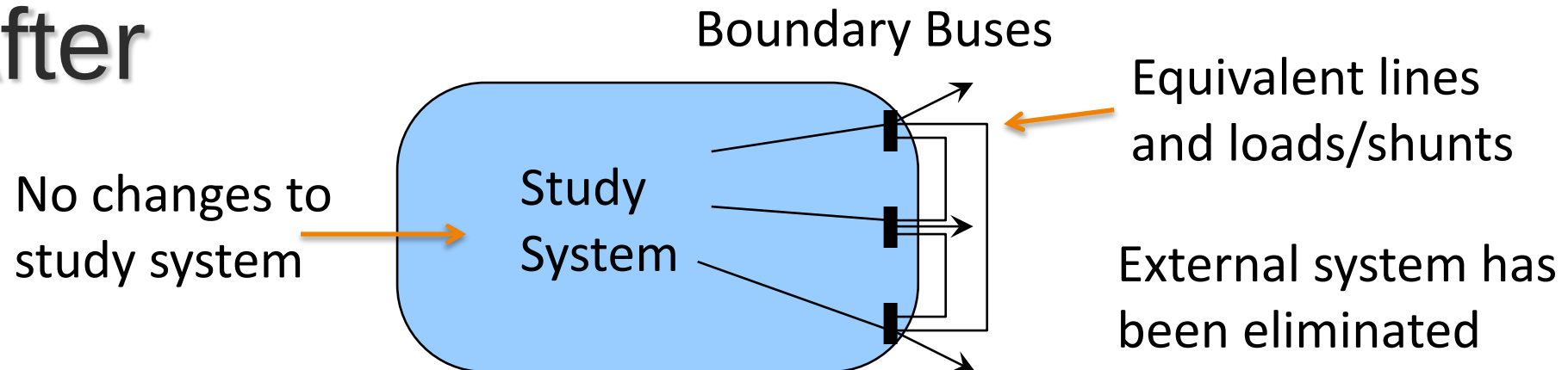
Equivalencing Process



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

$$\mathbf{I} = \mathbf{Y} \mathbf{V}$$

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

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

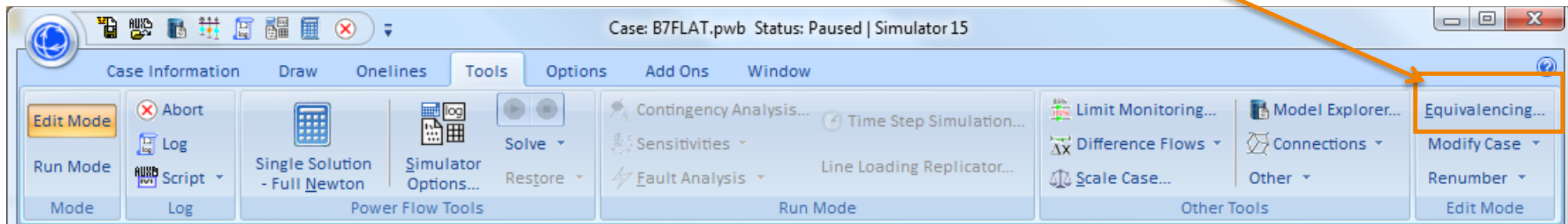
Results in new equivalent lines joining the boundary buses and shunts at the boundary buses

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

Note: This form is for choosing BUSES. The options regarding Areas and Zones are included to aid the task of selecting or unselecting blocks of buses.

Select what to add to the study and external systems

Make-up of the study and external systems				
Buses				
	Number	Name	Which system?	# Neig (ignore)
1	13	PEACHBTM	Study	
2	15	WHITPAIN	Study	
3	19	BURCHES	Study	
4	24	LIMERICK	Study	
5	30	CONE G1	Study	
6	31	CONE G2	Study	
7	32	KEYS G1	Study	
8	33	KEYS G2	Study	
9	34	PCHBTM 2	Study	
10	35	PCHBTM 3	Study	
11	36	SALEM G1	Study	
12	37	SALEM G2	Study	
13	38	SUSQ 2	Study	
14	39	HOPE CG1	Study	
15	40	C CLF1	Study	
16	41	C CLF2	Study	
17	42	LIMERCK2	Study	
18	249	SENECA#1	Study	

External

Areas Add

Zones Add

Buses Add

Include how many tiers of neighbors?

Study

Areas Add

Zones Add

Buses Add

☒ Filter by KV:

Max

Min

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



Power System Equivalents

Select The Buses | Create The Equivalent

Build Equivalent

☒ Delete All External Generators
or Retain External Generators with
Max MW Ratings Above

☐ Retain Remotely Regulated Buses

Retain Branch Terminals for

☐ Transformers
☐ Zero Impedance Ties ($X < 0.001$)
☐ Area Tie Lines
☐ Zone Tie Lines

☐ Remove External Objects from Onelines
☐ Convert Equivalent Shunts to PQ Load
☐ Remove Radial Systems
☒ Delete Empty Areas/Zones/Substations that occur from
Equivalent
☐ Adjust Area Unspecified Interchange to Zero Out ACE

Max Per Unit Impedance for Equivalent Lines
Two Character Circuit ID for New Equivalent Lines

The following are alternative non-equivalencing tasks that can be applied to the External System

Save External System in File

☐ Entire External System
☒ Entire External System and Ties

Delete External System

☐ Remove External Objects from Onelines
☒ Delete empty Areas/Zones/Substations included in the External System

Merge Bus Shunts Across Zero Impedance Branches

Merge Bus Shunt Values Above
Merge Across Branches
 $X, R < 0.00015$ and $B = 0$

Note: If bus shunt values are merged across area tie lines, the unspecified MW transactions for the areas will be adjusted accordingly.

Builds the equivalent system, removing the external subsystem

Allows saving External subsystem to a file

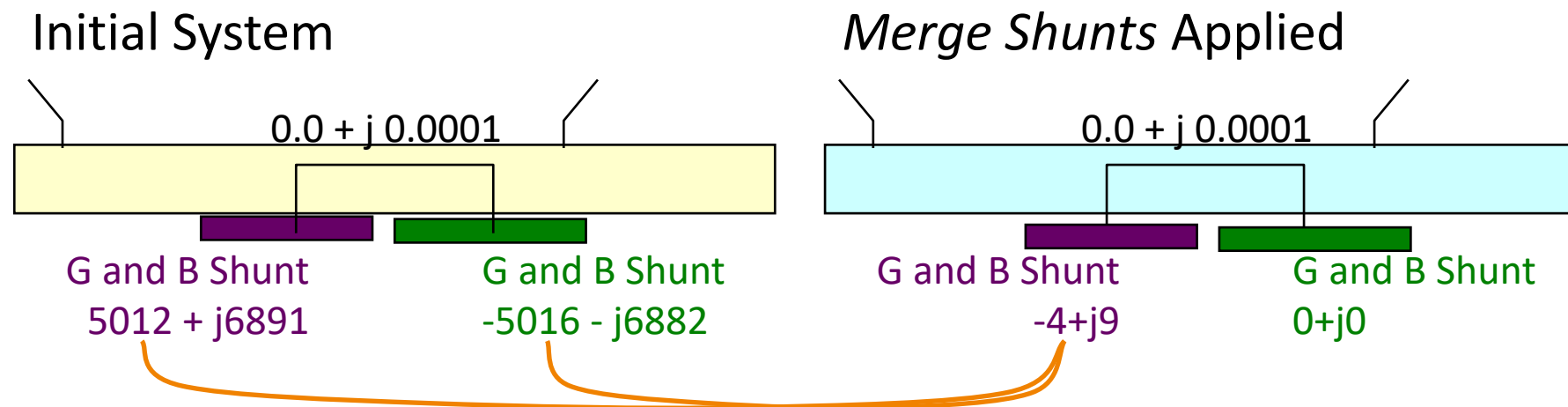
Merge Shunts fixes a data error seen in some models

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.

Save External System in File

☐ Entire External System

☒ Entire External System and Ties

Save External System

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.

Delete External System

☐ Remove External Objects from Onelines

☒ Delete empty Areas/Zones/Substations included in the External System

Delete External System

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.

A screenshot of a software dialog box titled "Build Equivalent System". It contains several options: a checked checkbox for "Delete All External Generators" with a sub-option "or Retain External Generators with" and a text input field for "Max MW Ratings Above" set to "0"; an unchecked checkbox for "Retain Remotely Regulated Buses"; a section titled "Retain Branch Terminals for" with four unchecked checkboxes: "Transformers", "Zero Impedance Ties (X < 0.001)", "Area Tie Lines", and "Zone Tie Lines"; and a "Build Equivalent System" button at the bottom.

☒ Delete All External Generators
or Retain External Generators with
Max MW Ratings Above

☐ Retain Remotely Regulated Buses

Retain Branch Terminals for

☐ Transformers

☐ Zero Impedance Ties ($X < 0.001$)

☐ Area Tie Lines

☐ Zone Tie Lines

Build Equivalent System

Build Equivalent



- **Max Per Unit Impedance for Equivalent Lines** 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
- Adjust the area unspecified interchange to zero out the ACE to prevent any MW discrepancies from going to the system slack

Max Per Unit Impedance for Equivalent Lines

Two Character Circuit ID for New Equivalent Lines

☐ Remove External Objects from Onelines

☐ Convert Equivalent Shunts to PQ Load

☐ Remove Radial Systems

☒ Delete Empty Areas/Zones/Substations that occur from Equivalencing

☐ Adjust Area Unspecified Interchange to Zero Out ACE

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.

Power System Equivalents

Select The Buses Create The Equivalent

Note: This form is for choosing BUSES. The options regarding Areas a...

DPT .00 .00 RECD Records

Make-up of the study and external systems

Buses Areas Zones

	Number	Name	Which system?	# Neighbo (ignore sta
1	1	One	External	
2	2	Two	External	
3	3	Three	External	
4	4	Four	External	
5	5	Five	Study	
6	6	Six	Study	
7	7	Seven	Study	

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

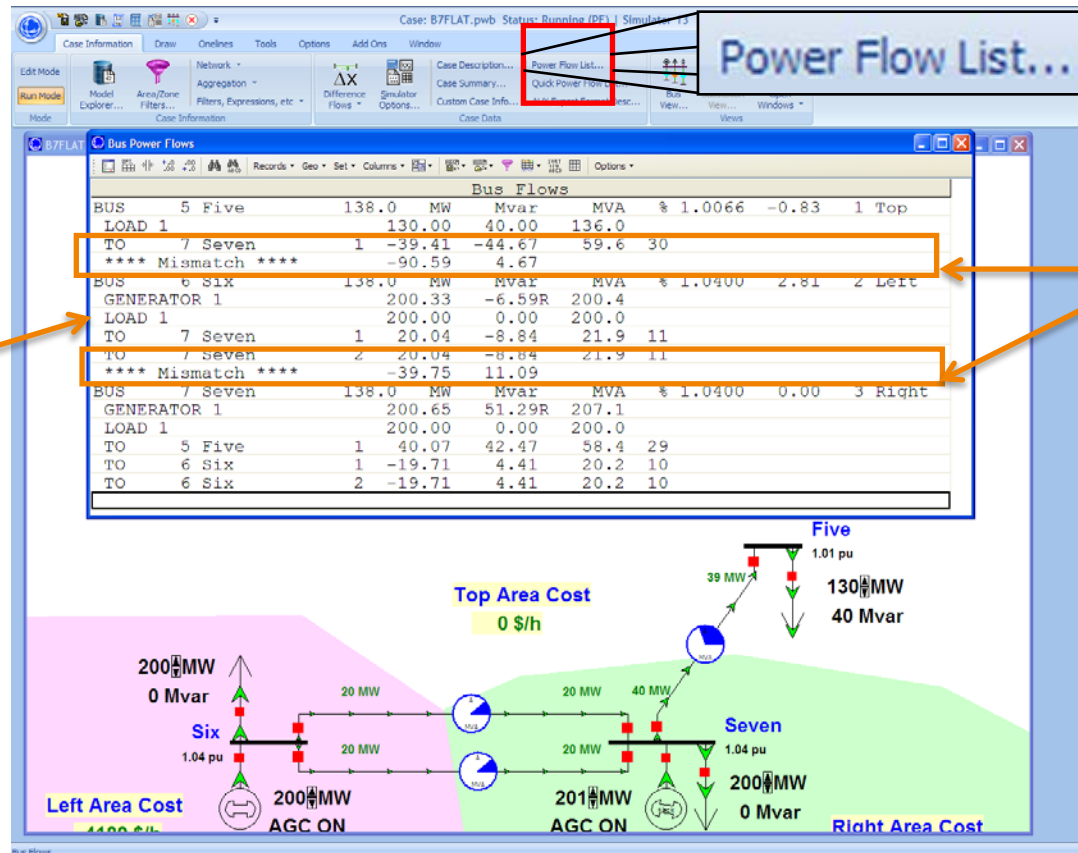
The screenshot shows the 'Power System Equivalents' dialog box with the 'Create The Equivalent' tab selected. The 'Build Equivalent' section contains several options: 'Delete All External Generators' (checked), 'Retain Remotely Regulated Buses' (unchecked), and 'Retain Branch Terminals for' (unchecked) with sub-options for Transformers, Zero Impedance Ties, Area Tie Lines, and Zone Tie Lines. On the right, there are checkboxes for 'Remove External Objects from Oneline' (unchecked), 'Convert Equivalent Shunts to PQ Load' (unchecked), 'Remove Radial Systems' (unchecked), 'Delete Empty Areas/Zones/Substations' (checked), and 'Adjust Area Unspecified Interchange' (unchecked). Below this is a 'Build Equivalent System' button. The bottom section, 'The following are alternative non-equivalencing tasks that can be applied to the External System', has two sub-sections. The first, 'Save External System in File', has radio buttons for 'Entire External System' and 'Entire External System and Ties' (selected), with a 'Save External System' button. The second, 'Delete External System', has a checkbox for 'Remove External Objects from Onelines' (checked) and a checkbox for 'Delete empty Areas/Zones/Substations included in the External System' (checked). This section is highlighted with an orange box, and an orange arrow points to it from the text 'Click Delete External System.' in the list. A 'Delete External System' button is also present. At the bottom of the dialog are 'Save To Aux', 'Help', and 'Close' buttons.

Deleting the External System



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

All objects
referencing the
external system
have been
removed



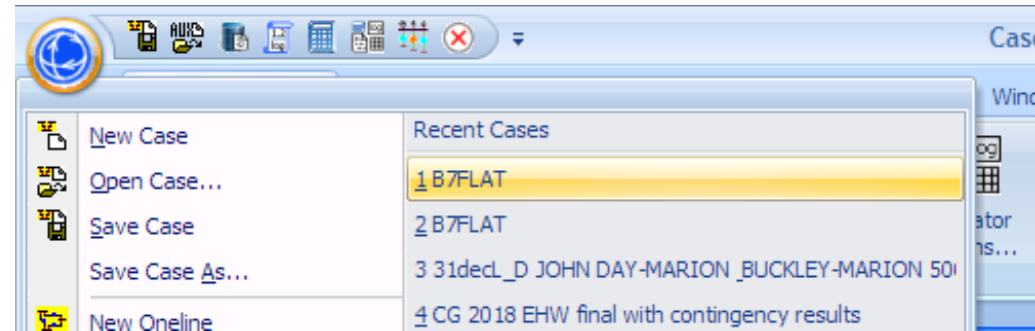
Initial mismatches
at boundary buses

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.



Power System Equivalents

Select The Buses | Create The Equivalent

Note: This form is for choosing BUSES. The options regarding Areas a

Make-up of the study and external systems

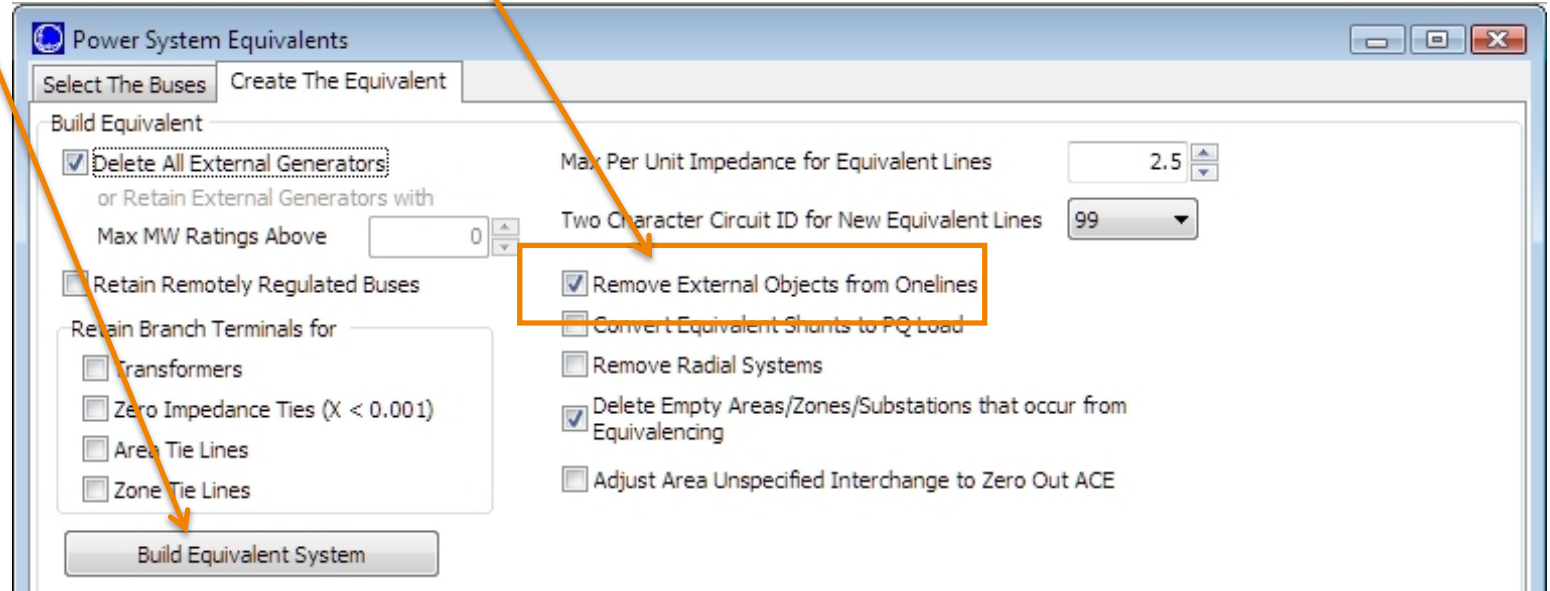
Buses | Areas | Zones

	Number	Name	Which system?	# Neighbo (ignore sta
1	1	One	External	
2	2	Two	External	
3	3	Three	External	
4	4	Four	External	
5	5	Five	Study	
6	6	Six	Study	
7	7	Seven	Study	

Build Equivalent System Example



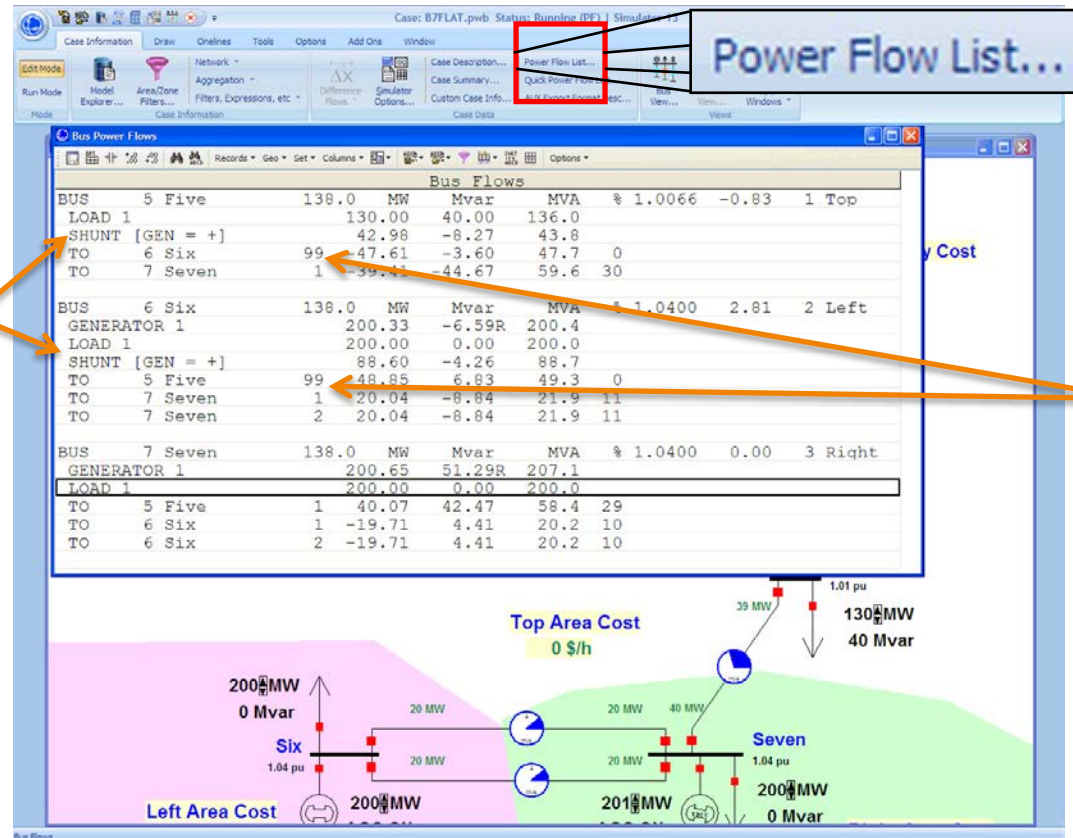
- Go to the Create The Equivalent Tab
 - Check the box **Remove External Objects from Onelines**
 - Click **Build Equivalent System**
- Click **Yes** when asked “Create an equivalent?”



Build Equivalent System Example



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



Bus Shunts have also been added at Buses 5 and 6

No Initial mismatches at boundary buses

New Branch between bus 5 and 6 has been added with Circuit ID "99"

No changes to internal Study system (bus 7)

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.

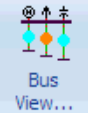
Western Example



- Open ACTIVSg10k.pwb
- Click Single Solution
- Case has 10,000 buses across 16 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

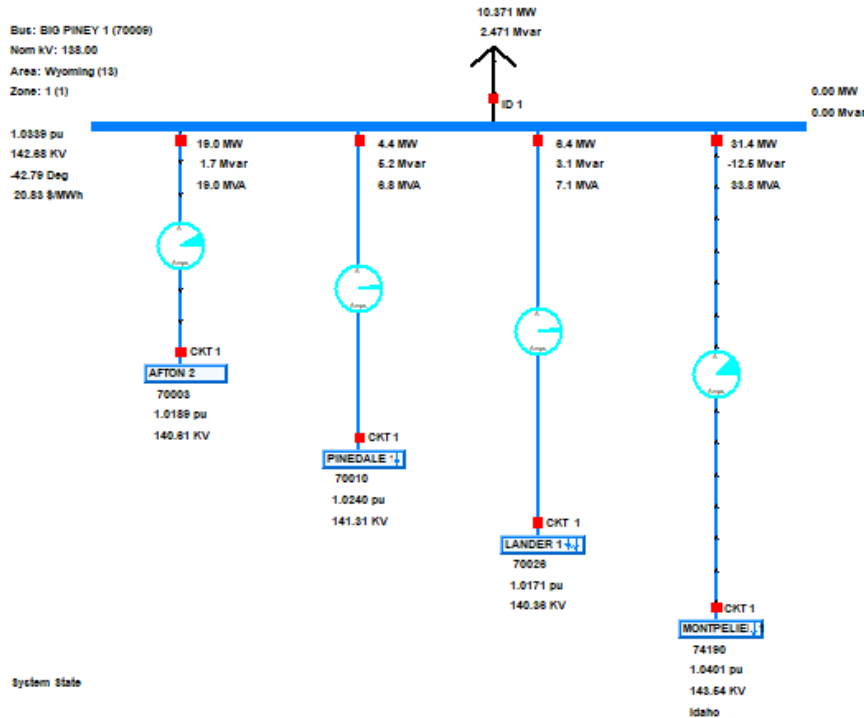


- Open the Bus View  to Bus 70009
Before Contingency

Take Line from 70003 – 70009 out of service and Solve. In **Difference Flows** → **Set Present as Base**

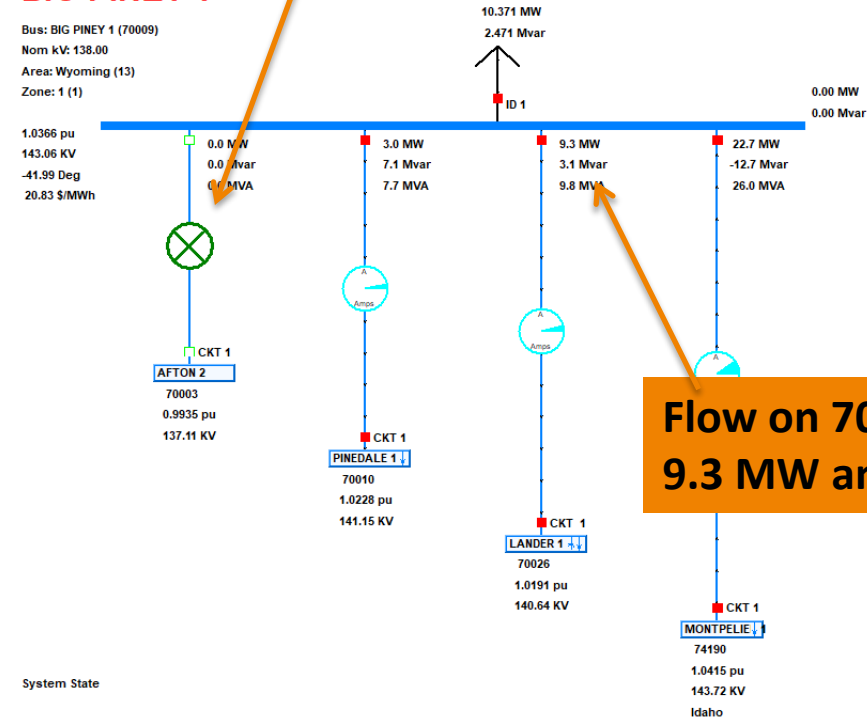
BIG PINEY 1

Bus: BIG PINEY 1 (70009)
Nom kV: 138.00
Area: Wyoming (13)
Zone: 1 (1)



BIG PINEY 1

Bus: BIG PINEY 1 (70009)
Nom kV: 138.00
Area: Wyoming (13)
Zone: 1 (1)



Flow on 70009-70026 is
9.3 MW and 3.1 Mvar

Wyoming Area Equivalent



- Return the line to service, Solve Power Flow, switch to **Edit Mode**, and Open **Equivalencing**
- Click **Set all as external**
- Enter 13 under Study Areas and Click **Add**

Power System Equivalents

Select The Buses | Create The Equivalent

Note: This form is for choosing BUSES. The options regarding Areas and Zones are included to aid the task of selecting or unselecting blocks of buses.

Make up the study and external systems

Buses | Areas | Zones | Substations

	Number	Name	Which system?	# Neig (ignore)
1	10001	NEAH BAY 1	Study	
2	10002	FORKS 1	Study	
3	10003	OCEAN SHORE	Study	
4	10004	WESTPORT 1	Study	
5	10005	WESTPORT 2	Study	
6	10006	LONG BEACH 1	Study	
7	10007	LONG BEACH 1	Study	
8	10008	OCEAN PARK 1	Study	
9	10009	OCEAN PARK 2	Study	
10	10010	HOQUIAM 1	Study	
11	10011	PORT ANGELES	Study	

Select what to add to the study and external systems

External

Areas Add Find...

Zones Add Find...

Buses Add Find...

Add First Neighbors to External

Include All in Same Substation

Include how many tiers of neighbors? 0

Set all as external

Study

Areas 13 Add Find...

Zones Add Find...

Buses Add Find...

Add First Neighbors to Study

Include All in Same Substation

Filter by kV

☒ Filter by kV:

Max 9999.0

Min 0.0

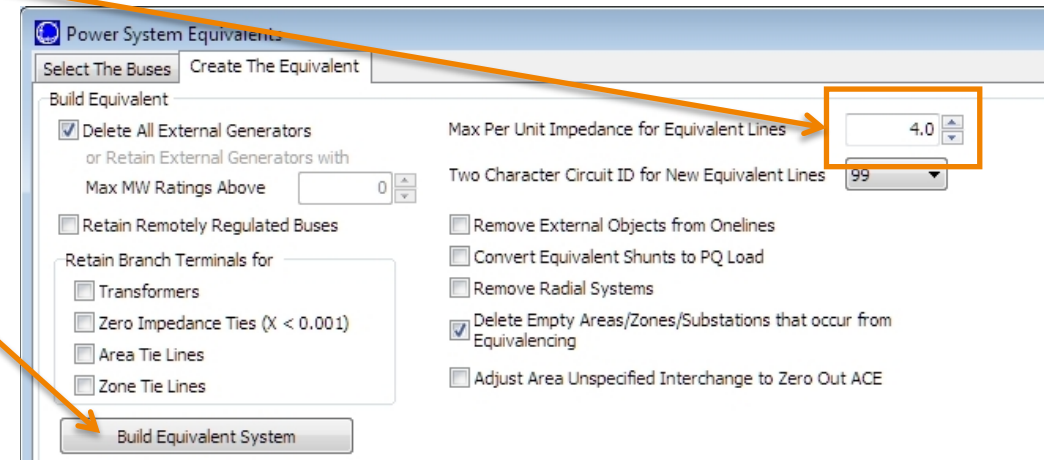
Switch to the next page to create equivalents

Close Help

Build Equivalent System for Wyoming



- Go to the Create The Equivalent Tab
 - Set Max Per Unit Impedance to 4.0 to eliminate high impedance equivalent branches
 - Click **Build Equivalent System**
 - Answer “Yes” to “Create an electrical equivalent, permanently removing 9809 buses, ...?”
- New Case has 191 buses now.
 - See this under **Case Summary...**



Contingency Result using the 191-bus equivalent

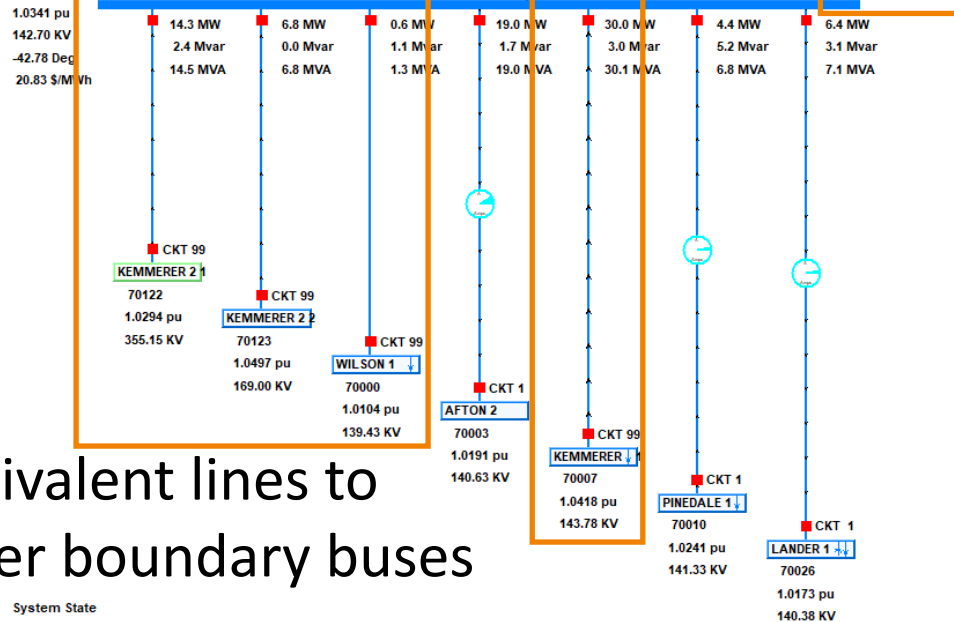


Shunt equivalent element has been added for tie line to Montpelier

Take Line from 70003 – 70009 out of service and Solve. Switch to **Difference Case**. Results are similar (except on new equivalent lines).

BIG PINEY 1

Bus: BIG PINEY 1 (70009)
Nom kV: 138.00
Area: Wyoming (13)
Zone: 1 (1)

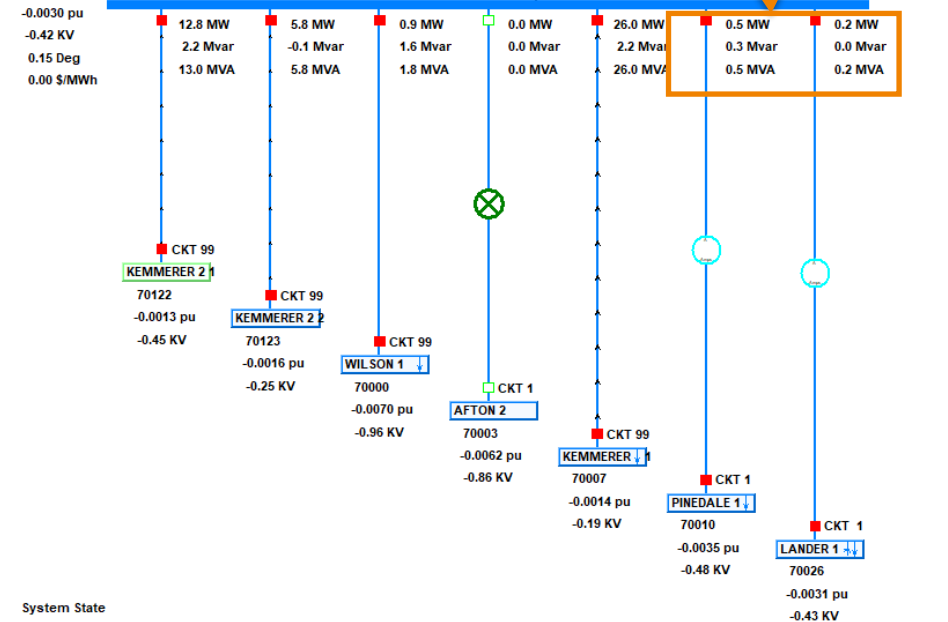


Equivalent lines to
other boundary buses

System State

BIG PINEY 1

Bus: BIG PINEY 1 (70009)
Nom kV: 138.00
Area: Wyoming (13)
Zone: 1 (1)



System State

Compare Contingency Flows



Branches in
Difference Mode
(with circuit ID = 99
removed by Quick
Filter)

Most values are small;
largest change due to
generation change at
new Slack Bus 70177

X Branches State (Filter:Quick) X Transformer Controls X Areas X Buses															
Filter Advanced Branch Quick Find... Remove Quick Filter															
Records Geo Set Columns Options															
	From Number	From Name	To Number	To Name	Cl	Status	Branch Device Type	Xfrmr	MW From	Mvar From	MVA Fr	Lim MVA	% of MVA Limit (Max)	MW Loss	Mvar Loss
1	70177	MEDICINE BOW 2 1	70178	MEDICINE BOW 2 2	1	Closed Line	NO		-2.3	0.0	-2.3	0.0	0.0	-0.00	-0.00
2	70113	ROCK RIVER 1 2	70178	MEDICINE BOW 2 2	1	Closed Line	NO		1.6	-0.3	-1.6	251.9	-0.6	-0.05	-0.24
3	70112	ROCK RIVER 1 1	70116	ROCK RIVER 1 5	1	Closed Line	NO		-1.5	0.3	-1.5	0.0	0.0	-0.00	-0.00
4	70113	ROCK RIVER 1 2	70112	ROCK RIVER 1 1	1	Closed Transformer	YES		1.5	0.3	-1.1	266.2	-0.4	-0.00	-0.01
5	70157	POINT OF ROCKS 7	70122	KEMMERER 2 1	1	Closed Line	NO		0.1	2.3	-0.6	1257.2	-0.0	-0.00	0.15
6	70151	POINT OF ROCKS 1	70157	POINT OF ROCKS 7	2	Closed Line	NO		-0.0	2.0	-0.6	0.0	0.0	-0.00	-0.00
7	70151	POINT OF ROCKS 1	70157	POINT OF ROCKS 7	1	Closed Line	NO		-0.0	2.0	-0.6	0.0	0.0	-0.00	-0.00
8	70004	ALPINE 3 1	70006	JACKSON 3 1	1	Closed Line	NO		-0.5	-0.4	-0.6	231.0	-0.3	-0.00	0.05
9	70132	GILLETTE 5 1	70101	GLENROCK 2 7	1	Closed Line	NO		0.6	0.1	0.6	1461.7	0.0	0.02	0.33
10	70011	DUBOIS 1	70006	JACKSON 3 1	1	Closed Line	NO		0.6	0.7	0.6	250.9	0.2	0.03	0.19
11	70116	ROCK RIVER 1 5	70101	GLENROCK 2 7	1	Closed Line	NO		-0.6	0.2	0.6	1380.9	0.0	0.02	0.19
12	70132	GILLETTE 5 1	70134	GILLETTE 5 3	1	Closed Transformer	YES		0.0	-2.1	0.6	601.3	0.1	0.00	0.02
13	70004	ALPINE 3 1	70001	THAYNE 1	1	Closed Line	NO		0.5	0.4	-0.6	232.0	-0.2	-0.00	0.03
14	70129	MEDICINE BOW 2 2	70129	ROCK RIVER 2 2	1	Closed Line	NO		-0.5	-0.0	-0.5	230.7	-0.2	-0.01	-0.03
15	70132	GILLETTE 5 1	70117	WRIGHT 2 1	1	Closed Line	NO		-0.1	0.9	0.5	1077.1	0.1	0.00	0.01
16	70117	WRIGHT 2 1	70101	GLENROCK 2 7	1	Closed Line	NO		0.5	0.0	0.5	1370.1	0.0	0.02	0.26
17	70101	GLENROCK 2 7	70161	ALCOVA 2 1	1	Closed Line	NO		0.4	0.0	0.4	1223.5	0.0	0.00	0.04
18	70129	ROCK RIVER 2 2	70042	SARATOGA 3 1	1	Closed Line	NO		-0.4	0.1	-0.4	221.6	-0.2	-0.01	-0.04
19	70132	BURNS 2 1	70082	CHEYENNE 4 1	1	Closed Line	NO		0.3	-0.1	-0.3	236.5	-0.1	-0.00	-0.02
20	70110	PINEDALE 1	70009	BIG PINEY 1	1	Closed Line	NO		-0.5	-0.2	0.3	266.7	0.1	0.00	0.06
21	70157	LARAMIE 2 1	70082	CHEYENNE 4 1	1	Closed Line	NO		-0.3	0.0	-0.3	255.4	-0.1	-0.01	-0.06
22	70157	LARAMIE 2 1	70129	ROCK RIVER 2 2	1	Closed Line	NO		0.3	-0.0	-0.3	267.7	-0.1	-0.02	-0.09
23	70109	CHEYENNE 6 3	70061	LARAMIE 1 1	1	Closed Line	NO		0.3	-0.2	-0.3	250.0	-0.1	-0.01	-0.07
24	70151	POINT OF ROCKS 1	70153	POINT OF ROCKS 3	1	Closed Transformer	YES		0.0	-1.0	-0.3	793.6	-0.0	-0.00	-0.01
25	70116	ROCK RIVER 1 5	70135	CHEYENNE 7 1	1	Closed Line	NO		-0.3	0.0	-0.3	1371.0	-0.0	-0.01	-0.09

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

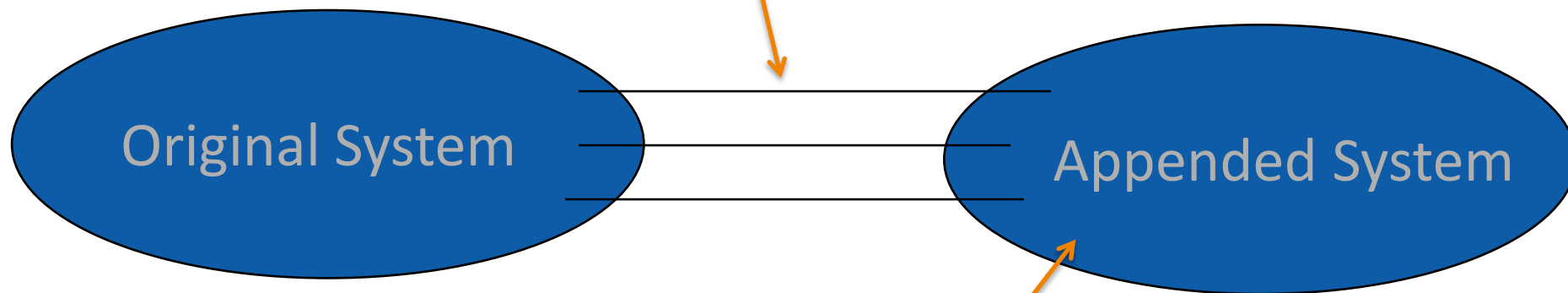


- The ability to merge several systems together is often important. For example, merging a detailed model of own system with a less detailed external system (e.g., the MAIN model).
- In Edit mode use **Tools** ribbon tab → **Modify Case** → **Append Case**
- Append command completely overwrites any duplicated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

Merging Systems



Tie-lines, usually stored with
appended system



Appended system can be saved using Equivalents
display using the Save External System in File option

Blank Page