

# Steady-State Power System Security Analysis with PowerWorld Simulator

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## S2: Advanced Power Flow using PowerWorld Simulator



**PowerWorld**  
Corporation

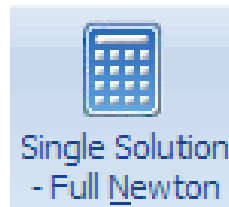
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# Overview



- 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?



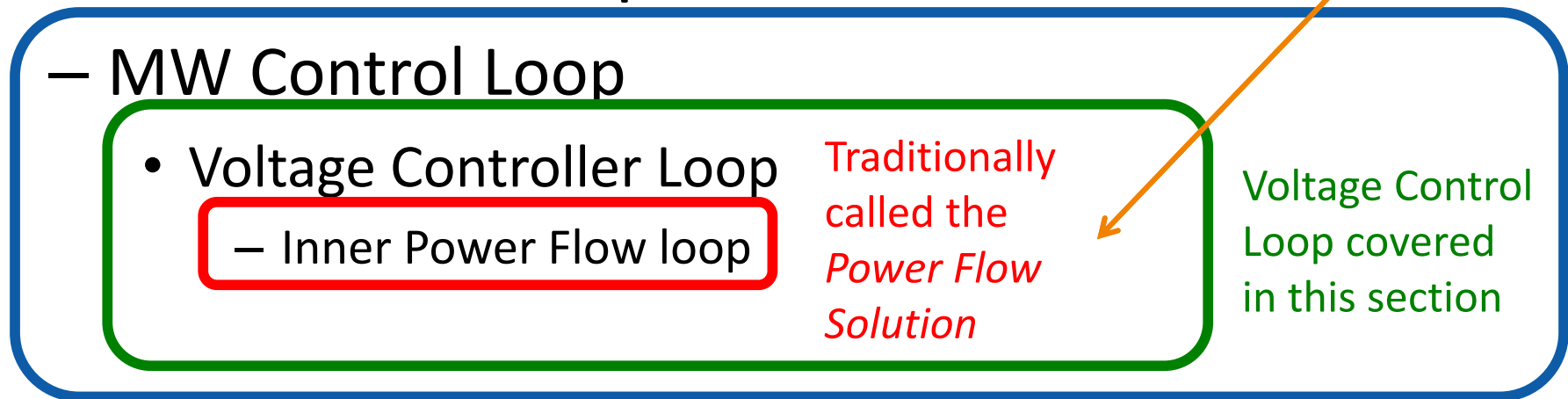
- Single solution should not be confused with a single Newton-Raphson (or other technique) power flow
- Simulator's "Single Solution" encompasses three nested loops that iterate between a power flow routine, logic for control device switching, and generation control until the power flow is solved and 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

Note: The Inner Power Flow Loop was covered in S1

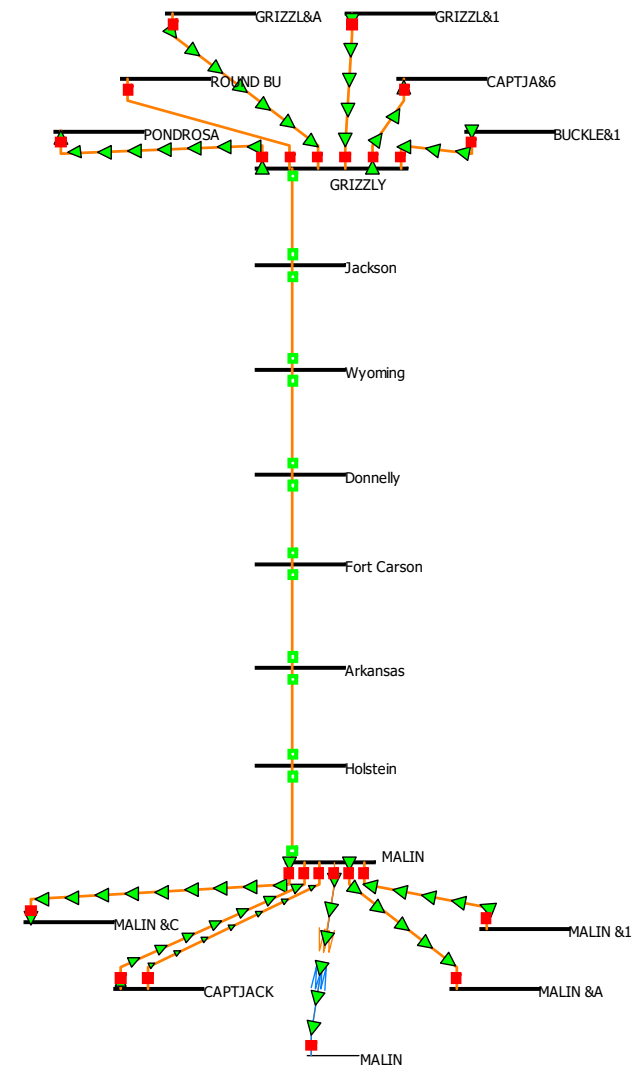


MW Control Loop covered later

# 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

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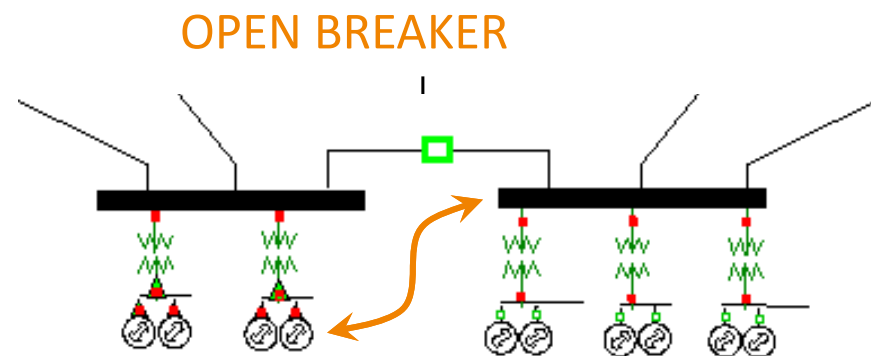
- When pre-processing the voltage profile of a solution before solving, Simulator will now look at groupings of buses connected by very low impedances lines. If a bus in a grouping of energized buses has a zero voltage while other buses in the group do not, the zero voltage will be changed to the first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

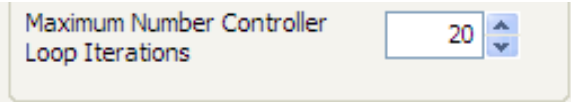


- MW Control (Outer Loop)
  - Repeat
    - Voltage Controller Loop
      - Inner Power Flow Loop
    - Change generation/load to meet ACE requirements
      - Redispatches generation and/or load using the selected AGC control method for each area (Super area or island)
  - Until no more generation/load 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)
  - Optionally (allow generators to only back off Mvar limits)
  - Perform power flow step
    - » Newton's Method (this is in rectangular form)
    - » Decoupled Power Flow
    - » Polar Form Newton's Method

Generator VAR Limits

- Disable Checking Gen VAR Limits (This results in unlimited Mvar outputs)
- Check Immediately
- Check Back Off Immediately

- ...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

Power Flow (Inner) Loop Options

MVA Convergence Tolerance: 0.1000

Maximum Number of Iterations: 100

Do Only One Iteration

# Step 2: Generator MVAR Limits

## Step 3: Solve DC line equations

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- 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

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- 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

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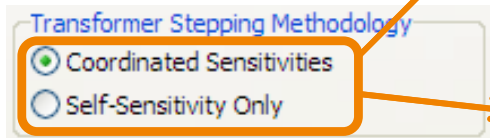


- Step 5: Discrete SVC Control
  - Only SVCs that are discrete-type SVCs are switched in this step
    - » SVSMO2
  - Checks regulated buses for voltage limit violations and adjusts SVC control appropriately
    - » Any fixed shunts controlled by the SVC are adjusted in this step
    - » SVCs are adjusted 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

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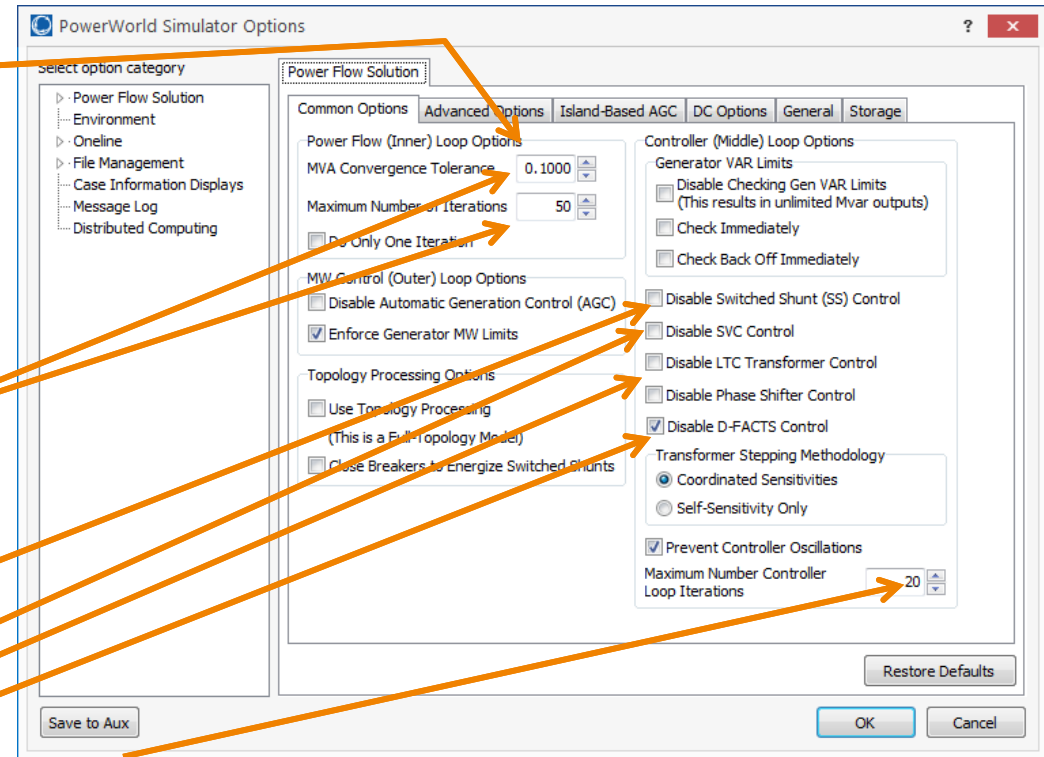
- Step 7: D-FACTS Control
  - D-FACTS devices attempt to keep the current on a branch within a specified range
  - Impedance of the D-FACTS is modified to adjust the current
  - D-FACTS that appear to be oscillating between control settings are internally set off of control
  - Updates Ybus with new 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)
      - Optionally (allow generators to only back off Mvar limits)
      - 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

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.

**Estimation of Generation**

**Inner Power Flow**

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

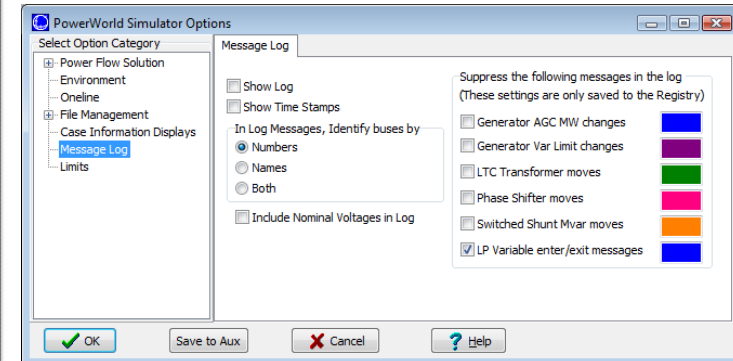
Gen(s) at bus 18259 at max vars  
Gen(s) at bus 18282 at max vars  
Gen(s) at bus 44271 has backed off var limit  
Gen(s) at bus 45026 has backed off var limit  
Gen(s) at bus 45246 at min vars  
Gen(s) at bus 47660 has backed off var limit  
Gen(s) at bus 66975 has backed off var limit  
DC Line Flow Adjustment  
Switched shunt at bus 40637 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 1.00433  
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+j0.04302 to 0.00070+j0.04505  
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+j0.04302 to 0.00070+j0.04505  
Taps at 42 transformers adjusted  
Finished voltage control loop iteration: 1

**Inner Power Flow**

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

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

**Inner Power Flow**

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 Check Immediately Mvar Limit Checking

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

**Inner Power Flow**

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 Check Immediately Mvar Limit Checking

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

**Inner Power Flow**

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.

**Area Automatic Generation Control Iteration**

**Inner Power Flow**

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 50982

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 incre  
 Finished voltage control loop iteration: 1

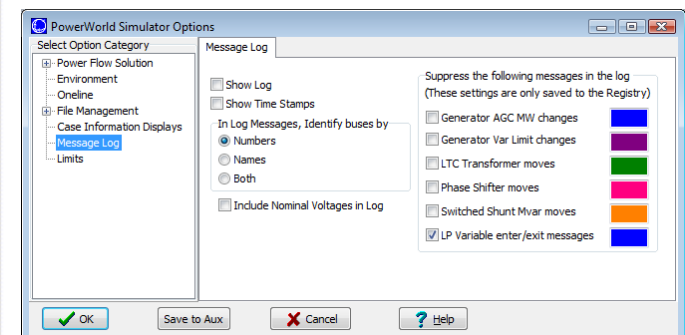
**Inner Power Flow**

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 50985

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

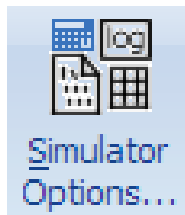
Colors of Messages determined by the Simulator, Message Log colors



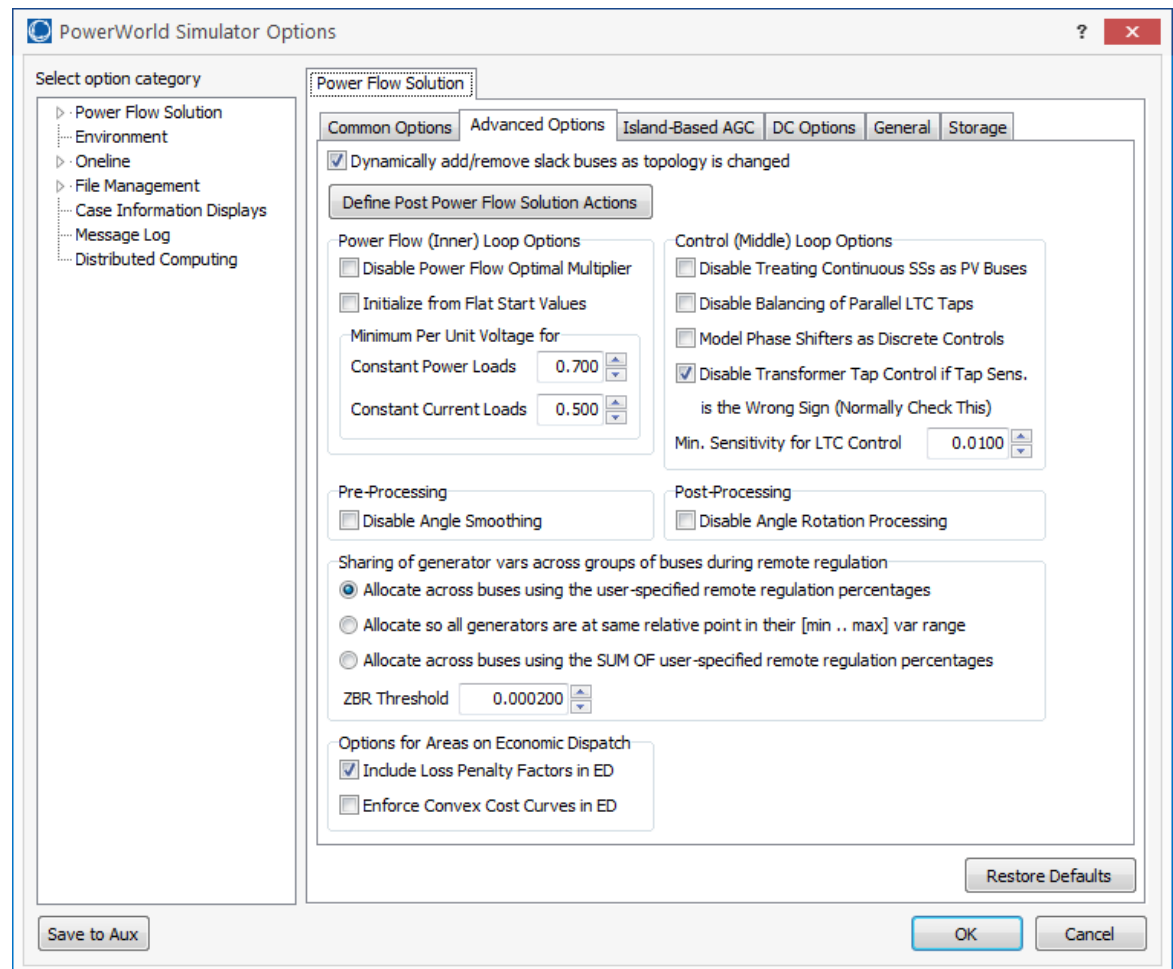
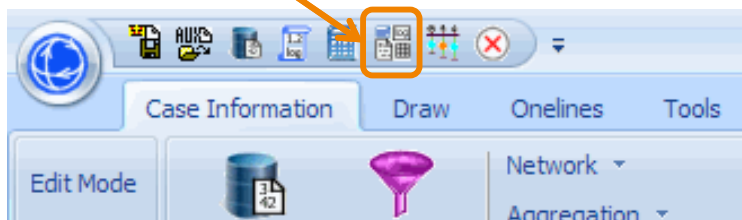
# Advanced Options for Power Flow Solution



- 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

Power Flow (Inner) Loop Options

Disable Power Flow Optimal Multiplier

Initialize from Flat Start Values

Minimum Per Unit Voltage for

Constant Power Loads	0.700	▲▼
Constant Current Loads	0.500	▲▼

Detailed description: This is a screenshot of a software dialog box titled 'Power Flow (Inner) Loop Options'. It contains two unchecked checkboxes: 'Disable Power Flow Optimal Multiplier' and 'Initialize from Flat Start Values'. Below these is a section titled 'Minimum Per Unit Voltage for' which contains two spinners. The first spinner is labeled 'Constant Power Loads' and has a value of '0.700'. The second spinner is labeled 'Constant Current Loads' and has a value of '0.500'. Both spinners have up and down arrow buttons.

# Minimum Per Unit Voltage for Constant Power and Current Loads

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- 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

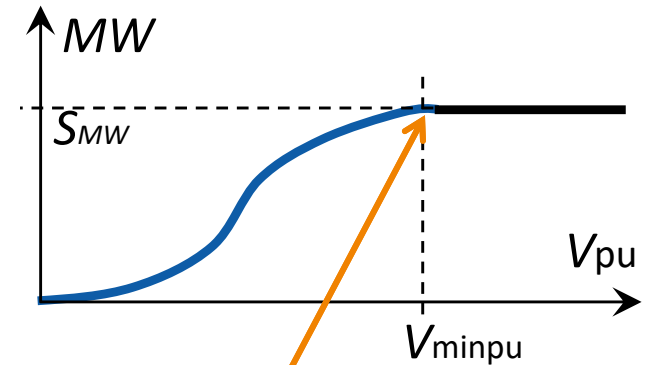


- Minimum Per Unit Voltage for Constant Power

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

(Default Values are 0.7 and 0.5)

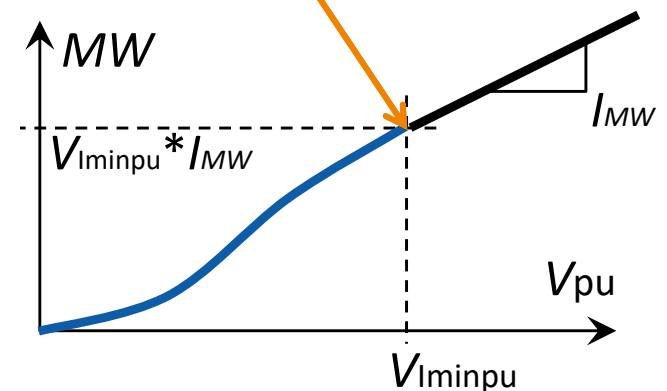
Minimum Per Unit Voltage for	
Constant Power Loads	0.700
Constant Current Loads	0.500



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

- Minimum Per Unit Voltage for Constant Current

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





# 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.
  - Disable Transformer Tap Control if Tap Sens. is the Wrong Sign (Normally Check This)
    - If a transformer is regulating one of its own terminals, the voltage-to-tap sensitivity should be positive if regulating the from bus and negative if regulating the to bus
    - Sensitivity with the wrong sign indicates an unusual system condition
  - Min. Sensitivity for LTC Control
    - Transformers with a sensitivity lower than this will be disabled

Control (Middle) Loop Options

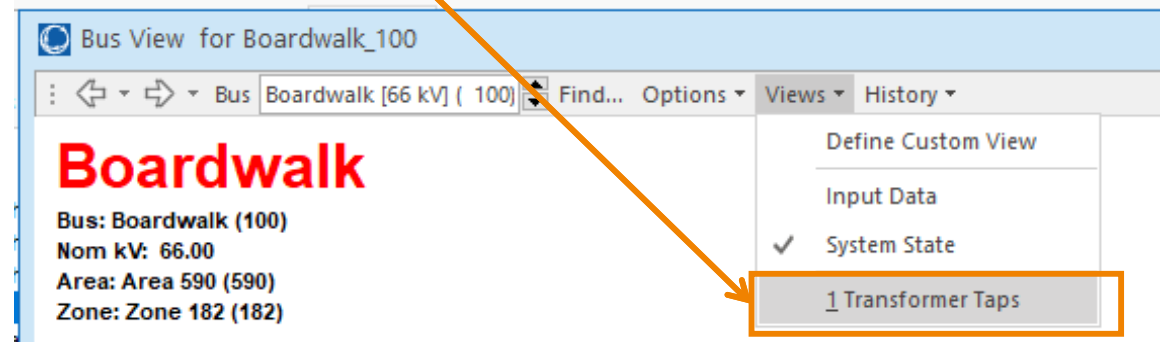
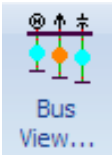
- Disable Treating Continuous SSs as PV Buses
- Disable Balancing of Parallel LTC Taps
- Model Phase Shifters as Discrete Controls
- Disable Transformer Tap Control if Tap Sens. is the Wrong Sign (Normally Check This)

Min. Sensitivity for LTC Control

# Example: Parallel Tap Balancing and Minimum Tap Sensitivity



- Choose Open Case
  - ... \S02\_AdvancedPowerFlow\AdvancedOptions.pwb
- Do NOT solve yet
- Open the Bus View
  - Choose **Views > Transformer Taps**
  - This is a Custom View that is already defined



# Parallel Tap Balancing



- On Bus View, go to Bus : Boardwalk (100)

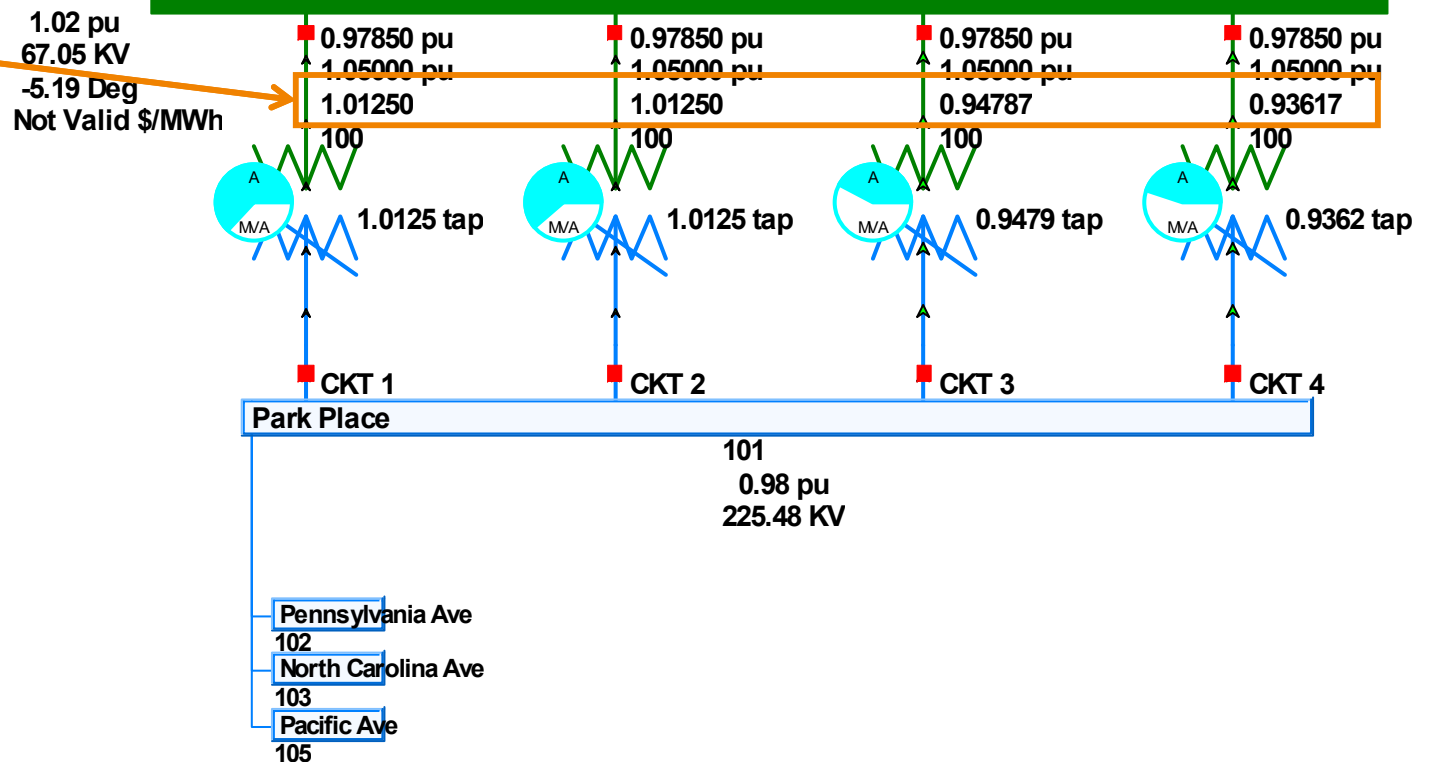
## Boardwalk

Bus: Boardwalk (100)  
 Nom kV: 66.00  
 Area: Area 590 (590)  
 Zone: Zone 182 (182)

365.4 MW  
 -23.6 Mvar  
 ID 1

0.00 MW  
 0.00 Mvar

Parallel Transformers should have the same tap ratios

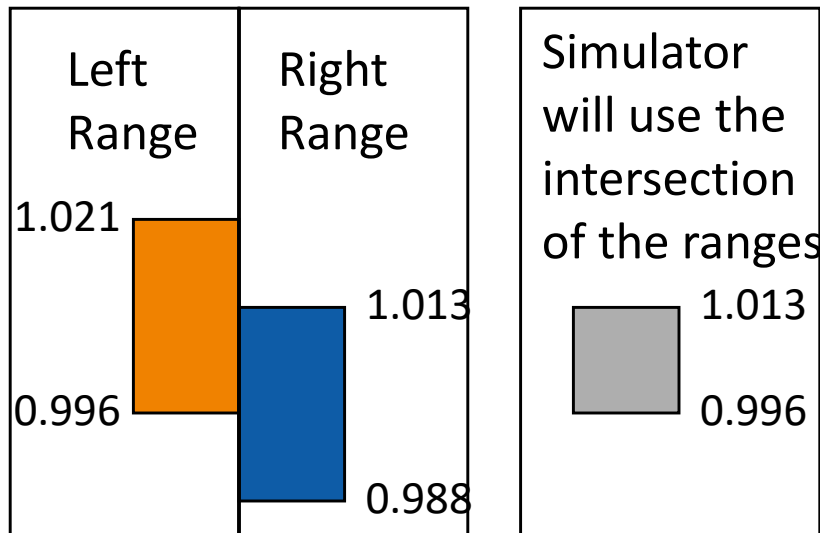


# Parallel Tap Balancing and Regulation Range Correction



- On Bus View, go to Bus : Water Works (106)

Two Transformers Regulate the same bus (106), but have different regulation ranges



If no intersection, then control turned off

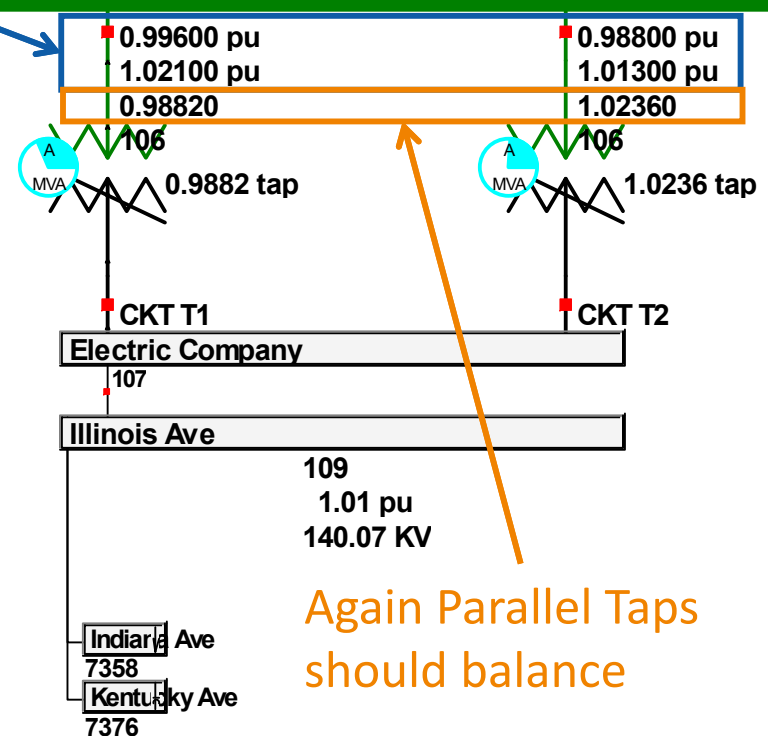
Error: The following parallel transformers have control ranges (Reg Min - Reg Max) which do not overlap.  
 Transformer 16102 TO 10382 CKT 2 has been turned off control.  
 Transformer 16102 TO 10382 CKT 1 has been turned off control.

## Water Works

Bus: Water Works (106)  
 Nom kV: 4.16  
 Area: Area 530 (530)  
 Zone: Zone 677 (677)

1.00 pu  
 4.17 KV  
 80.28 Deg  
 Not Valid \$/MWh

11.2 MW  
 2.5 Mvar  
 ID 1



Again Parallel Taps should balance

# Parallel Taps Regulated Bus Error Checking

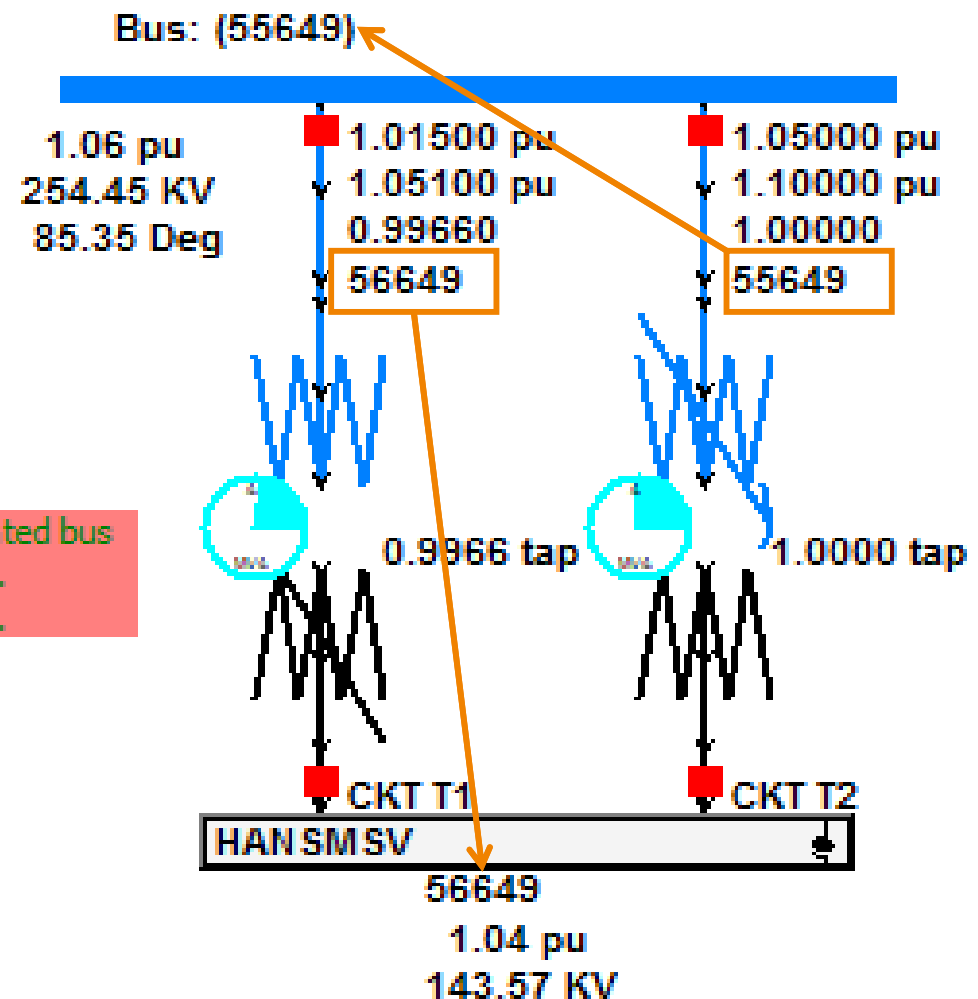


Note: Sample case does not have this problem. Slide is just example

- 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



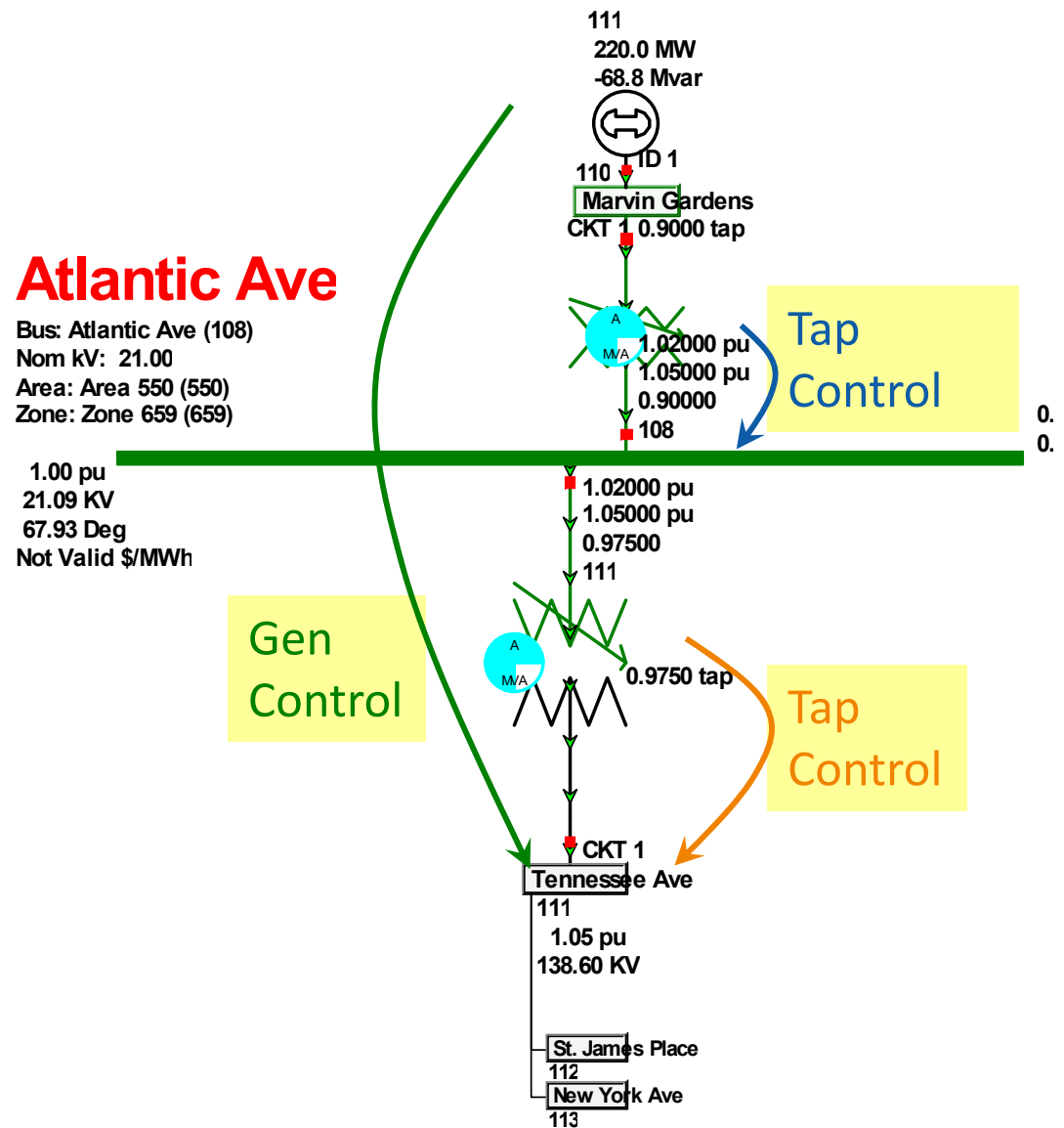
# Minimum Tap Sensitivity



- On Bus View, go to Bus : Atlantic Ave (108)

Because the Generator at bus 110 controls the voltage at bus 111, 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



Starting Solution using Rectangular Newton-Raphson

Transformer 101 TO 100 CKT 1 tap ratio moved from 1.01250 to 0.96250 to balance with parallel LTCs  
 Transformer 101 TO 100 CKT 2 tap ratio moved from 1.01250 to 0.96250 to balance with parallel LTCs  
 Transformer 101 TO 100 CKT 3 tap ratio moved from 0.94787 to 0.97128 to balance with parallel LTCs  
 Transformer 101 TO 100 CKT 4 tap ratio moved from 0.93617 to 0.96217 to balance with parallel LTCs

Boardwalk

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 107 TO 106 CKT T1 Reg Range specified: 0.99600-1.02100  
 Transformer 107 TO 106 CKT T2 Reg Range specified: 0.98800-1.01300  
 Transformer 107 TO 106 CKT T1 tap ratio moved from 0.98820 to 1.00000 to balance with parallel LTCs  
 Transformer 107 TO 106 CKT T2 tap ratio moved from 1.02360 to 1.00000 to balance with parallel LTCs

Water Works

Calculating Transformer Tap Sensitivities for 23 Transformers

Transformer 110 TO 108 CKT 1 can not effectively control voltage at bus 108; control will be ignored until the tap sensitivity magnitude increases

Transformer 108 TO 111 CKT 1 can not effectively control voltage at bus 111; control will be ignored until the tap sensitivity magnitude increases

Atlantic Ave

# Simulator Options: Power Flow Solution Page



- Advanced Options tab

- Disable Angle Rotation Processing

Post-Processing  
 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

- Disable Angle Smoothing

Pre-Processing  
 Disable Angle Smoothing

- Solution difficulties can result if branches are closed with large angle differences across them. Angle smoothing attempts to reconcile these differences prior to the power flow solution.

- Sharing of generator vars across groups of buses

Sharing of generator vars across groups of buses during remote regulation

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

ZBR Threshold

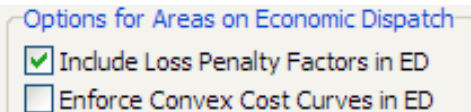
- Allocate across buses using the user-specified remote regulation percentages
- Allocate so all generators are at same relative point in their [min..max] var range
- Allocate across buses using the SUM OF user-specified remote regulation percentages



# Simulator Options: Power Flow Solution Page



- Advanced Options tab
  - ZBR Threshold
    - Determines which buses will be considered the same because they are connected by low impedance branches
    - This affects
      - Generator and switched shunt regulation
      - Parallel transformer tap balancing
      - Voltage pre-processing
  - 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



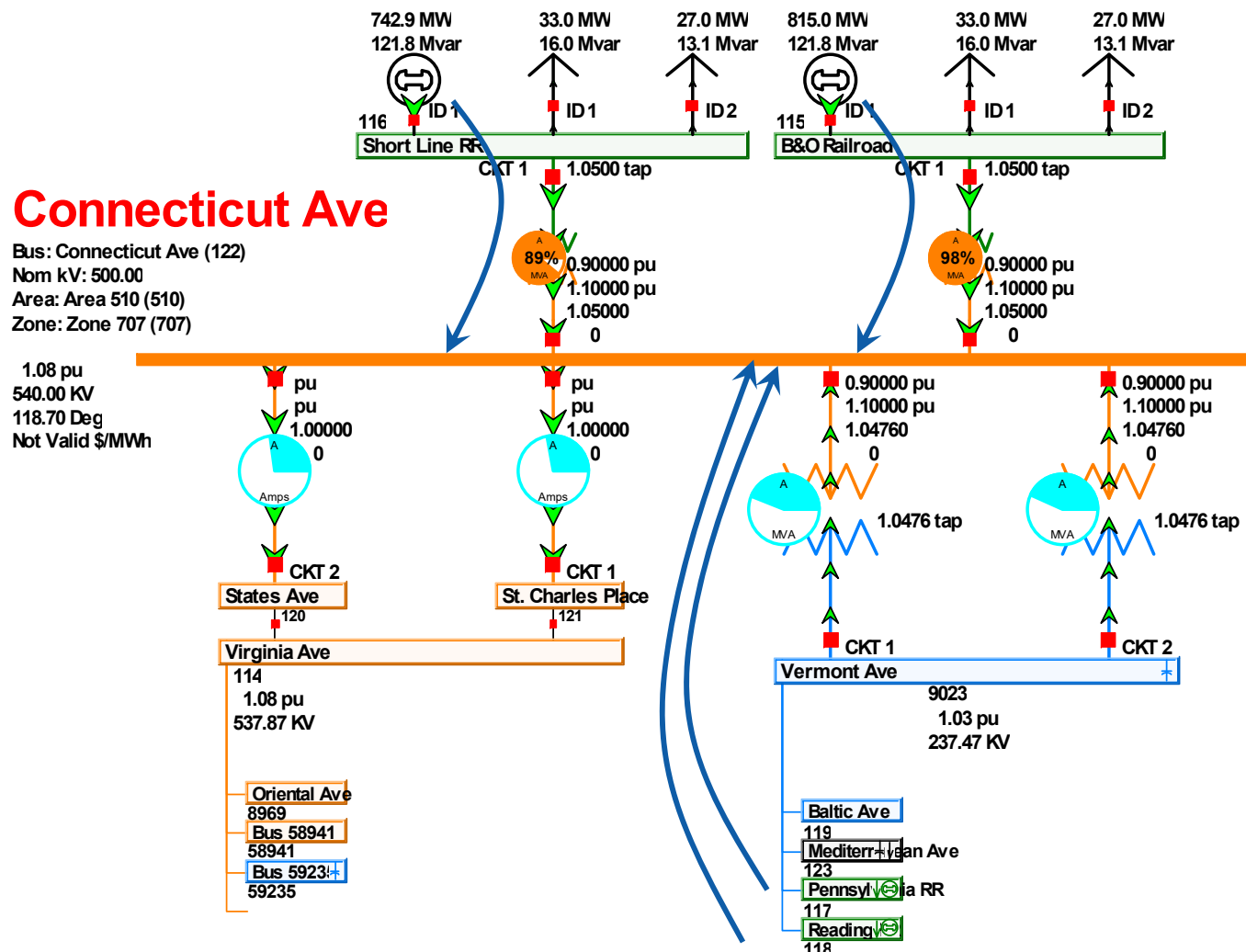
- On Bus View, go to Bus : Connecticut Ave (122)

- Generators at 115, 116, 117, 118 all regulate the voltage at this bus

## Connecticut Ave

Bus: Connecticut Ave (122)  
 Nom kV: 500.00  
 Area: Area 510 (510)  
 Zone: Zone 707 (707)

1.08 pu  
 540.00 KV  
 118.70 Deg  
 Not Valid \$/MWh



# 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

	Number Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Remote Reg %	Min Mvar	Max Mvar	Set Volt	AVR
1	115	B&O Railroad	1	Closed	815.00	121.78	35.00	-270.70	270.70	1.08000	YES
2	116	Short Line RR	1	Closed	742.88	121.78	35.00	-270.70	270.70	1.08000	YES
3	117	Pennsylvania RR	1	Closed	330.00	52.19	15.00	-115.00	115.00	1.08000	YES
4	118	Reading RR	1	Closed	330.00	52.19	15.00	-115.00	115.00	1.08000	YES

Sum = 347.96

$$0.35 = \frac{121.78}{347.96} \quad 0.15 = \frac{52.19}{347.96}$$

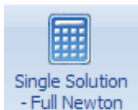
# Var “Responsibility”

## 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 115 to 150 Mvar

	Y	Number Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Remote Reg %	Min Mvar	Max Mvar	Set Volt	AVR
1		115	B&O Railroad	1	Closed	815.00	121.78	35.00	-270.70	150.00	1.08000	YES
2		116	Short Line RR	1	Closed	742.88	121.78	35.00	-270.70	270.70	1.08000	YES
3		117	Pennsylvania RR	1	Closed	330.00	52.19	15.00	-115.00	115.00	1.08000	YES
4		118	Reading RR	1	Closed	330.00	52.19	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 115 back to 270.7 Mvar

	Y	Number Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Remote Reg %	Min Mvar	Max Mvar	Set Volt	AVR
1		115	B&O Railroad	1	Closed	815.00	121.78	35.00	-270.70	270.70	1.08000	YES
2		116	Short Line RR	1	Closed	742.88	121.78	35.00	-270.70	270.70	1.08000	YES
3		117	Pennsylvania RR	1	Closed	330.00	52.19	15.00	-115.00	115.00	1.08000	YES
4		118	Reading RR	1	Closed	330.00	52.19	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 115 to 150 Mvar

	Y	Number Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Remote Reg %	Min Mvar	Max Mvar	Set Volt	AVR
1		115	B&O Railroad	1	Closed	815.00	61.34	35.00	-270.70	150.00	1.08000	YES
2		116	Short Line RR	1	Closed	742.88	156.60	35.00	-270.70	270.70	1.08000	YES
3		117	Pennsylvania RR	1	Closed	330.00	66.53	15.00	-115.00	115.00	1.08000	YES
4		118	Reading RR	1	Closed	330.00	66.53	15.00	-115.00	115.00	1.08000	YES



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

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

$$\frac{61.34 - (-270.7)}{150.0 - (-270.7)} = 0.789$$

$$\frac{156.6 - (-270.7)}{270.7 - (-270.7)} = 0.789$$

$$\frac{66.53 - (-115.0)}{115.0 - (-115.0)} = 0.789$$

# 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.

Switched Shunt Information for Present

Bus Number: 1040 (Find By Number)  
 Bus Name: Bus 1040 (Find By Name)  
 Shunt ID: 1 (Find ...)  
 Labels: no labels

Status:  Open  Closed  
 Energized:  NO (Offline)  YES (Online)

Status Branch:  (Choose Branch, Remove)

Parameters | Control Options | Faults | Owners, Area, Zone | Custom | Stability | GIC

Advanced Options | Time Step Options | SVC Control Options | SVC Fixed Shunt Options

Discrete Control Options

- Single Largest Step
- Allow switching in the inner power flow loop
- Use Continuous Element

Continuous Element Parameters

- Minimum Nominal Mvar: 0.0000
- Maximum Nominal Mvar: 0.0000

Use High Target Voltage  
 High Target Voltage: 1.08200  
 This target voltage will be used when the regulated point goes above the High/Low range

OK Cancel Save Save to Aux Help Print

# 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

Transformer Control Info

Common Options Time Step Options

Automatic Control Type

No Automatic Control

Voltage Regulation (AVR)

Reactive Power Control

Phase Shift Control

Regulation Minimum Voltage 0.979000

Regulation Maximum Voltage 1.021000

Regulation Target Type  Middle  Max/Min

Present Tap Ratio 1.043800

Minimum Tap Ratio 0.900000

Maximum Tap Ratio 1.100000

Tap Step Size 0.006250

Values above are on System Voltage Base

Impedance Correction Table 0

View Transformer Correction Table

Automatic Control Enabled

Regulated Bus Number 62469

Present Reg. Bus Voltage 0.993259

Voltage Error 0.000000

Voltage to Tap Sensitivity -0.9545

Use Line Drop Compensation

Line Drop Compensation Resistance (R) 0.000000

Line Drop Compensation Reactance (X) 0.000100

Line Drop Impedances are given on the system MVA Base

OK Cancel Help



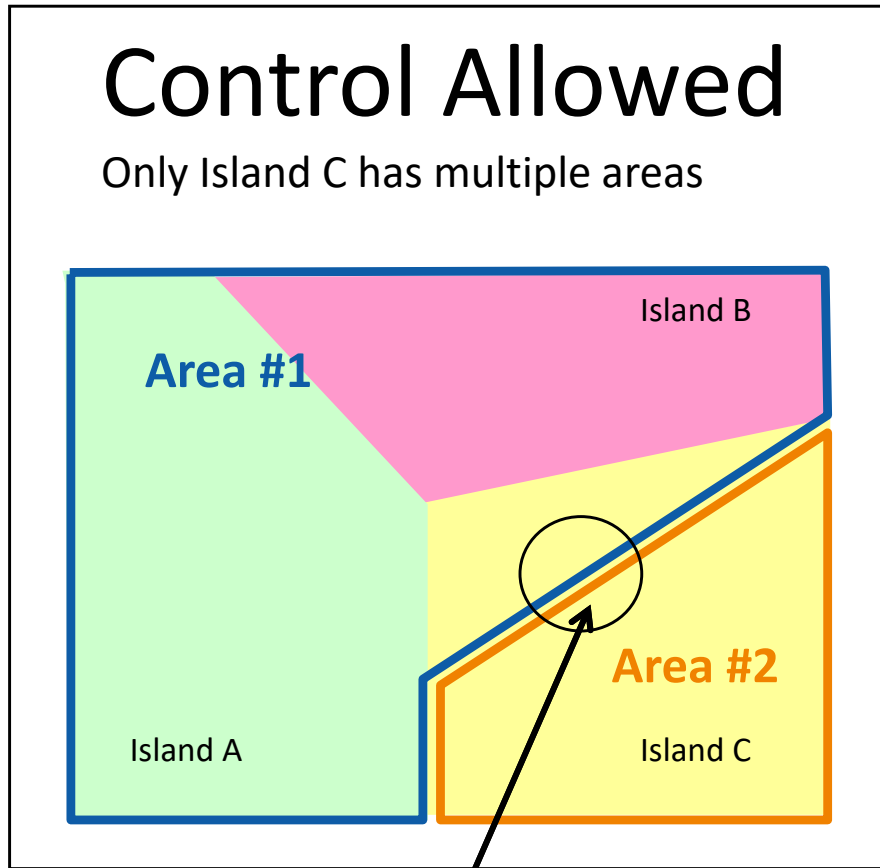
# Area Control with Multiple Islands

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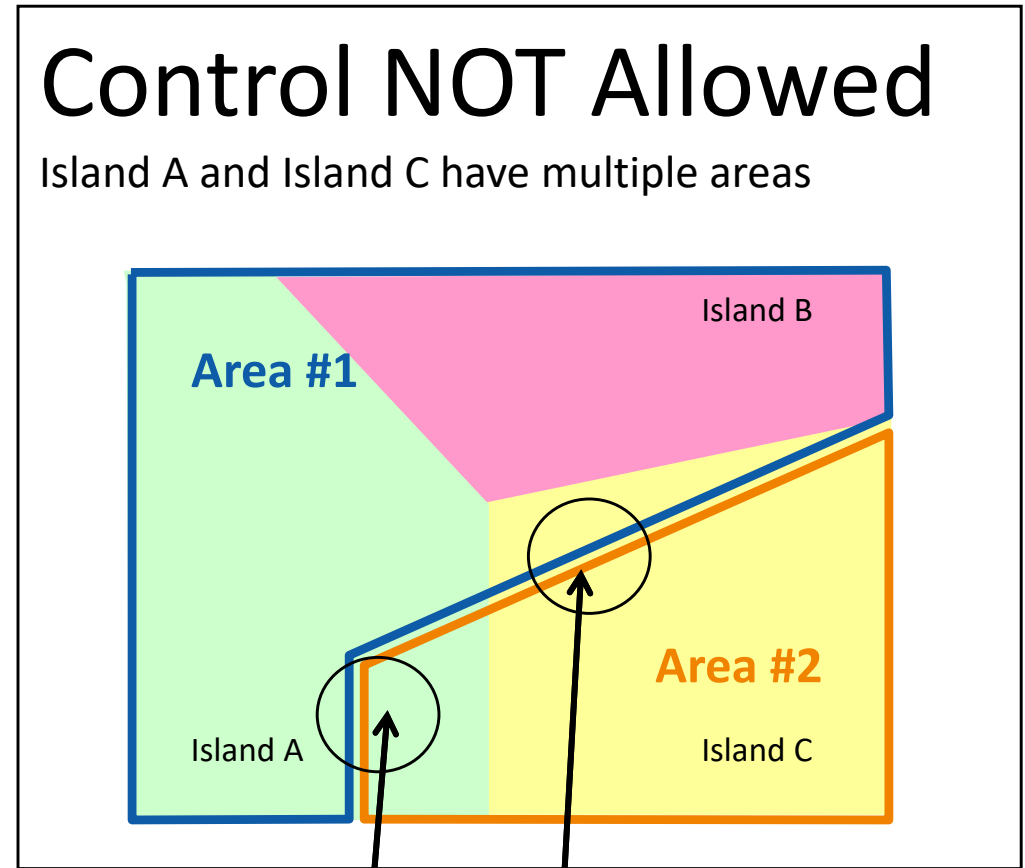


- When an area spans multiple electric islands, the MW Interchange Control for that area may not be possible
- An error check is done to allow for more complex situations
  - An area that belongs to multiple islands can be placed on control only if at most one of these islands contains multiple areas

# Areas Spanning Multiple Islands: Example for Area #1 Control



Island C has multiple areas



Island C has multiple areas  
Island A has multiple areas

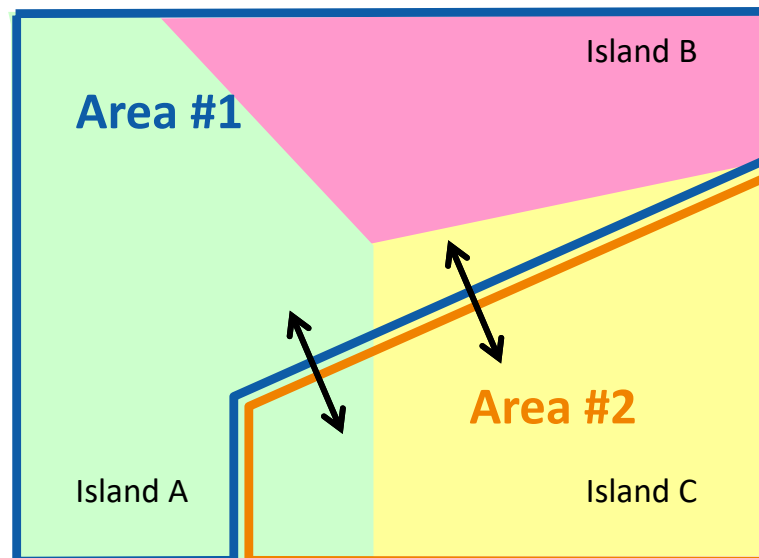
*This situation occurs for WAPA and  
ERCOT in Eastern Interconnect cases*

# 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

	Number	Name	Area Name	PU Volt	Set Volt	Volt Diff	AVR	Total Mvar	Mvar Min	Mvar Max	Rem Regs (gen)	Rem Regs (XFMR)
1	100	Boardwalk	Area 590	1.01994				0.0	0.0	0.0		LTCs: 101 TO 100 CKT 1, 101 TO 100
2	106	Water Works	Area 530	1.00712				0.0	0.0	0.0		LTCs: 107 TO 106 CKT T1, 107 TO 106
3	108	Atlantic Ave	Area 550	1.00410				0.0	0.0	0.0		LTC: 110 TO 108 CKT 1
4	111	Tennessee Ave	Area 550	1.05000	1.050	0.0000	Yes	-68.8	-87.0	122.0	Generator: 110 #1	LTC: 108 TO 111 CKT 1
5	114	Virginia Ave	Area 510	1.07580				0.0	0.0	0.0		
6	122	Connecticut Ave	Area 510	1.08000	1.080	0.0000	Yes	351.0	-771.4	650.7	<b>Generators: 115 #1, 116 #1, 117 #1, 118 #1</b>	
7	123	Mediterranean Ave	Area 510	1.03004				0.0	0.0	0.0		
8	1025	Bus 1025	Area 560	1.02600	1.026	0.0000	Yes	-7.7	-57.1	37.7	Generator: 21491 #1	
9	1040	Bus 1040	Area 560	1.08486				0.0	0.0	0.0		
10	1058	Bus 1058	Area 560	0.99679				0.0	0.0	0.0		LTC: 51033 TO 1058 CKT 1

# 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)

The screenshot shows the 'Model Explorer: Mismatches' window. The left pane shows a tree view with 'Mismatches' selected. The main pane displays a table with the following columns: Number, Name, Area Name, Type, Mismatch MW, Mismatch Mvar, and Mismatch MV. The table contains 15 rows of data.

Number	Name	Area Name	Type	Mismatch MW	Mismatch Mvar	Mismatch MV
1	Bus 16874	Area 580	PQ	0.00	-0.00	0.00
2	Bus 16871	Area 580	PQ	0.00	-0.00	0.00
3	Bus 8765	Area 520	PV (Remote Reg Primary)	-0.00	0.00	0.00
4	Bus 8864	Area 520	PV (Remote Reg Primary)	0.00	-0.00	0.00
5	Bus 8729	Area 520	PV (Remote Reg Primary)	0.00	-0.00	0.00
6	Bus 1898	Area 560	PV (Remote Reg Primary)	-0.00	0.00	0.00
7	Bus 1829	Area 560	PQ	0.00	0.00	0.00
8	Bus 6497	Area 550	PV (Remote Reg Primary)	0.00	0.00	0.00
9	Bus 53883	Area 560	PV (Remote Reg Primary)	-0.00	0.00	0.00
10	Bus 4199	Area 560	PV (Remote Reg Primary)	-0.00	0.00	0.00
11	Bus 51873	Area 560	PQ (Remote Reg Secondary)	0.00	-0.00	0.00
12	Bus 71352	Area 560	PV (Remote Reg Primary)	-0.00	0.00	0.00
13	Bus 1958	Area 560	PV (Remote Reg Primary)	-0.00	0.00	0.00
14	Bus 10034	Area 300	PV (Remote Reg Primary)	-0.00	0.00	0.00
15	Bus 1943	Area 560	PV (Remote Reg Primary)	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**

The screenshot shows the 'Model Explorer: Bus Zero-Impedance Branch Group' window. The left sidebar shows a tree view with 'Solution Details' expanded to 'Bus Zero-Impedance Branch Group'. The main area displays a table with 15 rows of bus data.

	Number	Name	Area Name	Nom kV	ZBR Bus Primary	ZBR Bus Neighbor List
1	60507	Bus 60507	Area 300	138.00	60507	9851,60507
2	9380	Bus 9380	Area 510	115.00	9380	9380,9386
3	9353	Bus 9353	Area 510	100.00	9353	9353,59322
4	9341	Bus 9341	Area 510	100.00	9341	9341,59316
5	9320	Bus 9320	Area 510	100.00	9320	9320,9332
6	9284	Bus 9284	Area 510	100.00	9284	9284,59256
7	9227	Bus 9227	Area 510	100.00	9227	9227,59202
8	9212	Bus 9212	Area 510	100.00	9212	9212,59187
9	9077	Bus 9077	Area 510	100.00	9077	9077,9266
10	8867	Bus 8867	Area 520	230.00	8867	8867,58842
11	8660	Bus 8660	Area 530	69.00	8660	8660,58023
12	57372	Bus 57372	Area 530	69.00	57372	8630,57372
13	57291	Bus 57291	Area 530	138.00	57291	8618,57291
14	58164	Bus 58164	Area 530	240.00	58164	8603,58164
15	58386	Bus 58386	Area 530	138.00	58386	8357,58386

# Power Flow Solution: Solution Diagnosis Aids



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

The screenshot shows the 'Island Information' dialog box with the 'Information' tab selected. The table below represents the data shown in the dialog.

	Number of Bus	Name of Bus	ID	Status	Gen MW	Gen Mvar	Min MW	Max MW	AGC	AVR	RegBus Num	Set Volt	Min Mvar	Max Mvar	Er M Li
1	110	Marvin Gardens	1	Closed	220.00	-68.79	0.00	270.00	YES	YES	111	1.05000	-87.00	122.00	YE
2	115	B&O Railroad	1	Closed	815.00	61.34	0.00	823.00	YES	YES	122	1.08000	-270.70	150.00	YE
3	116	Short Line RR	1	Closed	742.88	156.60	0.00	823.00	YES	YES	122	1.08000	-270.70	270.70	YE
4	117	Pennsylvania RR	1	Closed	330.00	66.53	0.00	360.00	YES	YES	122	1.08000	-115.00	115.00	YE
5	118	Reading RR	1	Closed	330.00	66.53	0.00	360.00	YES	YES	122	1.08000	-115.00	115.00	YE
6	1085	Bus 1085	1	Closed	7.00	5.60	0.00	10.50	YES	YES	1085	1.04346	-4.50	5.60	YE
7	1085	Bus 1085	2	Open	0.00	0.00	0.00	10.50	YES	YES	1085	1.04346	-5.50	6.30	YE
8	1115	Bus 1115	1	Closed	1.00	0.00	0.00	1.00	YES	YES	1115	1.01333	0.00	0.00	YE
9	1127	Bus 1127	1	Closed	40.00	2.56	0.00	46.00	YES	YES	1127	1.04500	-25.30	22.80	YE
10	1127	Bus 1127	2	Closed	40.00	2.56	0.00	46.00	YES	YES	1127	1.04500	-25.30	22.80	YE
11	1199	Bus 1199	3	Closed	82.00	15.13	0.00	102.50	YES	YES	1199	0.97000	-42.40	49.20	YE
12	1199	Bus 1199	4	Open	0.00	0.00	0.00	102.50	YES	YES	1199	0.97000	-42.40	49.20	YE
13	1202	Bus 1202	1	Closed	85.00	7.19	0.00	104.50	YES	YES	51180	1.03400	-63.30	39.10	YE
14	1202	Bus 1202	2	Closed	85.00	7.19	0.00	104.50	YES	YES	51180	1.03400	-63.30	39.10	YE
15	1205	Bus 1205	5	Open	0.00	0.00	0.00	127.20	YES	YES	51183	1.03500	-73.80	53.00	YE
16	1205	Bus 1205	6	Open	0.00	0.00	0.00	127.20	YES	YES	51183	1.03500	-73.80	53.00	YE
17	1226	Bus 1226	1	Closed	0.00	51.00	0.00	0.00	YES	YES	1226	1.05395	49.00	51.00	YE
18	1286	Bus 1286	1	Closed	67.00	-18.87	0.00	89.00	YES	YES	1286	1.03000	-33.70	51.10	YE
19	1364	Bus 1364	1	Closed	8.00	0.00	0.00	12.00	YES	YES	51336	1.01241	0.00	0.00	YE

Blank Page