Steady-State Power System Security Analysis with PowerWorld Simulator

S2: Advanced Power Flow using PowerWorld Simulator

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Overview

- Detailed Overview of "Single Solution"
  - Pre-Processing
  - MW Control Loop
  - Voltage Control Loop
  - Inner Power Flow Loop

- Power Flow Solution Advanced Options
  - Minimum Per Unit Voltage for Constant Power and Current Loads
  - Parallel Tap Balancing
  - Regulation Range Correction
  - Minimum Tap Sensitivity
  - Generator Mvar Sharing
  - Switched Shunt and Transformer Solution Options
- Area Control with Multiple Islands
- Solution Diagnosis Aids

What Does It Mean to do a Single Solution in Simulator?

- Single solution should not be confused with a single Newton-Raphson (or other technique) power flow
- Simulator's "Single Solution" encompasses three nested loops that iterate between a power flow routine, logic for control device switching, and generation control until the power flow is solved and no more device switching is detected

Overview of Single Solution Routine

- Pre-processing
  - Angle Smoothing
  - Generator remote regulation viability
  - Estimate MW change needed
- Three Nested Loops Solution Process
  - MW Control Loop
    - Voltage Controller Loop
      - Inner Power Flow loop

Traditionally called the *Power Flow Solution*

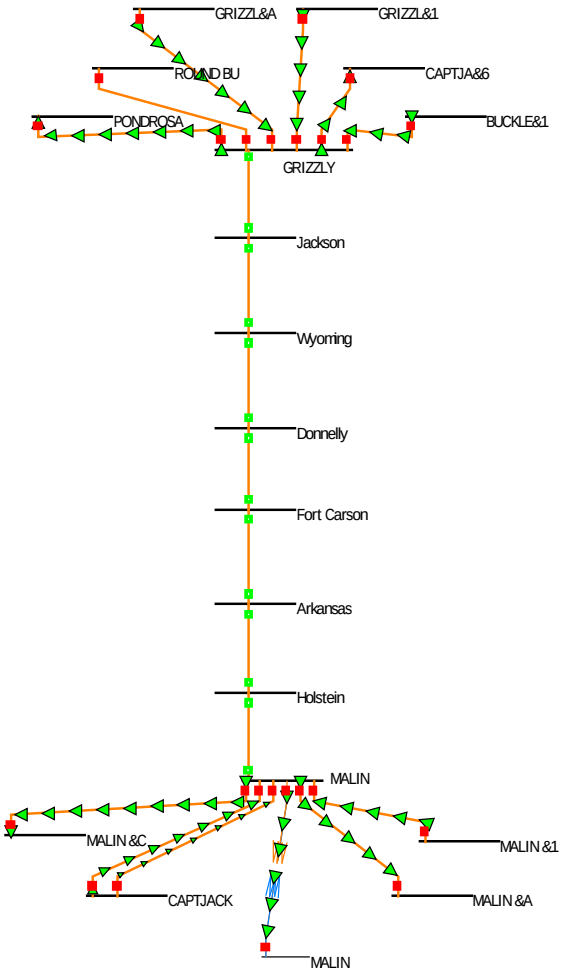
Voltage Control Loop covered in this section

Note: The Inner Power Flow Loop was covered in S1

MW Control Loop covered later

Pre-processing

- Angle Smoothing
  - Reduces large angle differences across transmission elements that have recently been closed to reduce initial power flow mismatches
  - If disabled, closing a line with a large angle difference often causes the power flow to diverge
  - Angle smoothing also works for a series of branches that are closed together
- Following a topology change, Simulator also adjusts zero-magnitude voltages in groups of buses connected by low impedance branches



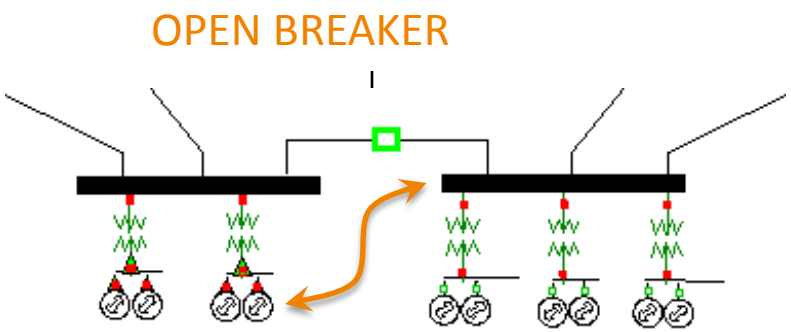
Pre-processing

- When pre-processing the voltage profile of a solution before solving, Simulator will now look at groupings of buses connected by very low impedances lines. If a bus in a grouping of energized buses has a zero voltage while other buses in the group do not, the zero voltage will be changed to the first non-zero voltage found in the grouping.

Pre-processing

- Generator Remote Regulation Viability
  - Checks for a viable transmission path between a generator bus and its remotely regulated bus
  - If a generator has no transmission path, or if all possible transmission routes to the regulated bus are intercepted by other voltage controlled buses, the generator is internally turned off of voltage regulation

If a generator on left is set to control voltage at the bus on the right, this would cause convergence difficulty



Pre-processing

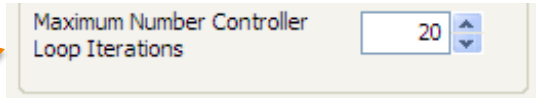
- Estimate MW Change
  - Stores the initial output of the generators for referencing during participation factor control
  - Modifies generator outputs in each area, super area, or island (depending on what control is being used) to meet approximate ACE requirements
  - Attempting to prevent slack bus from changing by drastic amounts during the first Newton-Raphson power flow calculation in the inner loop

MW Control Loop

- MW Control (Outer Loop)
  - Repeat
    - Voltage Controller Loop
      - Inner Power Flow Loop
    - Change generation/load to meet ACE requirements
      - Redispatches generation and/or load using the selected AGC control method for each area (Super area or island)
  - Until no more generation/load changes are required

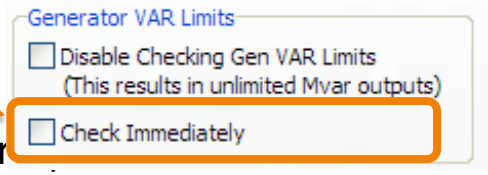
Power Flow and Control Loop

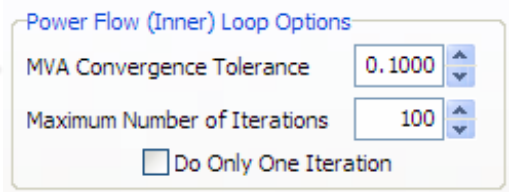
- Voltage control switching and Inner Power Flow Loop
  - Repeat
    - 1: Inner Power Flow loop
      - 1a: Continuous SVC Switching
    - 2: Generator MVAR Limit Checking
    - 3: DC Line Solution
    - 4: Switched Shunt Switching
    - 5: Discrete SVC Switching
    - 6: Transformer Switching
    - 7: D-FACTS Switching
  - Until no more control switching is required or maximum control loop iterations reached



Step 1: Inner Power Flow Loop
Step 1a: Continuous SVC Control

- Step 1: Inner Power Flow loop, Repeat…
  - Evaluate Mismatch
  - Generator MVAR output automatically calculated for PV buses
  - SVC MVAR output automatically calculated for continuous SVCs
  - Optionally (enforce Generator MVAR limits at each step)
  - Perform power flow step
    - » Newton's Method (this is in rectangular for
    - » Decoupled Power Flow
    - » Polar Form Newton's Method
- …Until no mismatch
- Step 1a: Continuous SVC Limit Check and Discrete Component Switching
  - Check MVAR limits on continuous SVCs
    - » SVSMO1 and SVSMO3
  - Switch any fixed shunts controlled by continuous SVCs
  - Goto Step 1 if any SVCs or controlled fixed shunts move





Step 2: Generator MVAR Limits
Step 3: Solve DC line equations

- Step 2: Generator MVAR Limit Check
  - Backs off or enforces MVAR limits
  - Checks for controller oscillation
    - » Generators that appear to be oscillating between control settings are internally set off of control
  - Updates mismatch and voltage vectors
    - » Incorporates voltage vector changes by processing each generator
- Step 3: Solve DC line equations
  - DC Lines will be discussed later, but to the power flow solution they look like a fixed MW injection with a Mvar injection that is a function of the AC line terminal voltages

Step 4: Switched Shunt Control

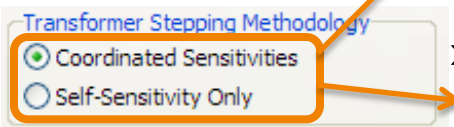
- Step 4: Switched shunt control
  - Checks regulated buses for voltage limit violations and adjusts switched shunt control appropriately
    - » Also can control the total VAR output for generators controlling the voltage at a particular bus (good for modeling a shunt that maintains VAR reserves)
    - » Shunts are adjusted one at a time with each shunt only considering its impact on the regulated bus' voltage. The interaction between different shunts is not modeled here.
  - Checks for controller oscillations
    - » Switched shunts that appear to be oscillating between control settings are internally set off of control
  - Updates mismatch and voltage vectors

Step 5: Discrete SVC Control

- Step 5: Discrete SVC Control
  - Only SVCs that are discrete-type SVCs are switched in this step
    - » SVSMO2
  - Checks regulated buses for voltage limit violations and adjusts SVC control appropriately
    - » Any fixed shunts controlled by the SVC are adjusted in this step
    - » SVCs are adjusted one at a time with each SVC only considering its impact on the regulated bus' voltage. The interaction between different SVCs is not modeled here.
  - Checks for controller oscillations
    - » SVCs that appear to be oscillating between control settings are internally set off of control
  - Updates mismatch and voltage vectors

Step 6: Transformer Switching

- Step 6: Transformer switching
  - Checks regulated Voltages, MVAR flows, and MW flows for limit violations and adjusts transformer controls in a manner dependent on the Transformer Stepping Methodology
    - » *Coordinated Sensitivities*: tap change calculation requires the construction and factorization of a full matrix dimensioned by the number of transformers which need to be switched. Normally a small number are changed.
    - » *Self-Sensitivity Only*: each transformer does not consider how it affects other transformers. This calculation is much faster, but may be less accurate and lead to more iterations
    - » Note: If more than 50 transformers are involved, Simulator always uses Self-Sensitivity Only
  - Checks for controller oscillations
    - » Transformers that appear to be oscillating between control settings are internally set off of control
  - Updates mismatch and voltage vectors

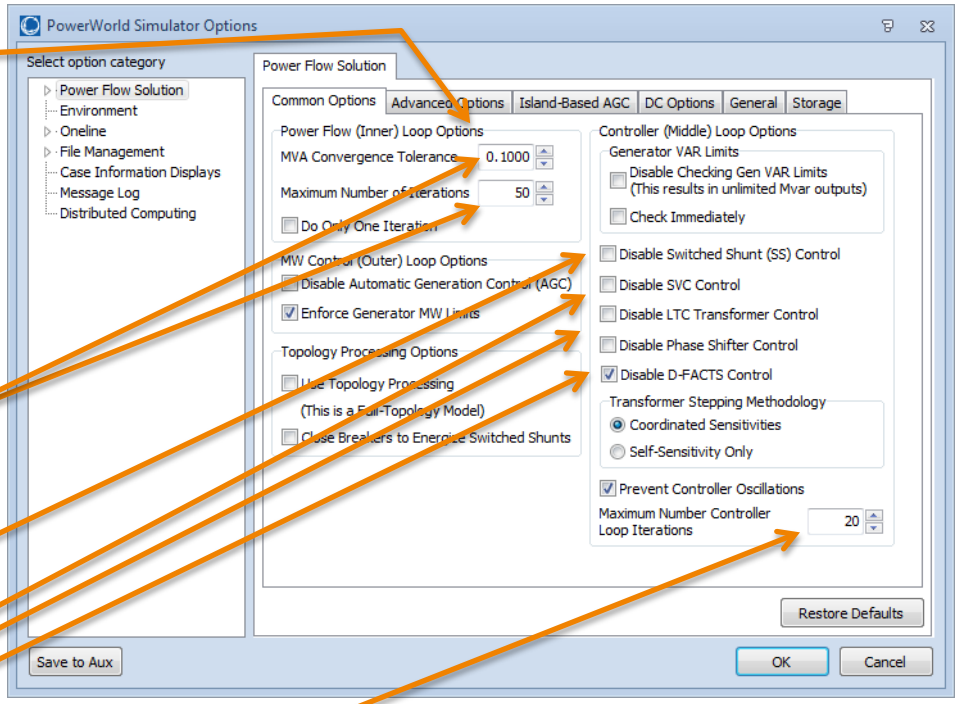


Step 7: D-FACTS Control

- Step 7: D-FACTS Control
  - D-FACTS devices attempt to keep the current on a branch within a specified range
  - Impedance of the D-FACTS is modified to adjust the current
  - D-FACTS that appear to be oscillating between control settings are internally set off of control
  - Updates Ybus with new impedance values

Complete Process

- Pre-processing
  - Angle Smoothing, Remote Viability Check, Area Generator Estimation
- Repeat (MW Control Loop)
  - Repeat (Controller Loop)
    - 1: Repeat (Inner Power Flow loop)
      - Evaluate Mismatch
      - Generator MVAR output automatically calculated for PV buses
      - SVC MVAR output automatically calculated for continuous SVCs
      - Optionally (enforce Generator MVAR limits at each step)
      - Perform power flow step
        - » Newton's Method
        - » Decoupled Power Flow
        - » Polar Newton
    - Until no more mismatch (or max iteration)
      - 1a: Continuous SVC Limit Check and Discrete Component Switching
      - Goto Step 1 until no more SVC switching
    - 2: Generator MVAR Limit Checking
    - 3: DC Line Solution
    - 4: Switched Shunt Control Switching
    - 5: Discrete SVC Switching
    - 6: Transformer Switching
    - 7: D-FACTS Switching
  - Until no more control switching is required (or at max iteration)
  - Change generation/load to meet ACE requirements
    - Redispatches generation/load using the AGC control method for area (island)
- Until no more generation changes are required



Example Message Log 1/2 (Image Only)

Area Loop Iteration #0

4 Inner Iterations

Voltage Loop Iteration #1

3 Inner Iterations

Voltage Loop Iteration #2

```
Starting Solution using Rectangular Newton-Raphson
AGC changed area NEVADA slack bus 18259 gen by -500.0MW
AGC changed area NORTHWEST slack bus 40296 gen by  500.3MW
Generation Change Estimate Completed.
Number:  0 Max P:  500.289 at bus 40296 Max Q:   0.038 at bus 44043
Number:  1 Max P:  268.380 at bus 18259 Max Q:  18.983 at bus 40296
Number:  2 Max P:   74.898 at bus 18259 Max Q:  18.821 at bus 40296
Number:  3 Max P:    5.093 at bus 18259 Max Q:   1.570 at bus 40296
Number:  4 Max P:    0.018 at bus 18259 Max Q:   0.002 at bus 40296
Gen(s) at bus 18259 at max vars
Gen(s) at bus 18282 at max vars
Gen(s) at bus 44271 has backed off var limit
Gen(s) at bus 45026 has backed off var limit
Gen(s) at bus 45246 at min vars
Gen(s) at bus 47660 has backed off var limit
Gen(s) at bus 66575 has backed off var limit
DC Line Flow Adjustment
Switched shunt at bus 40627 moved from   72.2 to    0.0 Mvars
Calculating Transformer Tap Sensitivities for 51 Transformers
Transformer 18004  TO  18034 CKT 1 tap ratio moved from 0.99239 to 0.97446
Transformer 18004  TO  18034 CKT 2 tap ratio moved from 0.99239 to 0.97446
Transformer 18011  TO  18145 CKT 1 tap ratio moved from 1.01028 to 1.00435
Transformer 45187  TO  45189 CKT 1 tap ratio moved from 0.95625 to 0.95000
Transformer 18002  TO  18001 CKT 1 phase moved from    8.1 to   13.2
   Changing impedance for transformer HA PS (18002)  TO  H ALLEN (18001) CKT 1 due to impedance correction table
   From  0.00067+j 0.04302 to  0.00070+j 0.04305
Transformer 18002  TO  18001 CKT 2 phase moved from    8.1 to   13.2
   Changing impedance for transformer HA PS (18002)  TO  H ALLEN (18001) CKT 2 due to impedance correction table
   From  0.00067+j 0.04302 to  0.00070+j 0.04305
Taps at 42 transformers adjusted
Finished voltage control loop iteration:  1
Number:  0 Max P:  432.135 at bus 18001 Max Q:  146.613 at bus 18004
Number:  1 Max P:   65.168 at bus 18001 Max Q:   38.007 at bus 18259
Number:  2 Max P:    0.464 at bus 64885 Max Q:    6.826 at bus 18259
Number:  3 Max P:    0.047 at bus 64885 Max Q:    0.037 at bus 18259
Gen(s) at bus 40344 has backed off var limit
Gen(s) at bus 40346 at max vars
Gen(s) at bus 40484 at max vars
Gen(s) at bus 45026 at max vars
Gen(s) at bus 45170 has backed off var limit
Gen(s) at bus 45246 has backed off var limit
DC Line Flow Adjustment
Calculating Transformer Tap Sensitivities for 33 Transformers
Transformer 12076  TO  12077 CKT 1 tap ratio moved from 1.07840 to 1.08462
Transformer 12090  TO  12091 CKT 1 tap ratio moved from 1.08125 to 1.08763
Transformer 62062  TO  62061 CKT 1 phase moved from  -40.3 to  -38.7
Taps at 18 transformers adjusted
Finished voltage control loop iteration:  2
```

Estimation of Generation

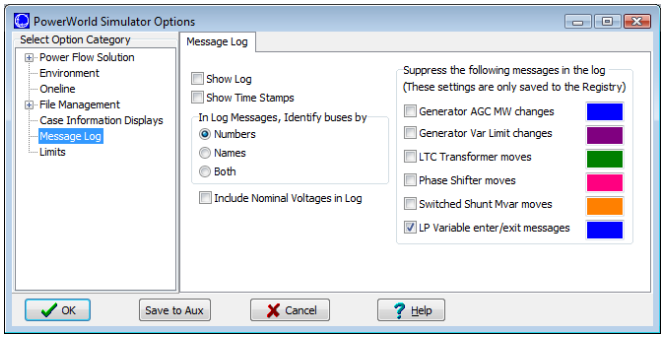
Inner Power Flow

One Voltage Control Iteration Consists Of

- Generator Var Limit Checking
- DC Transmission Line Adjustments
- Switched Shunt Mvar Changes
- Transformer Tap Ratio Changes
- Transformer Phase Angle Changes

Inner Power Flow

Colors of Messages determined by the Simulator, Message Log colors



Example Message Log 2/2 (Image Only)

3 Inner Iterations

Voltage Loop Iteration #3

2 Inner Iterations

Voltage Loop Iteration #4

Voltage Loop Iteration #5

Area Loop Iteration #1

2 Inner Iterations

```
Number:  0 Max P:  42.398 at bus 62061 Max Q:  166.572 at bus 40629
Number:  1 Max P:   0.109 at bus 62062 Max Q:    7.292 at bus 40346
Number:  2 Max P:   0.008 at bus 62062 Max Q:    0.111 at bus 40627
Gen(s) at bus 45026 has backed off var limit
Number:  3 Max P:   0.000 at bus 47097 Max Q:    0.000 at bus 66420
Switched shunt at bus 40877 moved from  10.2 to  0.0 Mvars
Calculating Transformer Tap Sensitivities for 22 Transformers
Transformer 18028  TO  18117 CKT 1 tap ratio moved from 0.93859 to 0.94457
Transformer 40627  TO  40625 CKT 1 tap ratio moved from 0.97230 to 0.98143
Transformer 40627  TO  40625 CKT 2 tap ratio moved from 0.97230 to 0.98143
Taps at 3 transformers adjusted
Finished voltage control loop iteration:  3
Number:  0 Max P:   5.432 at bus 40627 Max Q:   66.306 at bus 40627
Number:  1 Max P:   0.034 at bus 40625 Max Q:    0.229 at bus 40625
Gen(s) at bus 44271 at max vars
Gen(s) at bus 45026 at max vars
Number:  2 Max P:   0.002 at bus 41213 Max Q:    0.003 at bus 40625
Gen(s) at bus 47290 has backed off var limit
Calculating Transformer Tap Sensitivities for 20 Transformers
Finished voltage control loop iteration:  4
Number:  0 Max P:   0.002 at bus 41213 Max Q:    0.031 at bus 47290
Number:  1 Max P:   0.002 at bus 41213 Max Q:    0.031 at bus 47290
Calculating Transformer Tap Sensitivities for 20 Transformers
Finished voltage control loop iteration:  5
AGC changed area NEW MEXICO slack bus 10321 gen by   1.5MW
AGC changed area ARIZONA slack bus 15926 gen by   6.9MW
AGC changed area NEVADA slack bus 18259 gen by   7.8MW
AGC changed area SOCALIF slack bus 24004 gen by  -6.9MW
AGC changed area NORTHWEST slack bus 40296 gen by  -10.0MW
AGC changed area IDAHO slack bus 60100 gen by  -7.0MW
AGC changed area MONTANA slack bus 62048 gen by  -3.6MW
AGC changed area PACE slack bus 66055 gen by  -12.5MW
Generation Adjustment Completed.
Number:  0 Max P:  12.478 at bus 66055 Max Q:    0.002 at bus 26003
Number:  1 Max P:   0.364 at bus 66055 Max Q:    1.747 at bus 18259
Number:  2 Max P:   0.004 at bus 66055 Max Q:    0.023 at bus 30982
Calculating Transformer Tap Sensitivities for 18 Transformers
Transformer 50462  TO  51239 CKT 1 can not effectively control voltage at bus 51239; control will be ignored until the tap sensitivity magnitude incre
Transformer 59246  TO  56249 CKT T1 can not effectively control voltage at bus 56249; control will be ignored until the tap sensitivity magnitude inc
Finished voltage control loop iteration:  1
Number:  0 Max P:   0.398 at bus 18259 Max Q:    0.425 at bus 26003
Number:  1 Max P:   0.000 at bus 16115 Max Q:    0.008 at bus 30985
Calculating Transformer Tap Sensitivities for 20 Transformers
Finished voltage control loop iteration:  1
Solution Finished in   4.522 Seconds
Simulation: Successful Power Flow Solution
Starting Solution using Rectangular Newton-Raphson
```

Inner Power Flow

Check Immediately Mvar Limit Checking

Inner Power Flow

Check Immediately Mvar Limit Checking

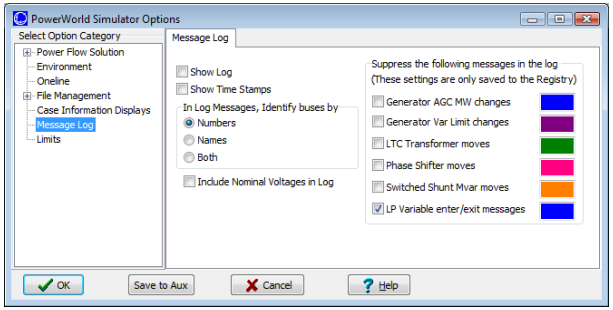
Inner Power Flow

Area Automatic Generation Control Iteration

Inner Power Flow

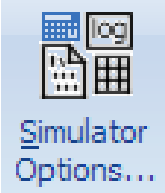
Inner Power Flow

Colors of Messages determined by the Simulator, Message Log colors

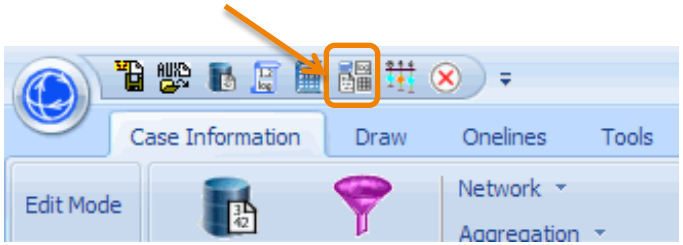


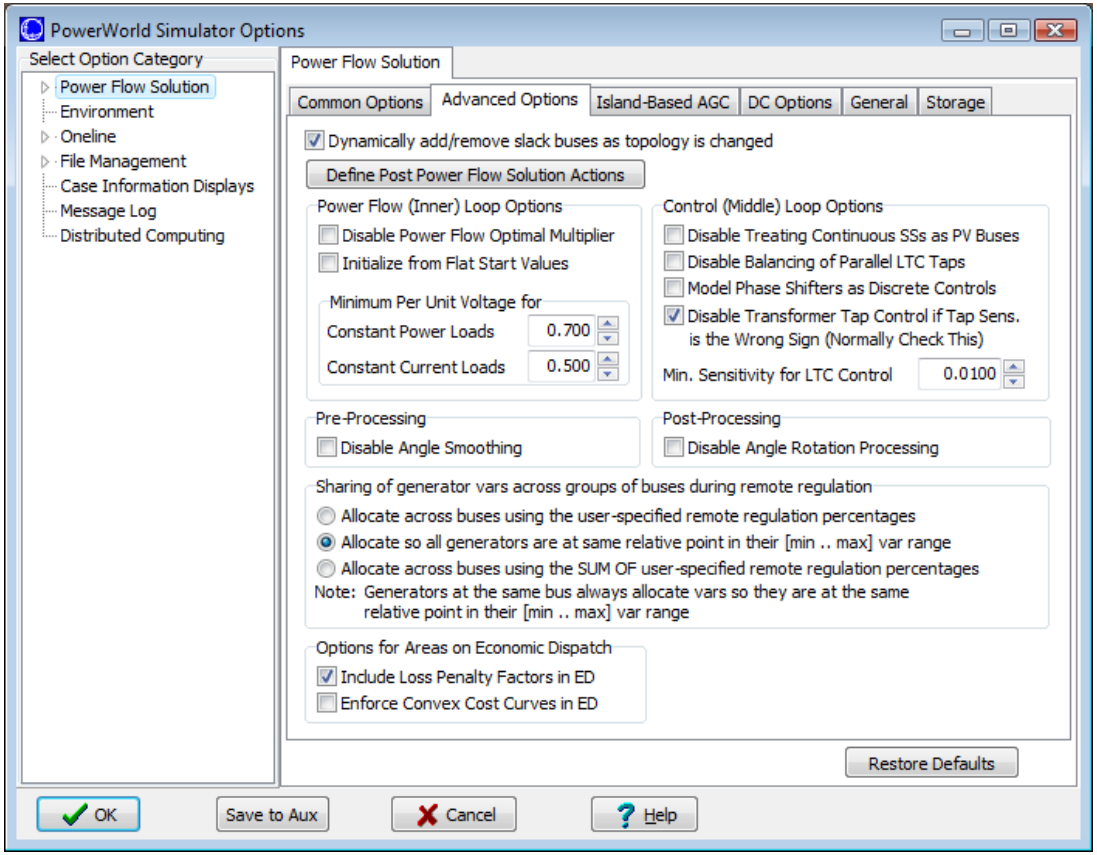
Advanced Options for Power Flow Solution

- To customize the power flow solution, go to the **Options** ribbon tab and select **Simulator Options →Power Flow Solution** page
  - Advanced Options Tab



Also on the
Quick Access Toolbar

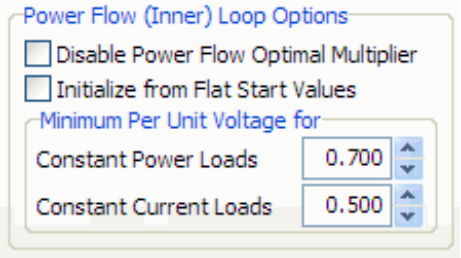




Simulator Options: Power Flow Solution Page

- Advanced Options Tab
  - Dynamically add/remove slack buses as topology is changed (Allow Multiple Islands)
    - If a single island is split into two islands (by opening lines), then a new slack bus is chosen (usually generator with the largest MW limit that regulates its terminal bus)
  - Post Power Flow Solution Actions
    - Allow you to define a list of conditional actions (much like a contingency definition) which occur at the end of *EVERY* power flow solution
    - An example would be loads that are automatically taken out of service when the voltage drops too low

Simulator Options: Power Flow Solution Page



- Advanced Options Tab
  - Disable Power Flow Optimal Multiplier
    - The optimal multiplier is a mathematically calculated step size for Newton's Method that prevents the mismatch equations from increasing between iterations
  - Initialize From Flat Start Values
    - Always starts power flow solution with voltages and angles set to specific values
    - Generator buses or buses regulated by a generator are set to the setpoint voltage of the generator
    - 1.0 per unit for all other buses
    - Angles equal to the slack bus angle (not recommended)
  - Minimum Per Unit Voltage for Constant Power Loads and Constant Current Loads
    - At voltages less than the defined values, the constant power and constant current loads will be reduced
    - To disable either of these features, set the values to 0

Minimum Per Unit Voltage for Constant Power and Current Loads

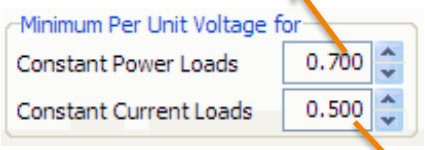
- When a bus voltage is below these thresholds the constant power or current load will gradually decrease to zero MW at zero voltage
  - Constant Power Loads
    - Uses a cosine function
  - Constant Current Loads
    - Uses a sine function multiplied by voltage
- Functions are chosen so that the derivative of the load with respect to voltage is continuous

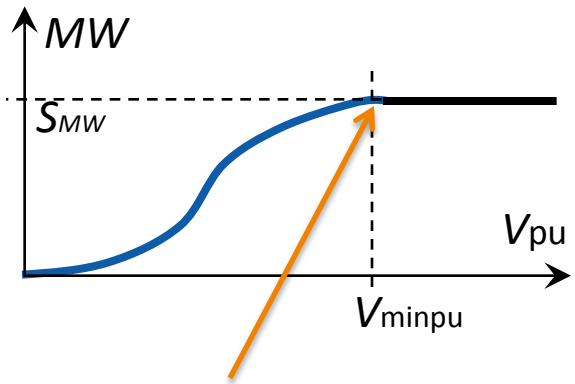
Minimum Per Unit Voltage for Constant Power and Current Loads

- Minimum Per Unit Voltage for Constant Power

$$MW(V_{pu}) = \frac{S_{MW}}{2}\left(1 - \cos\left(\frac{\pi V_{pu}}{\boxed{V_{S\min pu}}}\right)\right)$$

(Default Values are 0.7 and 0.5)

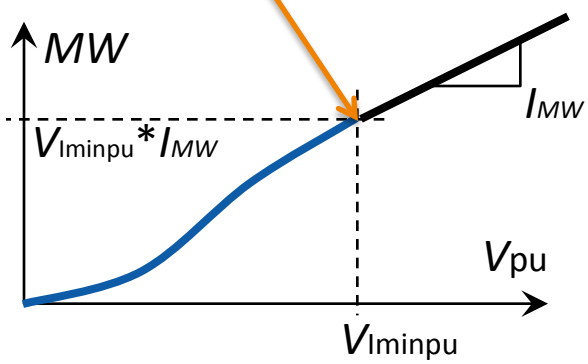




Derivatives with respect to voltage remains continuous at min per unit value

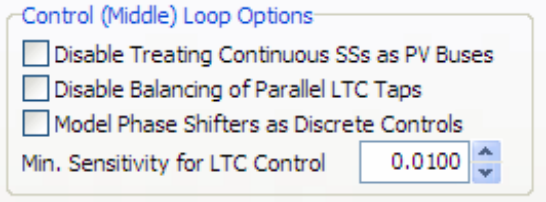
- Minimum Per Unit Voltage for Constant Current

$$MW(V_{pu}) = I_{MW} V_{pu} \sin\left(\frac{\pi}{2}\frac{V_{pu}}{\boxed{V_{I\min pu}}}\right)$$



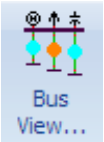
Simulator Options: Power Flow Solution Page

- Advanced Options Tab
  - Disable Treating Continuous SSs as PV Buses
    - Continuous switched shunts are normally treated as buses with fixed real power and voltage inside the inner power flow loop
  - Disable Balancing of Parallel LTC taps
    - Parallel LTC taps normally have their tap values synchronized to prevent circulating var flow
  - Model Phase Shifters as Discrete Controls
    - Phase shifters will switch tap positions discretely based on the tap step size
    - Normally users do not model the discrete properties of the phase-shifters. Including this can slow power flow solution.
  - Min. Sensitivity for LTC Control
    - Transformers with a sensitivity lower than this will be disabled

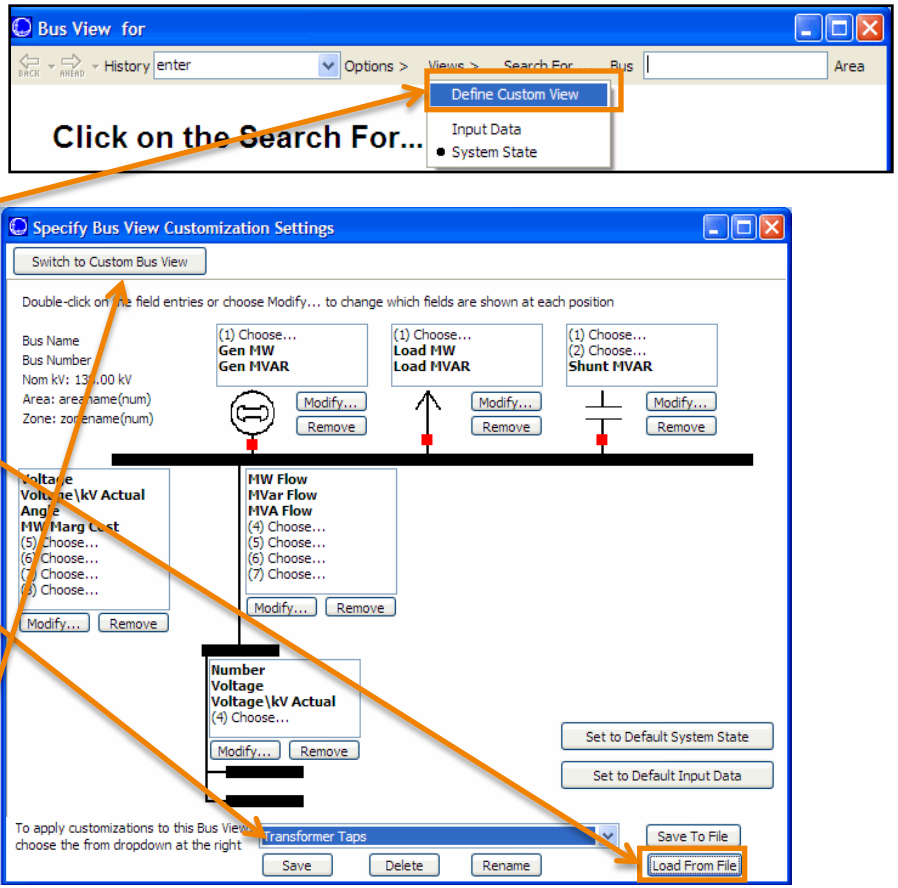


Example: Parallel Tap Balancing and Minimum Tap Sensitivity

- Choose Open Case
  - *…\S02_AdvancedPowerFlow\AdvancedOptions.raw*
- Do NOT solve yet
- Open the Bus View



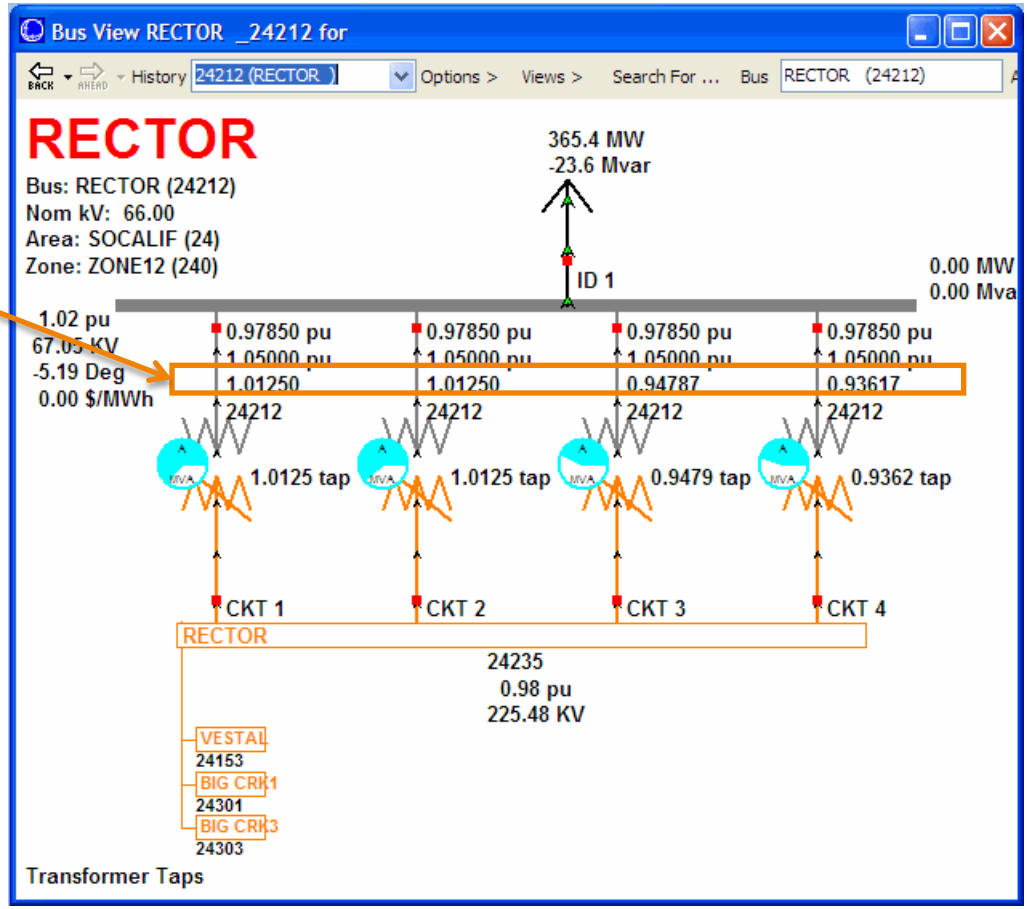
  - Choose **Views > Define Custom View**
  - Click **Load From File** (in Bottom Right)
  - Open *BusViewTaps.aux*
  - Choose **Transformer Taps** From the Customizations
  - Click **Switch to Custom Bus View**



Parallel Tap Balancing

- On Bus View, go to Bus : RECTOR (24212)

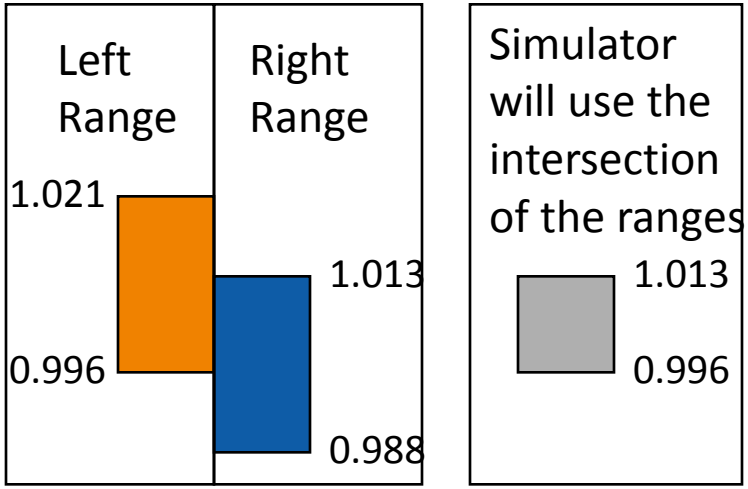
Parallel Transformers should have the same tap ratios



Parallel Tap Balancing and Regulation Range Correction

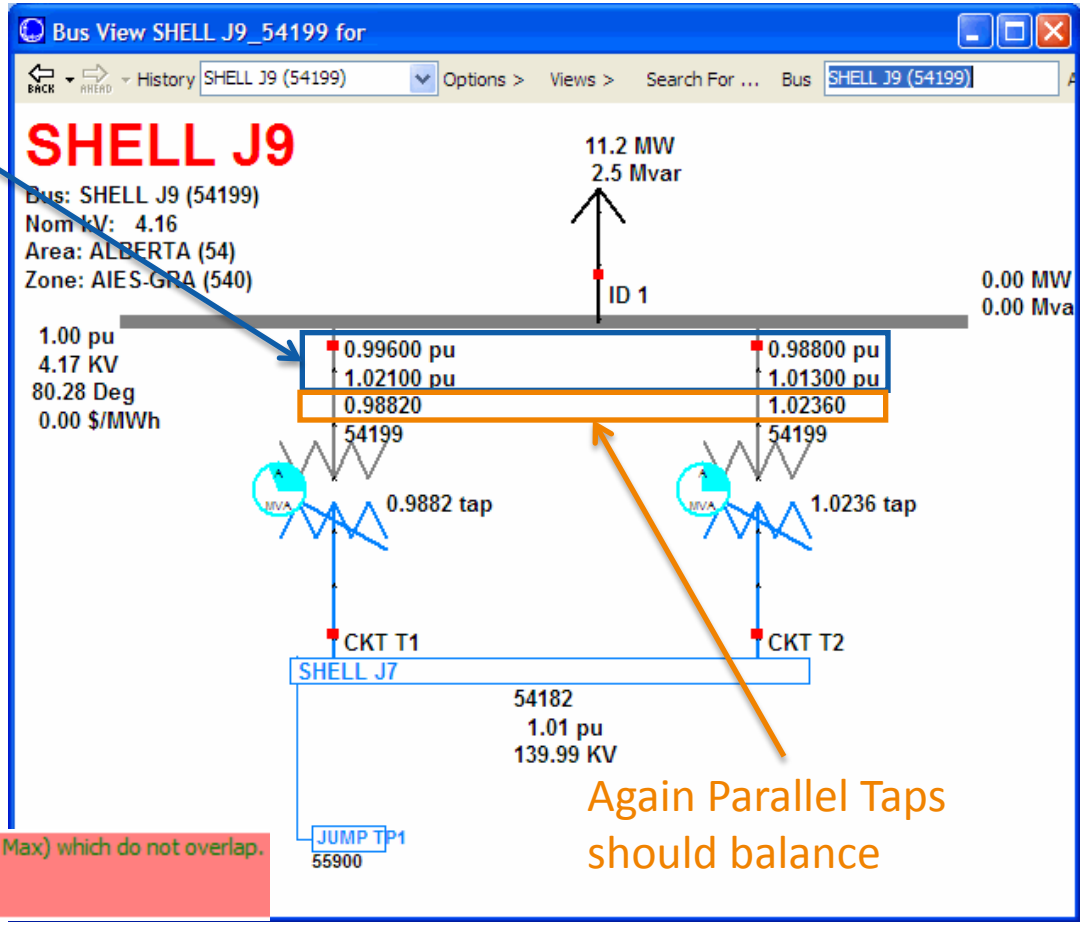
- On Bus View, go to Bus : SHELL J9 (54199)

Two Transformers Regulate the same bus (54199), but have different regulation ranges



If no intersection, then control turned off

Error: The following parallel transformers have control ranges (Reg Min - Reg Max) which do not overlap.
Transformer 16102 TO 10382 CKT 2 has been turned off control.
Transformer 16102 TO 10382 CKT 1 has been turned off control.



Again Parallel Taps should balance

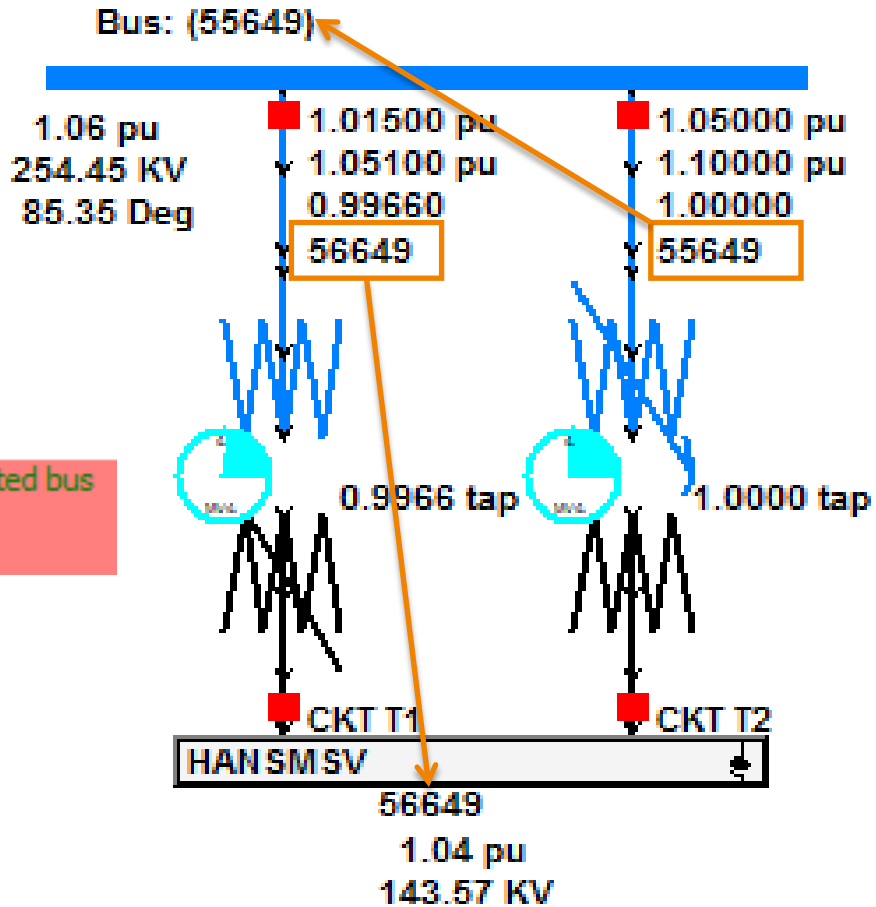
Parallel Taps Regulated Bus Error Checking

Note: Sample case does not have this problem. Slide is just example

- Parallel transformer taps which do not have the same regulated bus
  - Transformer will be turned off control if this occurs
  - Log message will be shown

Error: The following parallel transformers do not share the same regulated bus
Transformer 55649 TO 56649 CKT T2 has been turned off control.
Transformer 56649 TO 55649 CKT T1 has been turned off control.

  - Also allow control if the regulated buses are within the a group of buses connected by very low impedance branches

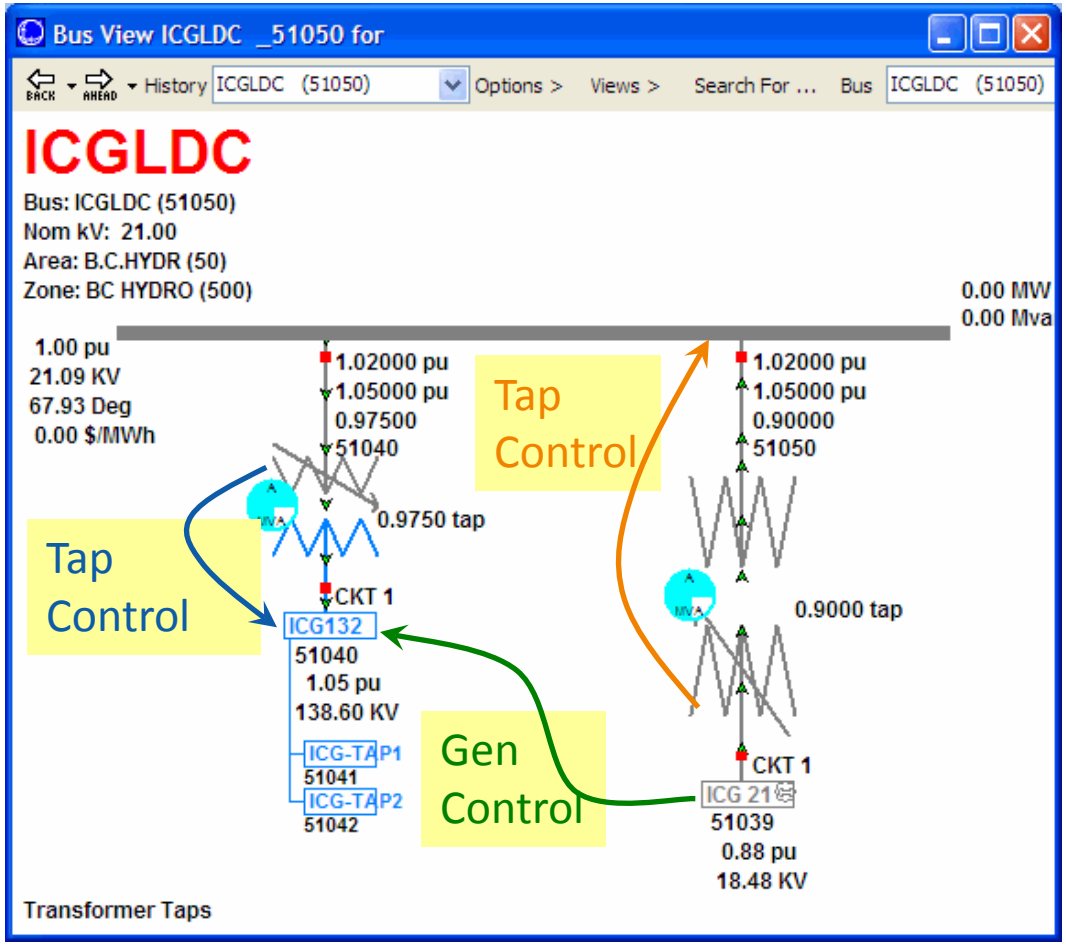


Minimum Tap Sensitivity

- On Bus View, go to Bus : ICGLDC (51050)

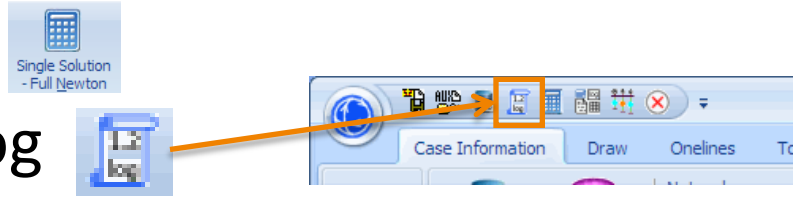
Because the Generator at bus 51039 controls the voltage at bus 51040,
The two transformer taps will not be able to influence their voltages

Taps will only be useful when generator hits its Mvar limits



What Simulator does with these

- Click Single Solution
- Open the Message Log



Message Log: Transformer Options.raw

```
Starting Solution using Rectangular Newton-Raphson
Transformer 52220 TO 52161 CKT 1 has a TapMin to TapMax range which is greater than 0.9. Transformer has been turned off control.
Transformer 52220 TO 52162 CKT 2 has a TapMin to TapMax range which is greater than 0.9. Transformer has been turned off control.
Transformer 52221 TO 52163 CKT 3 has a TapMin to TapMax range which is greater than 0.9. Transformer has been turned off control.
Transformer 52221 TO 52164 CKT 4 has a TapMin to TapMax range which is greater than 0.9. Transformer has been turned off control.
Number: 0 Max P: 1106.130 at bus 45040 Max Q: 396.771 at bus 26048
Number: 1 Max P: 2.438 at bus 26048 Max Q: 6.231 at bus 26048
Number: 2 Max P: 0.000 at bus 14012 Max Q: 0.001 at bus 62057
 Transformer 24008 TO 24007 CKT 1 tap ratio moved from 0.96579 to 0.96054 to balance with parallel LTCs
 Transformer 24016 TO 24201 CKT 1 tap ratio moved from 0.96800 to 0.95595 to balance with parallel LTCs
```

etc...

```
Transformer 24235 TO 24212 CKT 3 tap ratio moved from 0.94787 to 0.97128 to balance with parallel LTCs
Transformer 24235 TO 24212 CKT 2 tap ratio moved from 1.01250 to 0.96250 to balance with parallel LTCs
Transformer 24235 TO 24212 CKT 1 tap ratio moved from 1.01250 to 0.96250 to balance with parallel LTCs
```

RECTOR

etc...

```
The following parallel transformers have control ranges (Reg Min - Reg Max) that are not the same.
Reg range of 0.99600-1.01300 is being used for all (intersection of the control ranges).
   Transformer 54182 TO 54199 CKT T2 Reg Range specified: 0.98800-1.01300
   Transformer 54182 TO 54199 CKT T1 Reg Range specified: 0.99600-1.02100
```

SHELL J9

etc...

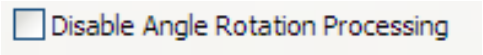
```
Calculating Transformer Tap Sensitivities for 24 Transformers
Transformer 51039 TO 51050 CKT 1 can not effectively control voltage at bus 51050; control will be ignored until the tap sensitivity magnitude increases
Transformer 51050 TO 51040 CKT 1 can not effectively control voltage at bus 51040; control will be ignored until the tap sensitivity magnitude increases
Transformer 54617 TO 54853 CKT 1T can not effectively control voltage at bus 54617; control will be ignored until the tap sensitivity magnitude increases
Finished voltage control loop iteration: 1
Number: 0 Max P: 1.899 at bus 24201 Max Q: 42.946 at bus 54118
Number: 1 Max P: 0.006 at bus 24201 Max Q: 0.060 at bus 24201
```

ICGLDC

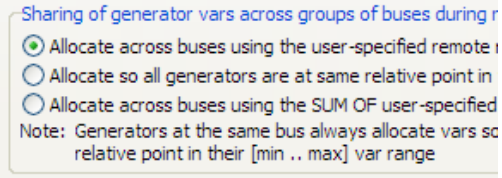
etc...

Simulator Options: Power Flow Solution Page

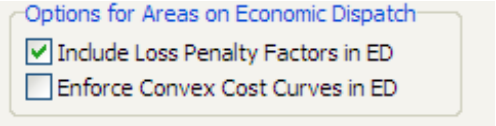
- Advanced Options Tab
  - Disable Angle Rotation Processing



    - Voltage angles are rotated so that the angle range in an island is equally spaced around zero degrees if any angles fall outside +/- 160 degrees
  - Sharing of generator vars across groups of buses



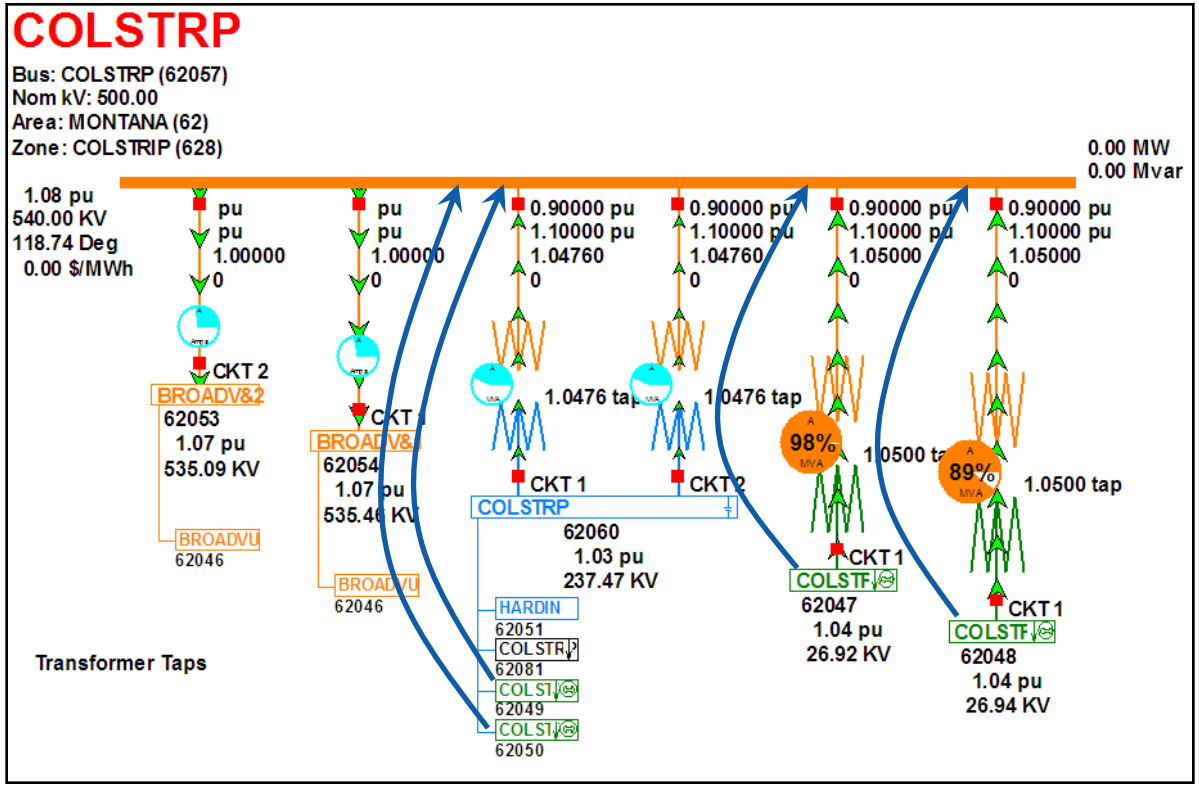
    - Allocate across buses using the user-specified remote regulation percentages
    - Allocate so all generators are at same relative point in their [min..max] var range
    - Allocate across buses using the SUM OF user-specified remote regulation percentages
  - Options for Areas on Economic Dispatch



    - Include Loss Penalty Factors in ED will consider losses in determining the dispatch
    - Enforce Convex Cost Curves in ED will turn units that are operating outside the convex portion of their cost curve off automatic control

Sharing of Generator Vars across a group of buses

- On Bus View, go to Bus : COLSTRP (62057)
  - Generators at 62047, 62048, 62049, 62050 all regulate the voltage at this bus



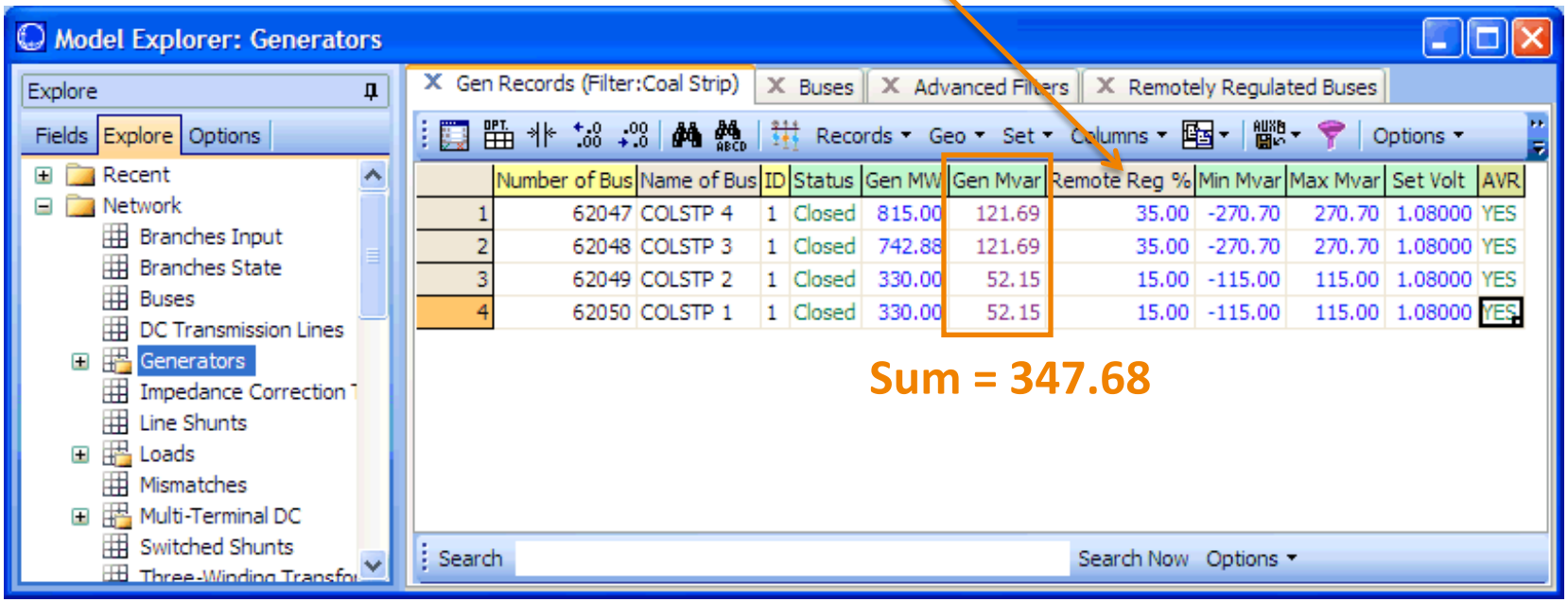
Var "Responsibility" Sharing

- Go to Model Explorer
  - Navigate to Network → Generators
  - Present setting is to "Allocate across buses using the user-specified remote regulation percentages"

Sharing of generator vars across groups of buses during remote regulation

- (•) Allocate across buses using the user-specified remote regulation percentages
- ( ) Allocate so all generators are at same relative point in their [min .. max] var range
- ( ) Allocate across buses using the SUM OF user-specified remote regulation percentages

Note: Generators at the same bus always allocate vars so they are at the same relative point in their [min .. max] var range



	Number of Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Remote Reg %	Min Mvar	Max Mvar	Set Volt	AVR
1	62047	COLSTP 4	1	Closed	815.00	121.69	35.00	-270.70	270.70	1.08000	YES
2	62048	COLSTP 3	1	Closed	742.88	121.69	35.00	-270.70	270.70	1.08000	YES
3	62049	COLSTP 2	1	Closed	330.00	52.15	15.00	-115.00	115.00	1.08000	YES
4	62050	COLSTP 1	1	Closed	330.00	52.15	15.00	-115.00	115.00	1.08000	YES

Sum = 347.68

Var "Responsibility" Sharing using Remote Reg %

- If you modify the values for *Min Mvar* and *Max Mvar*, the *Gen Mvar* values will not change
  - Change the *Max Mvar* value for generator at bus 62047 to 150 Mvar

	Number of Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Remote Reg %	Min Mvar	Max Mvar	Set Volt	AVR
1	62047	COLSTP 4	1	Closed	815.00	121.69	35.00	-270.70	150.00	1.08000	YES
2	62048	COLSTP 3	1	Closed	742.88	121.69	35.00	-270.70	270.70	1.08000	YES
3	62049	COLSTP 2	1	Closed	330.00	52.15	15.00	-115.00	115.00	1.08000	YES
4	62050	COLSTP 1	1	Closed	330.00	52.15	15.00	-115.00	115.00	1.08000	YES

  - Click Single Solution
  - No change in *Gen Mvar* outputs are seen
  - Change the *Max Mvar* value for generator at bus 62047 back to 270.7 Mvar

	Number of Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Remote Reg %	Min Mvar	Max Mvar	Set Volt	AVR
1	62047	COLSTP 4	1	Closed	815.00	121.69	35.00	-270.70	270.70	1.08000	YES
2	62048	COLSTP 3	1	Closed	742.88	121.69	35.00	-270.70	270.70	1.08000	YES
3	62049	COLSTP 2	1	Closed	330.00	52.15	15.00	-115.00	115.00	1.08000	YES
4	62050	COLSTP 1	1	Closed	330.00	52.15	15.00	-115.00	115.00	1.08000	YES

Var "Responsibility" Sharing using relative [min..max] var range

- Open the Simulator Options Dialog again
  - Go to Power Flow Options, Advanced Options
  - Change to "Allocate so all generators are at same relative point in their [min..max] var range"
  - Click Single Solution
  - Not much change now because the Var Range Ratio is the same as the Remote Reg % values

$$\frac{270.70}{115.00} = \frac{0.35}{0.15}$$

  - To see the different behavior, change *Min Mvar* and *Max Mvar* values

Var "Responsibility" Sharing using relative [min..max] var range

- If you modify the values for *Min Mvar* and *Max Mvar*, the *Gen Mvar* values will change
  - Change the *Max Mvar* value for generator at bus 62047 to 150 Mvar

	Number of Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Remote Reg %	Min Mvar	Max Mvar	Set Volt	AVR
1	62047	COLSTP 4	1	Closed	815.00	61.26	35.00	-270.70	150.00	1.08000	YES
2	62048	COLSTP 3	1	Closed	742.88	156.50	35.00	-270.70	270.70	1.08000	YES
3	62049	COLSTP 2	1	Closed	330.00	66.48	15.00	-115.00	115.00	1.08000	YES
4	62050	COLSTP 1	1	Closed	330.00	66.48	15.00	-115.00	115.00	1.08000	YES

$$\frac{61.26-(-270.7)}{150.0-(-270.7)}=0.789$$

$$\frac{156.5-(-270.7)}{270.7-(-270.7)}=0.789$$

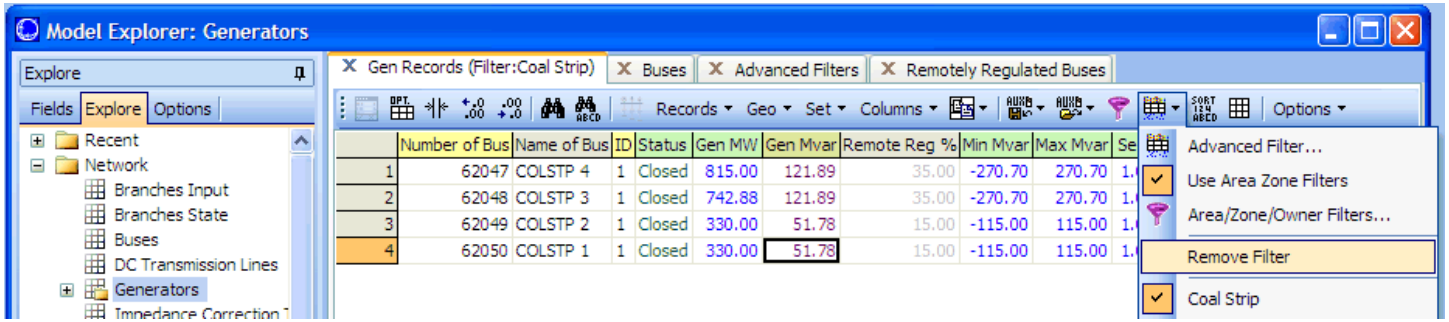
$$\frac{66.48-(-115.0)}{115.0-(-115.0)}=0.789$$

  - Click Single Solution
  - *Gen Mvar* outputs change
    - We enforce constant ratio of

$$\frac{\text{GenMvar}-\text{MinMvar}}{\text{MaxMvar}-\text{MinMvar}}=\text{Constant}$$

Var "Responsibility" Sharing

- The Var Sharing option only applies to generators that have different terminal buses
- For a group of generators that have the same terminal bus, PowerWorld will always allocate the Mvar values using the "relative [min..max] var range" method
- See bus GHOST A9 (54171) for an example
  - Go back to the Model Explorer, Network Generators
  - Remove the Advanced Filter "Coal Strip"

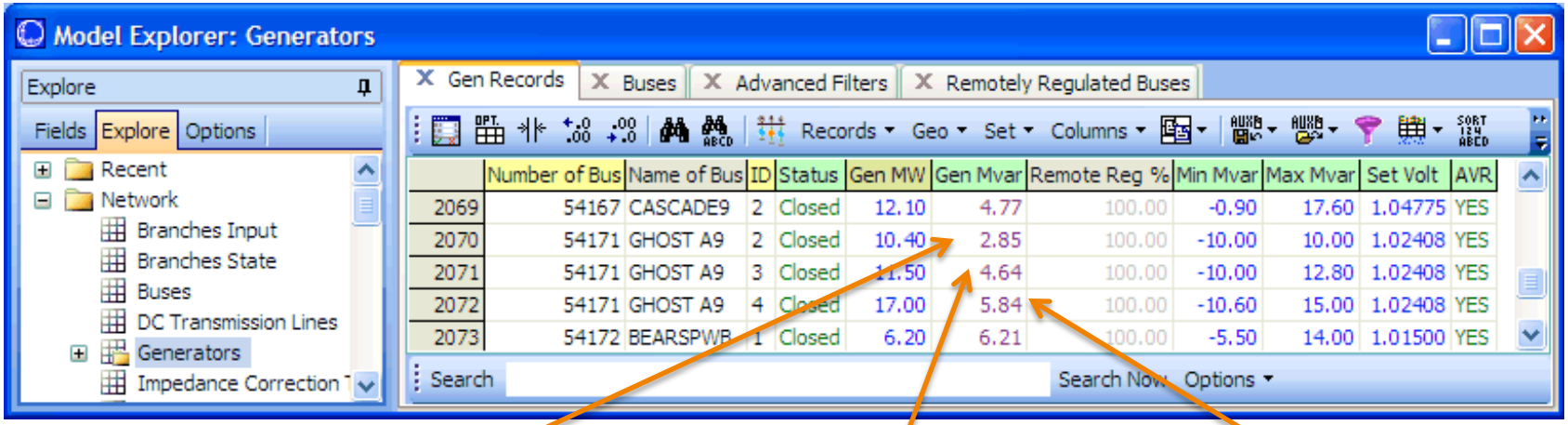


  - Navigate to find GHOST A9 (54171)

Var "Responsibility" Sharing

- Generator at same bus GHOST A9 (54171) are obeying the ratio

$$\frac{\text{GenMvar} - \text{MinMvar}}{\text{MaxMvar} - \text{MinMvar}} = \text{Constant}$$

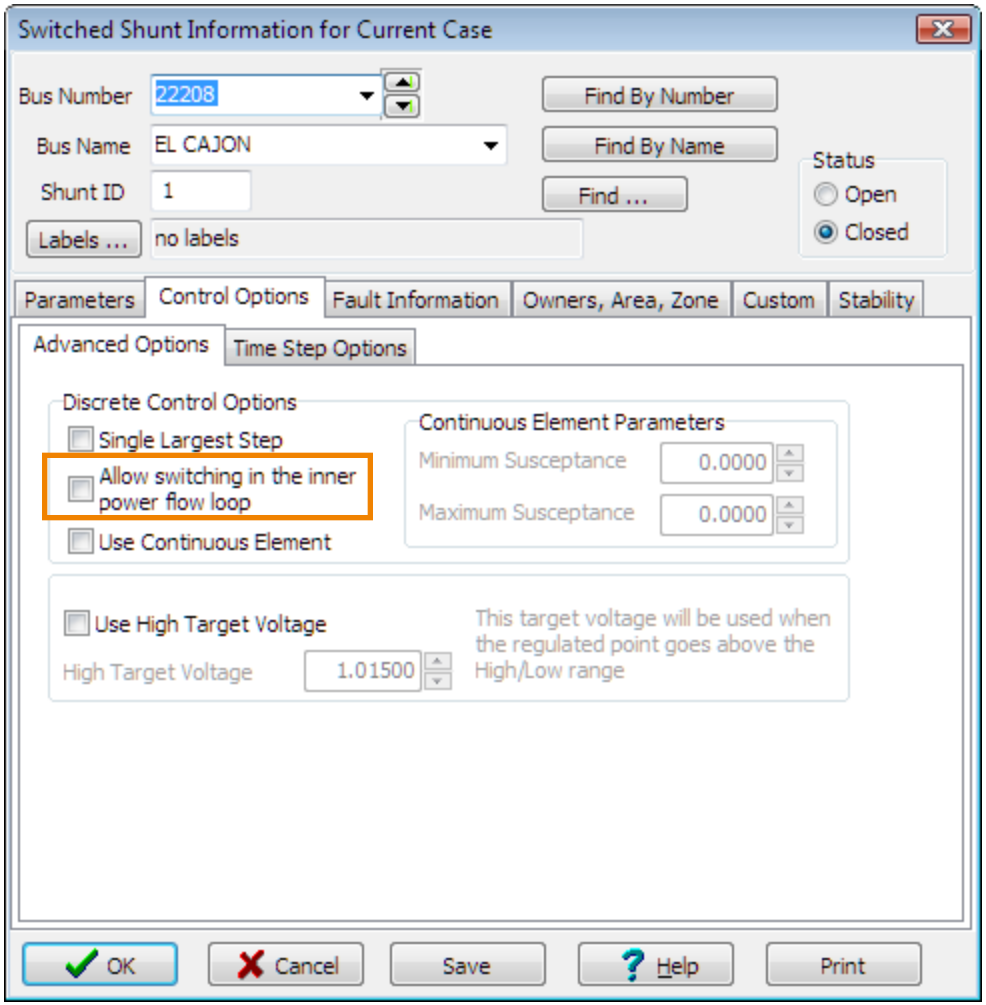


	Number of Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Remote Reg %	Min Mvar	Max Mvar	Set Volt	AVR
2069	54167	CASCADE9	2	Closed	12.10	4.77	100.00	-0.90	17.60	1.04775	YES
2070	54171	GHOST A9	2	Closed	10.40	2.85	100.00	-10.00	10.00	1.02408	YES
2071	54171	GHOST A9	3	Closed	11.50	4.64	100.00	-10.00	12.80	1.02408	YES
2072	54171	GHOST A9	4	Closed	17.00	5.84	100.00	-10.60	15.00	1.02408	YES
2073	54172	BEARSPWB	1	Closed	6.20	6.21	100.00	-5.50	14.00	1.01500	YES

$$\frac{2.85-(-10.0)}{10.0-(-10.0)} = 0.642 \qquad \frac{4.64-(-10.0)}{12.8-(-10.0)} = 0.642 \qquad \frac{5.84-(-10.6)}{15.0-(-10.6)} = 0.642$$

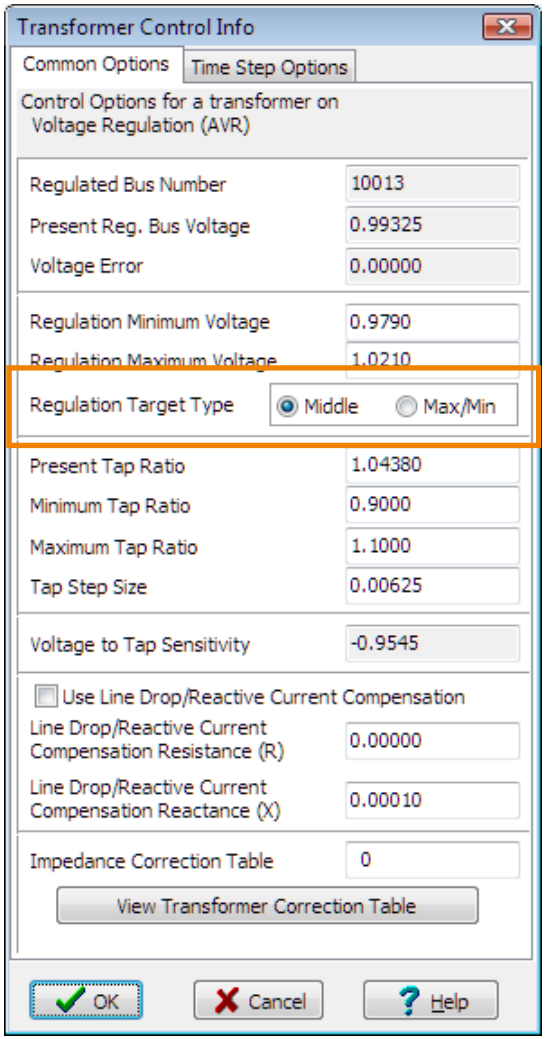
Power Flow Solution: Switched Shunt-Specific Features

- Each Switched Shunt has an option to allow it to switch during the inner power flow loop
  - This allows discrete switched shunts to be treated as PV buses initially and then revert back to discrete shunts after an initial solution
  - Reverting back to discrete shunts is done in Step 1a of the overall power flow solution process. This will cause additional inner power flow loop iterations.



Power Flow Solution: Transformer-Specific Features

- With each transformer, a field called "Regulation Range Target Type" is available
  - Choices are
    - Middle of Reg Range
    - Max/Min of Reg Range
  - Determines what the "target" is for the transformer control when it is not meeting its regulation range



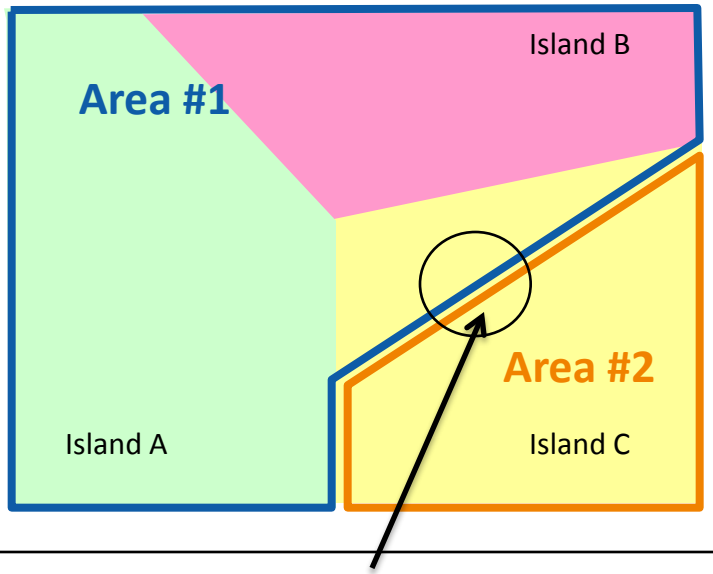
Area Control with Multiple Islands

- When an area spans multiple electric islands, the MW Interchange Control for that area may not be possible
- An error check is done to allow for more complex situations
  - An area that belongs to multiple islands can be placed on control only if at most one of these islands contains multiple areas

Areas Spanning Multiple Islands: Example for Area #1 Control

Control Allowed

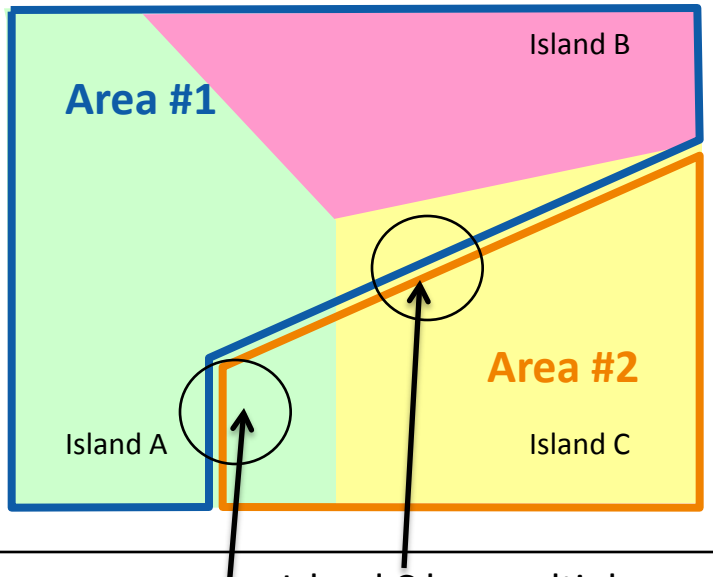
Only Island C has multiple areas



Island C has multiple areas

Control NOT Allowed

Island A and Island C have multiple areas



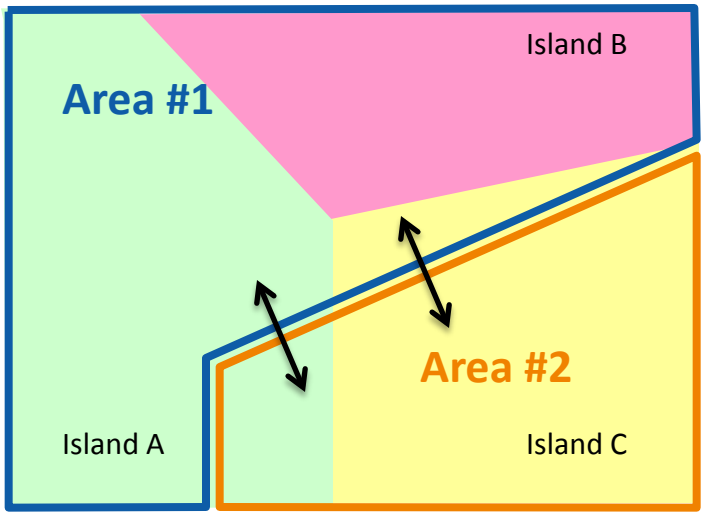
Island C has multiple areas

Island A has multiple areas

This situation occurs for WAPA and ERCOT in Eastern Interconnect cases

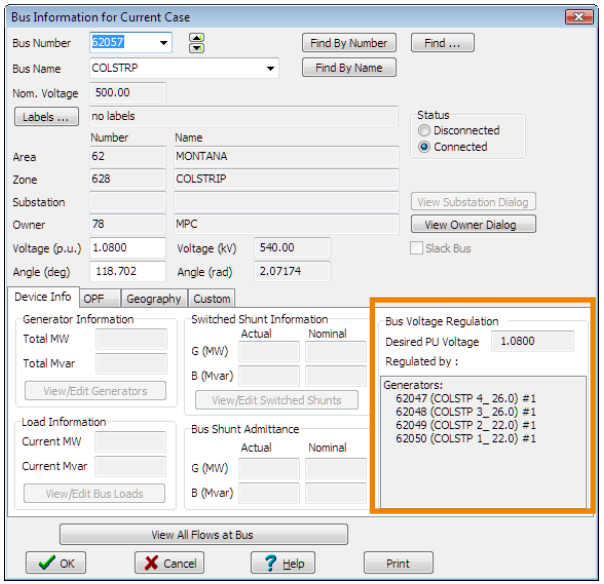
Areas Spanning Multiple Islands : Why control is NOT Allowed

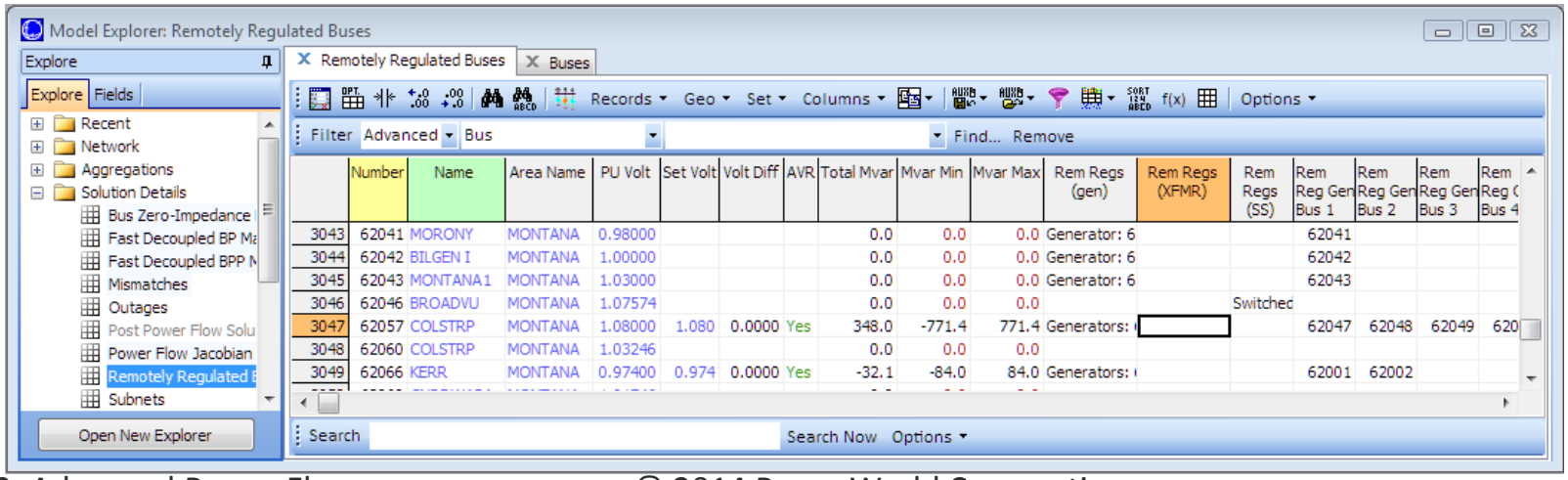
- Not allowed because Simulator doesn't have enough information to know which generators should respond when transactions are specified
  - For example: Area 1 – Area 2 transfer
  - Should transfer occur in Island A or Island C?
    - Because Simulator doesn't know, control is NOT allowed



Power Flow Solution: Solution Diagnosis Aids

- Displays for showing which devices remotely regulate a particular bus are available (generators, LTCs, and shunts)
  - Appears on Run Mode Bus dialog
  - On Model Explorer under **Solution Details\Remotely Regulated Buses** display

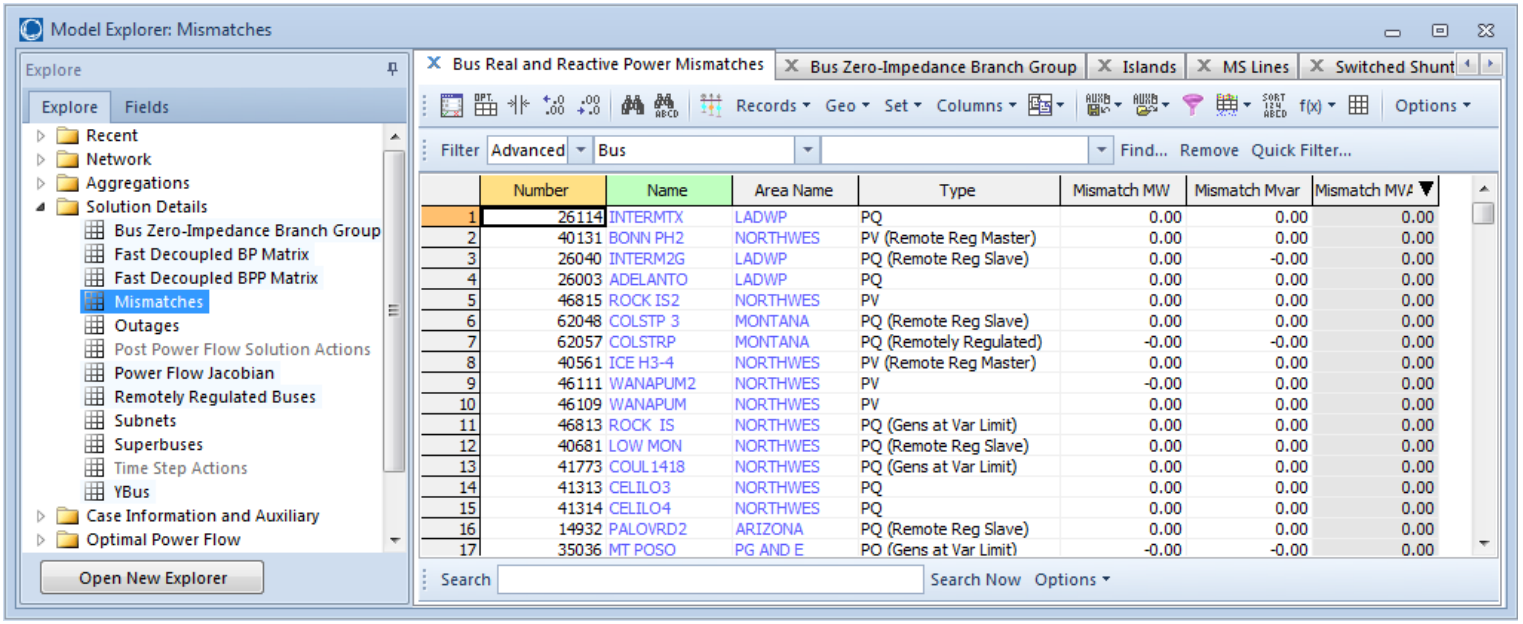




Power Flow Solution: Solution Diagnosis Aids

- There is a field for buses called **Solution\Type (PV, PQ, Slack, etc.)**
  - Descriptive strings to better help understand the power flow solution
  - Column is shown by default on **Network\Mismatches** table

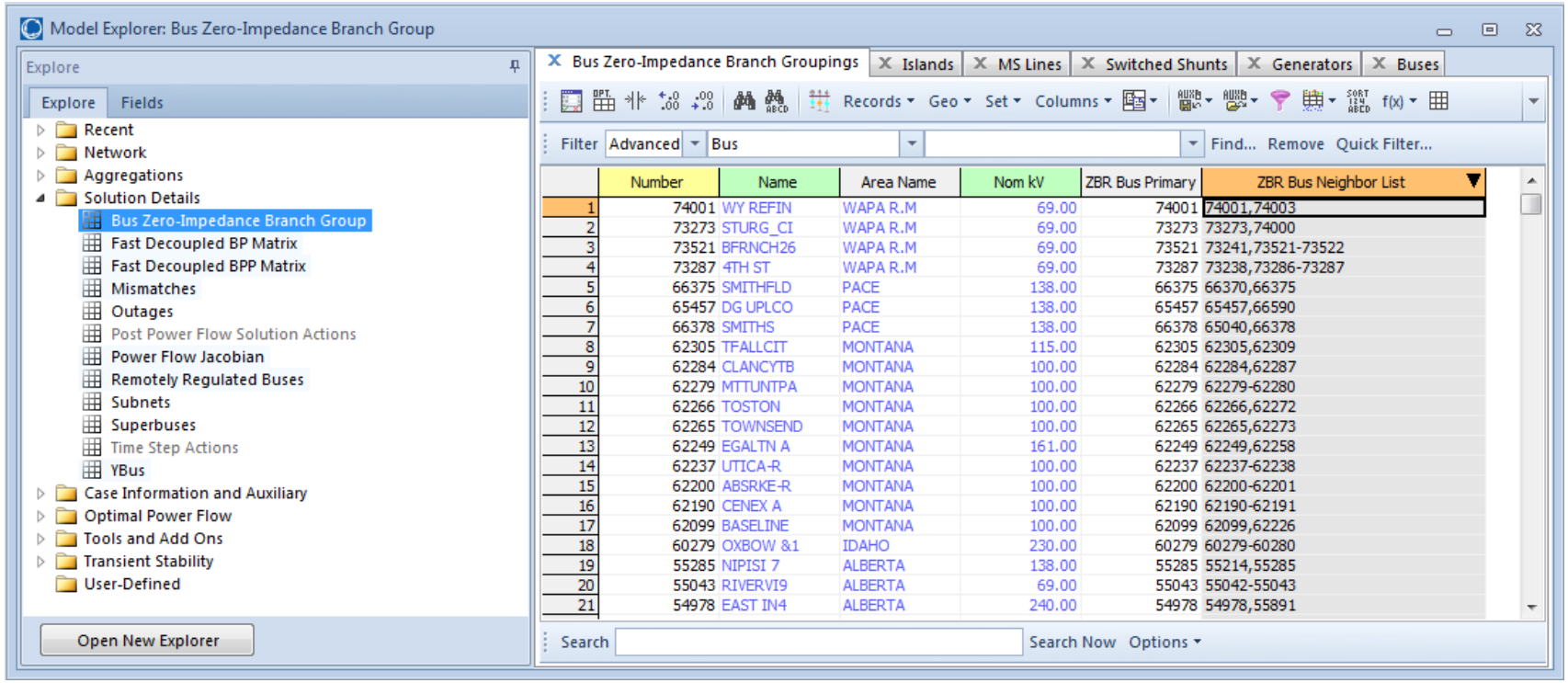
Slack, PQ, and PV
PV (Remote Reg Master)
PQ (Continuous Shunts at Var Limit)
PQ (Remotely Regulated at Var Limit)
PQ (Remote Reg Slave)
PQ (Gens at Var Limit)
PQ (Remotely Regulated)



	Number	Name	Area Name	Type	Mismatch MW	Mismatch Mvar	Mismatch MVA
1	26114	INTERMTX	LADWP	PQ	0.00	0.00	0.00
2	40131	BONN PH2	NORTHWES	PV (Remote Reg Master)	0.00	0.00	0.00
3	26040	INTERM2G	LADWP	PQ (Remote Reg Slave)	0.00	-0.00	0.00
4	26003	ADELANTO	LADWP	PQ	0.00	0.00	0.00
5	46815	ROCK IS2	NORTHWES	PV	0.00	0.00	0.00
6	62048	COLSTP 3	MONTANA	PQ (Remote Reg Slave)	0.00	0.00	0.00
7	62057	COLSTRP	MONTANA	PQ (Remotely Regulated)	-0.00	-0.00	0.00
8	40561	ICE H3-4	NORTHWES	PV (Remote Reg Master)	0.00	0.00	0.00
9	46111	WANAPUM2	NORTHWES	PV	-0.00	0.00	0.00
10	46109	WANAPUM	NORTHWES	PV	0.00	0.00	0.00
11	46813	ROCK IS	NORTHWES	PQ (Gens at Var Limit)	0.00	0.00	0.00
12	40681	LOW MON	NORTHWES	PQ (Remote Reg Slave)	0.00	0.00	0.00
13	41773	COUL1418	NORTHWES	PQ (Gens at Var Limit)	0.00	0.00	0.00
14	41313	CELILO3	NORTHWES	PQ	0.00	0.00	0.00
15	41314	CELILO4	NORTHWES	PQ	0.00	0.00	0.00
16	14932	PALOVRD2	ARIZONA	PQ (Remote Reg Slave)	0.00	0.00	0.00
17	35036	MT POSO	PG AND E	PQ (Gens at Var Limit)	-0.00	-0.00	0.00

Power Flow Solution: Solution Diagnosis Aids

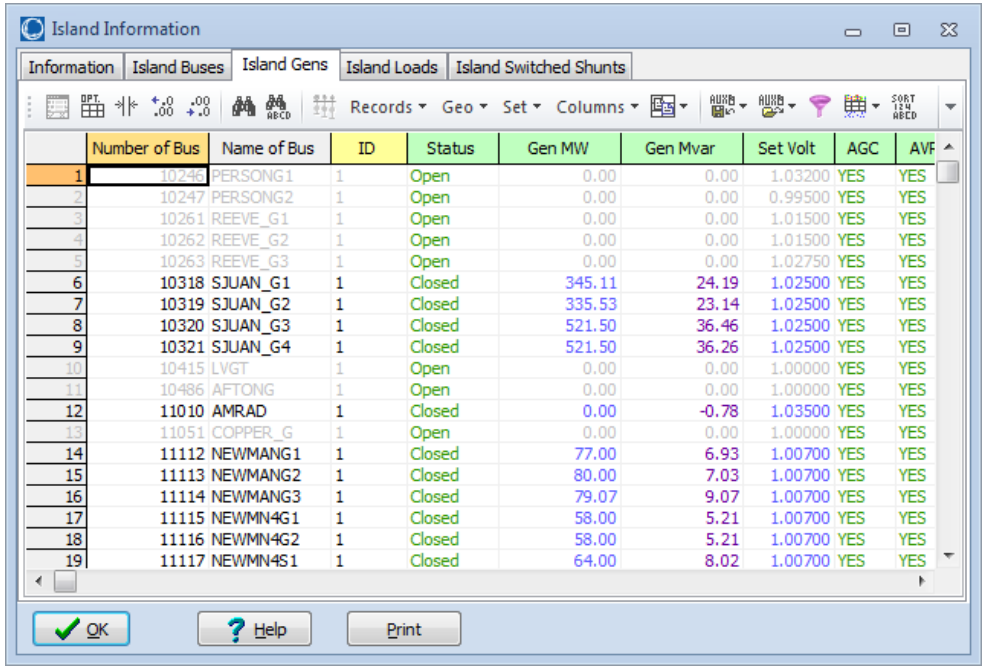
- Bus Zero Impedance branch groupings display
  - Model Explorer under **Solution Details\Bus Zero-Impedance Branch Group**



	Number	Name	Area Name	Nom kV	ZBR Bus Primary	ZBR Bus Neighbor List
1	74001	WY REFIN	WAPA R.M	69.00	74001	74001,74003
2	73273	STURG_CI	WAPA R.M	69.00	73273	73273,74000
3	73521	BFRNCH26	WAPA R.M	69.00	73521	73241,73521-73522
4	73287	4TH ST	WAPA R.M	69.00	73287	73238,73286-73287
5	66375	SMITHFLD	PACE	138.00	66375	66370,66375
6	65457	DG UPLCO	PACE	138.00	65457	65457,66590
7	66378	SMITHS	PACE	138.00	66378	65040,66378
8	62305	TFALLCIT	MONTANA	115.00	62305	62305,62309
9	62284	CLANCYTB	MONTANA	100.00	62284	62284,62287
10	62279	MTTUNTPA	MONTANA	100.00	62279	62279-62280
11	62266	TOSTON	MONTANA	100.00	62266	62266,62272
12	62265	TOWNSEND	MONTANA	100.00	62265	62265,62273
13	62249	EGALTN A	MONTANA	161.00	62249	62249,62258
14	62237	UTICA-R	MONTANA	100.00	62237	62237-62238
15	62200	ABSRKE-R	MONTANA	100.00	62200	62200-62201
16	62190	CENEX A	MONTANA	100.00	62190	62190-62191
17	62099	BASELINE	MONTANA	100.00	62099	62099,62226
18	60279	OXBOW &1	IDAHO	230.00	60279	60279-60280
19	55285	NIPISI 7	ALBERTA	138.00	55285	55214,55285
20	55043	RIVERVI9	ALBERTA	69.00	55043	55042-55043
21	54978	EAST IN4	ALBERTA	240.00	54978	54978,55891

Power Flow Solution: Solution Diagnosis Aids

- Island Information dialog lists the buses, generators, loads, and switched shunts that are part of an island



	Number of Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Set Volt	AGC	AVR
1	10246	PERSONG1	1	Open	0.00	0.00	1.03200	YES	YES
2	10247	PERSONG2	1	Open	0.00	0.00	0.99500	YES	YES
3	10261	REEVE_G1	1	Open	0.00	0.00	1.01500	YES	YES
4	10262	REEVE_G2	1	Open	0.00	0.00	1.01500	YES	YES
5	10263	REEVE_G3	1	Open	0.00	0.00	1.02750	YES	YES
6	10318	SJUAN_G1	1	Closed	345.11	24.19	1.02500	YES	YES
7	10319	SJUAN_G2	1	Closed	335.53	23.14	1.02500	YES	YES
8	10320	SJUAN_G3	1	Closed	521.50	36.46	1.02500	YES	YES
9	10321	SJUAN_G4	1	Closed	521.50	36.26	1.02500	YES	YES
10	10415	LVGT	1	Open	0.00	0.00	1.00000	YES	YES
11	10486	AFTONG	1	Open	0.00	0.00	1.00000	YES	YES
12	11010	AMRAD	1	Closed	0.00	-0.78	1.03500	YES	YES
13	11051	COPPER_G	1	Open	0.00	0.00	1.00000	YES	YES
14	11112	NEWMANG1	1	Closed	77.00	6.93	1.00700	YES	YES
15	11113	NEWMANG2	1	Closed	80.00	7.03	1.00700	YES	YES
16	11114	NEWMANG3	1	Closed	79.07	9.07	1.00700	YES	YES
17	11115	NEWMN4G1	1	Closed	58.00	5.21	1.00700	YES	YES
18	11116	NEWMN4G2	1	Closed	58.00	5.21	1.00700	YES	YES
19	11117	NEWMN4S1	1	Closed	64.00	8.02	1.00700	YES	YES

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