

Introduction to PowerWorld Simulator: Interface and Common Tools



17: Power System Analysis and Voltage Control



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Power Flow Analysis and Voltage Control using Simulator



- Formulation of the power flow problem
- Newton's method for solving the power flow
- Description of the **PowerWorld Simulator Options** dialog accessed from the **Options** ribbon tab, **Simulator Options** button.
- Explanation of voltage-related controls
 - generator AVR
 - transformer taps
 - switched shunts

Overall Simulator Solution Methodology



- Simulator actually uses THREE nested loops to solve the power flow
- MW Control Loop
 - Voltage Controller Loop

- Inner Power Flow loop

Traditionally
called the
*Power Flow
Solution*

Voltage Control
Loop also
covered in this
section

MW Control Loop also covered later

Overall Simulator Solution Methodology



- Colored outlines in log correspond to the loop that generates the message
- This can be helpful for tracking down the reasons for divergence
- Highlighting colors are also used to identify messages originating from other tools and add-ons (i.e., contingency analysis, OPF, ATC, etc.)

Message Log: 08june23_tmp1.pwb
Starting Solution using Rectangular Newton-Raphson

```
Number: 0 Max P: 0.000 at bus HELMS 2 (34602) Max Q: 0.056 at bus ADELANTO (26003)
Calculating Transformer Tap Sensitivities for 47 Transformers
Transformer JACKSN1 (45687) TO JACKSN (45685) CKT 1 can not effectively control voltage at bus 45685; control will be ignored
Transformer JACKSN2 (45689) TO JACKSN (45685) CKT 1 can not effectively control voltage at bus 45685; control will be ignored
Taps at 3 transformers adjusted
Finished voltage control loop iteration: 1
Number: 0 Max P: 8.018 at bus ANTELOPE (24401) Max Q: 63.282 at bus ANTELOPE (24402)
Number: 1 Max P: 0.125 at bus ANTELOPE (24402) Max Q: 0.462 at bus ANTELOPE (24401)
Number: 2 Max P: 0.000 at bus SPRGRE12 (16117) Max Q: 0.001 at bus HUNTINGTN (65805)
Calculating Transformer Tap Sensitivities for 8 Transformers
Taps at 3 transformers adjusted
Finished voltage control loop iteration: 2
Number: 0 Max P: 8.120 at bus ANTELOPE (24402) Max Q: 66.103 at bus ANTELOPE (24402)
Number: 1 Max P: 0.104 at bus ANTELOPE (24402) Max Q: 0.444 at bus ANTELOPE (24401)
Number: 2 Max P: 0.000 at bus ANTELOPE (24402) Max Q: 0.000 at bus EMERY (65510)
Calculating Transformer Tap Sensitivities for 8 Transformers
Finished voltage control loop iteration: 3
Determining the side of transformer on which regulated buses are. This is needed to write to some non-PowerWorld file formats.
Using Tap Sensitivities to determine if Reg Buses are more than 1 bus away from the From or To bus.
Solution Finished in 0.374 Seconds
Simulation: Successful Power Flow Solution
```

Formulation of Power Flow: “Inner Power Flow Loop”



- Goal is to solve the nonlinear power balance equations for all system buses
- For an n bus power system

$$I = Y_{bus} V$$

where

I = complex vector of current injection at all buses

V = complex vector of voltage at all buses

Y_{bus} = complex n by n bus admittance matrix

Nonlinear Power Flow Equations



- Complex nonlinear power balance equations

$$S^* = V^* I$$

$$S^* = V^* Y_{bus} V$$

- Convert to $2(n-1)$ real equations

$$S = g(x) \text{ or } f(x) = 0$$

where

$S = 2(n-1)$ power injections

$x = 2(n-1)$ voltage magnitudes and angles

Slack and PV Buses



- Exactly one bus in each electrical island is designated as a slack bus
 - provides an angle and voltage reference
 - must be a bus with a generator
 - voltage angle and magnitude fixed
 - real/reactive output of generator free to vary
 - Simulator tries to maintain them within limits, but if that is not possible, this generator will violate limits
- At AVR generator buses (PV buses)
 - voltage magnitude is fixed
 - reactive output of generator is free to vary
- At other buses (PQ buses)
 - Power and Reactive power injections are fixed

Solving the Power Flow Equations



- Nonlinear equations must be solved iteratively
- There are a number of common solution methods
 - Newton's Method
 - Simulator uses an enhanced Newton's method algorithm
 - Fast Decoupled
 - an option in Simulator
 - Gauss-Seidel
 - presently not available in Simulator

Newton's Method



Guess initial value of voltages x^0 , $k = 0$

Repeat

While ($|f(x^k)| > \varepsilon$) and ($k < k^{\max}$) Do

$$x^{k+1} = x^k - [J(x^k)]^{-1} f(x^k)$$

$$k = k + 1$$

End While

Until (no more automatic control changes)

Newton's Method



Where

k = Iteration count

$k^{\max}$ = Maximum number of iterations

x^k = Voltages at the k^{th} iteration

$f(x^k)$ = Mismatch equations

ε = Convergence tolerance (in MVA)

$J(x^k)$ = Jacobian matrix

Seven Bus Example



- Open case B7FLAT.PWB, switch into Run Mode and make sure Message Log visible.
- To view initial mismatches, go to the **Case Information** ribbon tab and select **Model Explorer**. In the **Network** category select **Mismatches**. All mismatches are initially less than 0.1 MVA.
- Open line from bus 2 to bus 5; refresh the mismatches. There are now large values at buses 2 and 5. Solve the case.

Power Flow Solution

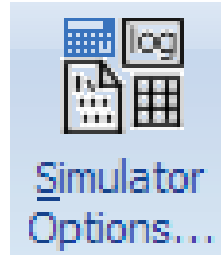


- Go to the **Tools** ribbon tab and select **Solve Power Flow** to resolve the power flow equations
- Refresh the mismatch display; notice that mismatches are again less than 0.1 MVA.
- Notice that voltage magnitude has remained fixed at the generator buses. This is because they are being modeled as PV buses.

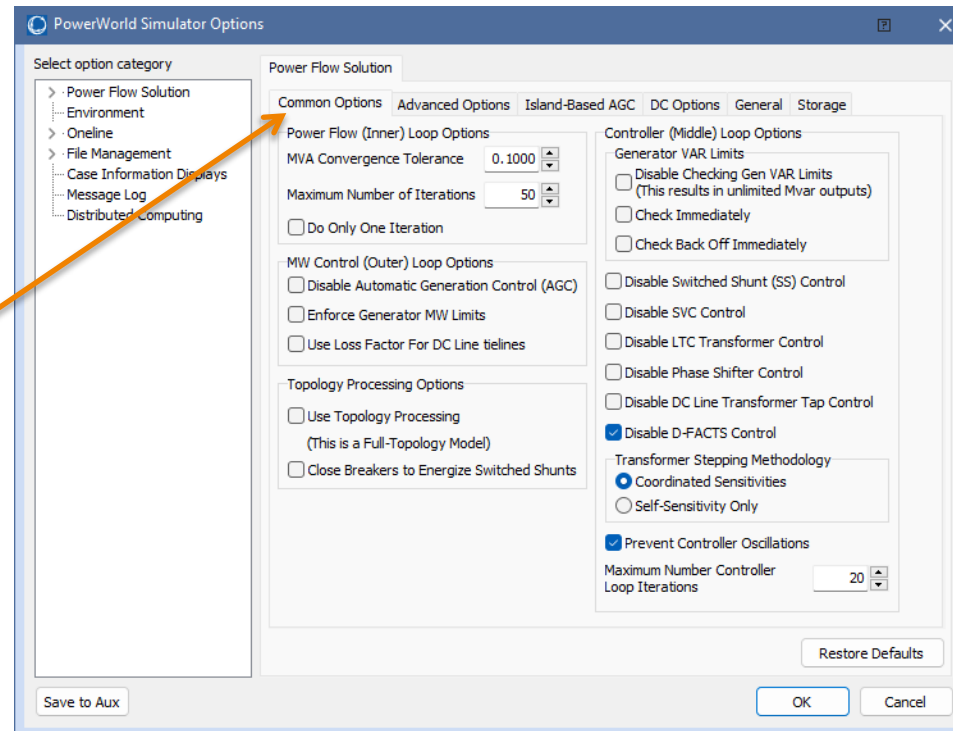
Simulator Options: Power Flow Solution Page



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



This will open to the
Common Options
tab by default



Simulator Options: Power Flow Solution Page



- Common Options Tab
 - MVA Convergence Tolerance
 - Tolerance for the Inner Power Flow Loop
 - Must be larger than zero
 - Maximum Number of Iterations
 - the maximum iterations for the inner power flow loop
 - Do only one iteration
 - Same as setting Maximum Number of Iterations to 1.
 - Disable Automatic Generation Control (AGC) disables enforcement of MW interchange for entire case,
 - Unchecking Enforce Generator MW Limits means generator MW limits are not enforced
 - Use Loss Factor for DC Line tielines uses the aLoss factor for two-terminal DC lines when calculating MW metering flows in area interchange calculations

A screenshot of the 'Power Flow (Inner) Loop Options' and 'MW Control (Outer) Loop Options' sections from the simulator interface. The 'Power Flow (Inner) Loop Options' section includes a text input for 'MVA Convergence Tolerance' set to '0.1000', a spinner for 'Maximum Number of Iterations' set to '50', and a checkbox for 'Do Only One Iteration'. The 'MW Control (Outer) Loop Options' section includes three checkboxes: 'Disable Automatic Generation Control (AGC)', 'Enforce Generator MW Limits', and 'Use Loss Factor For DC Line tielines', all of which are currently unchecked.

Power Flow (Inner) Loop Options

MVA Convergence Tolerance 0.1000

Maximum Number of Iterations 50

☐ Do Only One Iteration

MW Control (Outer) Loop Options

☐ Disable Automatic Generation Control (AGC)

☐ Enforce Generator MW Limits

☐ Use Loss Factor For DC Line tielines

Simulator Options: Power Flow Solution Page



- Common Options Tab
 - Generator VAR Limits
 - Disable Checking means generator MVAR limits are not enforced
 - Check immediately means that MVAR limits are checked in the inner power flow loop
 - Check Back Off Immediately means that generators are allowed to switch from being off control at limits to being on control in the inner power flow loop (switch from PQ to PV)
 - Disable Classes of Power and Impedance Controls (global settings that disable all such devices in case)
 - Switched Shunt (SS)
 - SVC (switched shunt devices on SVC control mode)
 - LTC Transformer
 - Phase Shifter
 - DC Line Transformer Tap Control
 - D-FACTS (distributed FACTS devices that control effective transmission line impedance)

Controller (Middle) Loop Options

Generator VAR Limits

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

☐ Disable Switched Shunt (SS) Control

☐ Disable SVC Control

☐ Disable LTC Transformer Control

☐ Disable Phase Shifter Control

Simulator Options: Power Flow Solution Page



- Common Options Tab

- Transformer Stepping Methodology

- *Coordinated Sensitivities* looks at all transformers that are out-of-range and coordinates the movement to bring all back within regulation range
 - *Self-Sensitivity Only* looks at each transformer individually and determines the sensitivity of its regulated value with respect to changing its own tap or phase only
 - Note: If more than 50 transformers are involved, Simulator always uses *Self-Sensitivity Only*

- Prevent Controller Oscillations

- keeps controlled devices from continually switching between two control states for the entire case

- Maximum Number of Controller Loop Iterations

- The voltage control loop will be limited to this many iterations

Transformer Stepping Methodology

☒ Coordinated Sensitivities

☐ Self-Sensitivity Only

☒ Prevent Controller Oscillations

Maximum Number Controller Loop Iterations: 20



Covered in
More Detail
in other
Courses

Simulator Options: Power Flow Solution Page



- Advanced Options Tab

The screenshot shows the 'PowerWorld Simulator Options' dialog box with the 'Power Flow Solution' tab selected. The 'Advanced Options' sub-tab is active. The left sidebar shows a tree view with 'Power Flow Solution' expanded. The main area contains various settings for the power flow solution, including checkboxes for dynamically adding/removing slack buses, evaluating power flow for each island, and requiring the largest island for a successful solution. It also includes sections for defining post-power flow actions, power flow (inner) loop options, control (middle) loop options, pre-processing, post-processing, and sharing of generator vars across groups of buses during remote regulation. The 'ZBR Threshold' is set to 0.000290. Buttons for 'Save to Aux', 'Restore Defaults', 'OK', and 'Cancel' are at the bottom.

PowerWorld Simulator Options

Select option category

- > Power Flow Solution
 - Environment
 - Online
 - File Management
 - Case Information Displays
 - Message Log
 - Distributed Computing

Power Flow Solution

Common Options Advanced Options Island-Based AGC DC Options General Storage

☐ Dynamically add/remove slack buses as topology is changed

☐ Evaluate Power Flow Solution For Each Island

☐ Require Largest Island Solved for Successful Solution

Define Post Power Flow Solution Actions

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

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 0.0500

Var Limit Backoff Volt Tolerance 0.000050

Pre-Processing

☐ Disable Angle Smoothing

Post-Processing

☐ Disable Angle Rotation Processing

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

ZBR Threshold 0.000290

Restore Defaults

Save to Aux OK Cancel



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 terminal bus)
- Evaluate Power Flow Solution for Each Island
 - A partial solution can result if some islands solve and others do not
- Require Largest Island Solved for Successful Solution
 - Island with the most buses must solve or the entire solution will be reported as unsolved
- 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.

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 solutions with voltages at 1.0 per unit and 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 Solution Page: Advanced Options Tab



- Disable Treating Continuous SSs as PV Buses
 - Continuous switched shunts are normally treated as buses with fixed 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
- Min. Sensitivity for LTC Control
 - Transformers with a sensitivity lower than this will be disabled.



Power Flow Solution Page: Advanced Options Tab

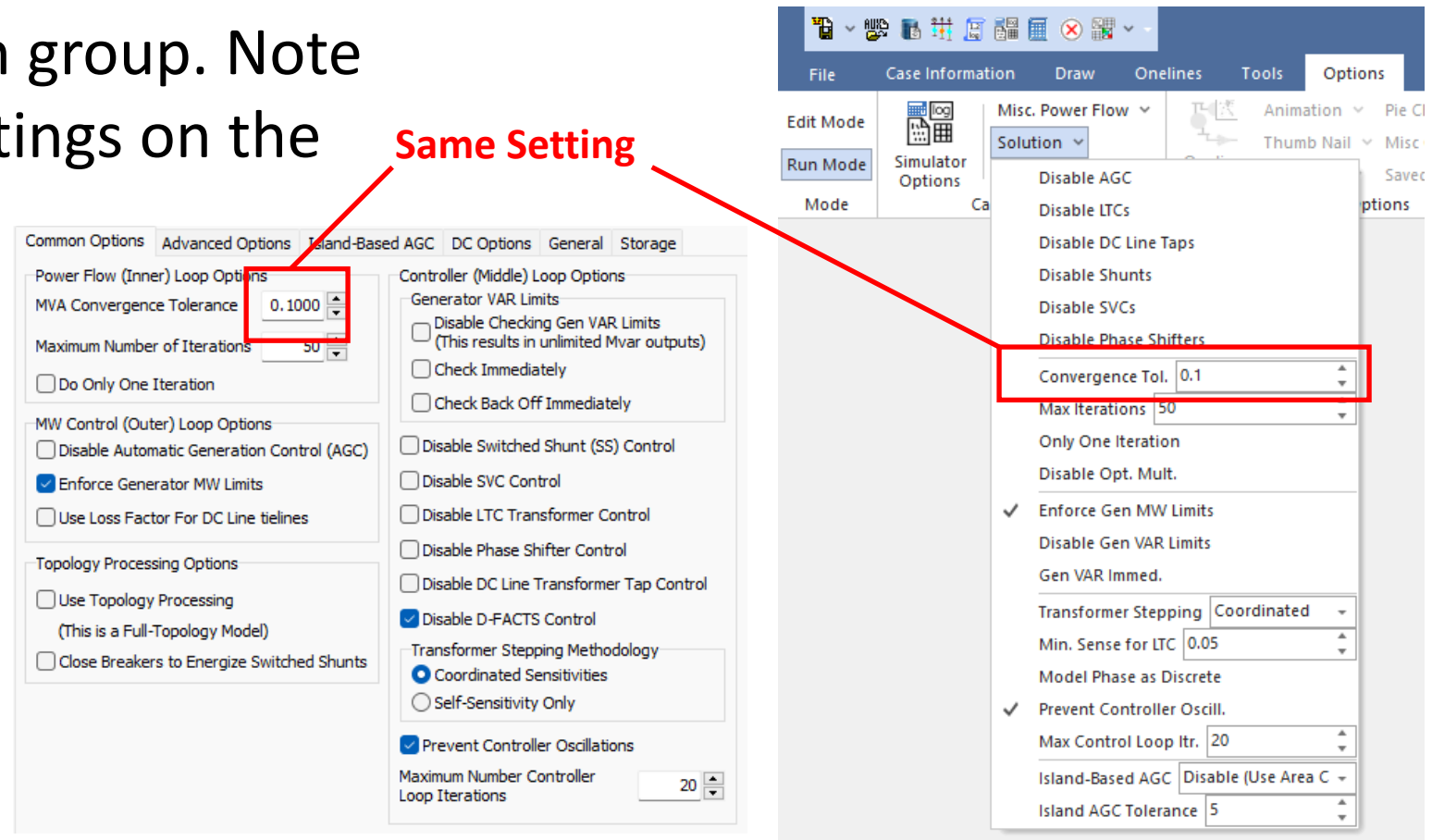


- Disable Angle Rotation Processing
 - Voltage angles are rotated so that the angle range in an island is equally spaced around zero degrees if any angles fall outside +/- 160 degrees
- Sharing of generator vars across groups of buses
 - Allocate across buses using the user-specified remote regulation 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

Solution Options Toolbar



- Select the **Solution** button on the **Case Options** ribbon group. Note that most of the settings on the dialog are available.



Power Flow Solution Page: Island-Based AGC Tab



- Enable to allow load and generation balancing across an island, instead of Areas or Super Areas

Options used for
Injection Group
Dispatch

PowerWorld Simulator Options

Select option category

- > Power Flow Solution
- Environment
- > Online
- > File Management
- Case Information Displays
- Message Log
- Distributed Computing

Power Flow Solution

Common Options Advanced Options **Island-Based AGC** DC Options General Storage

☐ Enable Island-based Automatic Generation Control (AGC)

Note: This overrides the Area and Super Area Dispatch settings

Island AGC Tolerance 5.0000

Island-based Automatic Generation Control (AGC)

☒ Use Participation Factors of individual generators

☐ Calculate Participation Factors from Area Make Up Power Values

Specify Area Make Up Power Values

☐ Dispatch using an Injection Group (Loads and Generators will respond)

Injection Group Name

☐ Allow only AGC units to vary

☐ Enforce unit MW limits

☐ Do not allow negative loads

How should reactive power load change as real power load is ramped?

☐ Keep ratio between real and reactive power constant at each load then scale Mvar by a factor of 1.00

☒ As MW changes, change Mvar at a power factor of 1.00

Restore Defaults

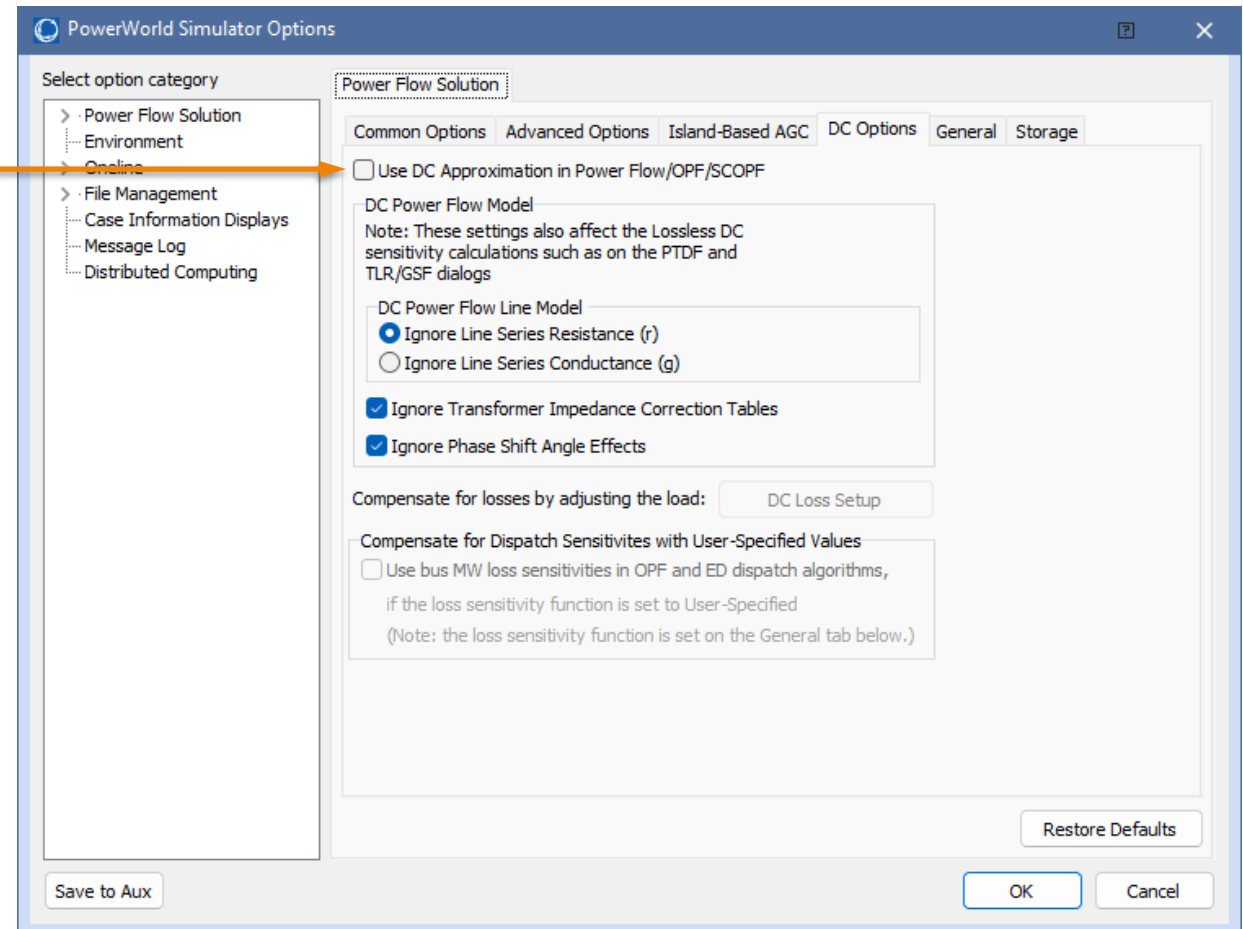
Save to Aux OK Cancel

Power Flow Solution Page: DC Options Tab



- Use DC Approx. in Power Flow/ OPF/SCOPF
 - Check this box to model the system using a DC power flow.

Note: Once you convert a large system to a DC power flow, it is very difficult to get the AC system to resolve.



Power Flow Solution Page:

DC Options Tab



- Compensate for Losses by Adjusting the Load
 - Specify a load multiplier at each bus. When solving the DC power, Simulator will artificially increase loads by this multiplier
- Compensate for Dispatch Sensitivities with User-Specified Values
 - Allows you to make use of loss sensitivities even in the DC power flow

Power Flow Solution Page:

DC Options Tab

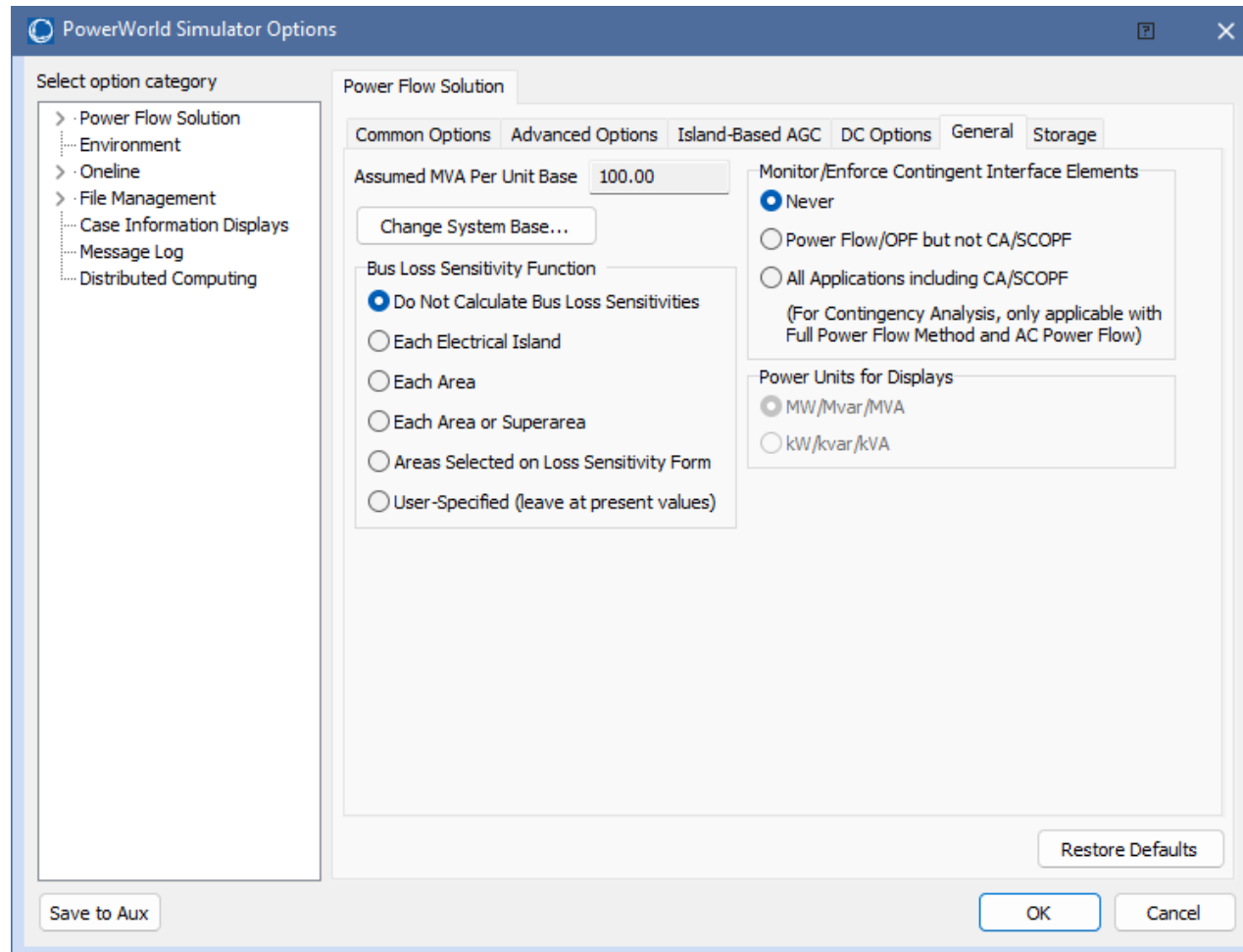


- DC Power Flow Model
 - Ignore Line Series Resistance (r)
 - $b = -1/x$, $g = 0$
 - Ignore Line Series Conductance (g)
 - $b = -x/(r^2+x^2)$, $g = 0$
 - Ignore Transformer Impedance Correction Tables and Ignore Phase Shift Angle Effects (default is to ignore)
 - Impedance correction tends to increase impedance and phase shift effects tend to decrease impedance
 - By not ignoring, DC equations become a function of the system state and removes some of the advantages of the DC approximation

Simulator Options: Power Flow Solution Page



- General Tab



Power Flow Solution Page: General Tab

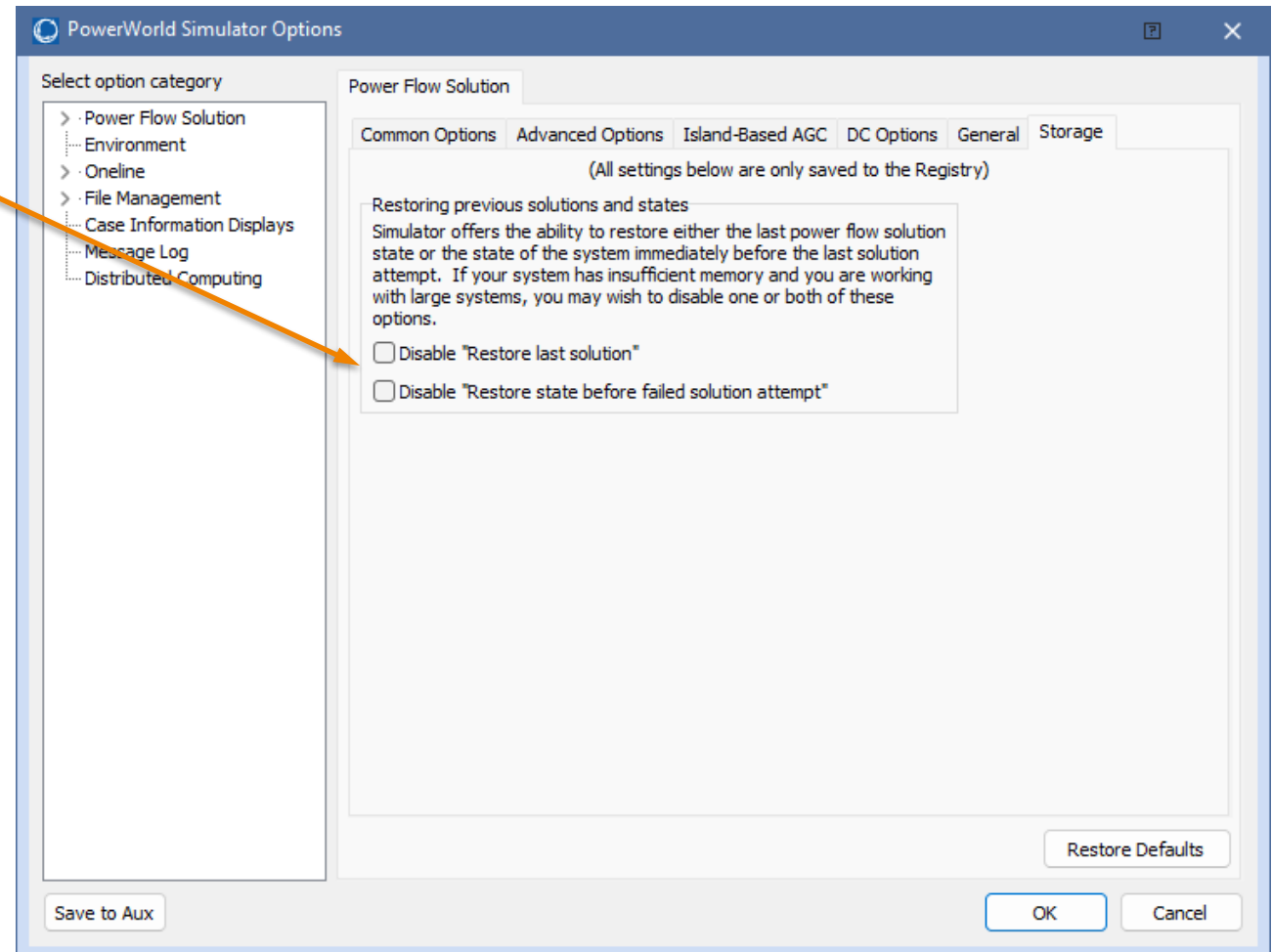


- Assumed MVA Per Unit Base
 - MVA base used for the entire case
 - Default is 100 MVA
- Monitor/Enforce Contingent Interface Elements
 - Determine when the impact of contingent interface elements should be calculated
- Bus Loss Sensitivity Function
 - Discussed when we go over sensitivities in the Sensitivity Training section

Simulator Options: Power Flow Solution Page



- Storage Tab
 - Might check these boxes if system memory is a limitation
 - Normally preferred to leave them unchecked



Islands - Defined



- Often, a power system consists of a single interconnected system operating in synchronism
- However sometimes multiple systems exist that are either unconnected or connected only through DC transmission lines.
- Such systems operate asynchronously with one another and are called “Islands”.
- Each island must have a slack bus.

Multiple Islands in Simulator



- In **Simulator Options** → **Power Flow Solution** → **Advanced Options**, check “Dynamically add/remove slack buses as topology is changed”
- In the B7FLAT case, the slack bus is 7.
- To create two islands, open lines 2-6 and 5-7.
- If new island does not have a slack, Simulator automatically chooses largest generator
- Repeat with “Dynamically add/remove...” unchecked

The diagram illustrates a power system with the following components and data:

- Left Area (Pink):**
 - One:** 100 MW, AGC ON, 1.05 pu.
 - Two:** 40 MW, 20 Mvar, 1.04 pu.
 - Six:** 200 MW, 0 Mvar, 1.04 pu.
 - Left Area Cost:** 4184 \$/hr.
- Top Area (Yellow):**
 - Three:** 110 MW, 40 Mvar, 0.99 pu.
 - Four:** 80 MW, 30 Mvar, 1.00 pu.
 - Five:** 130 MW, 40 Mvar, 0.95 pu.
 - Top Area Cost:** 8084 \$/hr.
- Right Area (Green):**
 - Seven:** 200 MW, 0 Mvar, 1.04 pu.
 - Right Area Cost:** 4701 \$/hr.
- Other Components:**
 - 115% MVA:** A central red circle indicating a 115% MVA limit.
 - Power Flows:** Indicated by green arrows with values (e.g., 43 MW, 42 MW, 30 MW, 34 MW, 33 MW, 28 MW, 27 MW, 103 MW, 108 MW, 57 MW, 56 MW, 39 MW, 38 MW, 34 MW, 0 MW).
 - AGC ON:** Automatic Generation Control is enabled for units One, Two, Six, and Seven.

Two orange arrows point to the tie-lines between the areas, labeled "Open tie-lines".

The diagram illustrates a power system with the following components and data:

- Left Area (Pink):**
 - One:** 100 MW, AGC ON, 1.05 pu.
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 - Six:** 200 MW, 0 Mvar, 1.04 pu.
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 - Top Area Cost:** 8084 \$/hr.
- Right Area (Green):**
 - Seven:** 200 MW, 0 Mvar, 1.04 pu.
 - Right Area Cost:** 4701 \$/hr.
- Other Components:**
 - 115% MVA:** A central red circle indicating a 115% MVA limit.
 - Power Flows:** Various power flows are indicated by arrows, such as 43 MW, 42 MW, 30 MW, 34 MW, 33 MW, 28 MW, 27 MW, 108 MW, 103 MW, 0 MW, and 0 Mvar.
 - AGC ON:** Automatic Generation Control is enabled for several units.

Open tie-lines are highlighted with orange arrows, connecting the Left Area to the Top Area and the Top Area to the Right Area.

Island Records Display

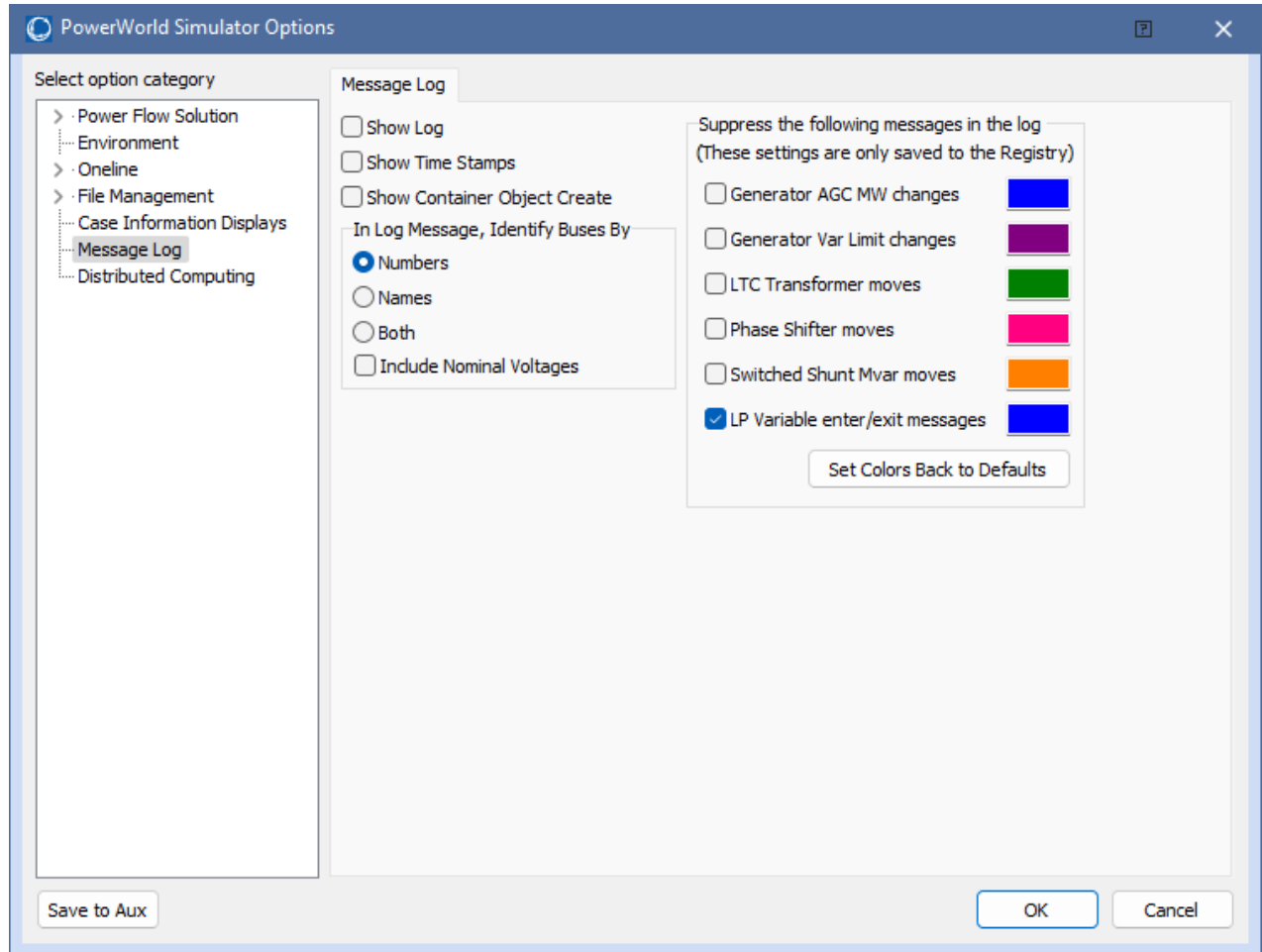


- **Model Explorer → Aggregations → Island Records** shows information about each island in the case, including its slack bus.
- It is not uncommon to have multiple islands. Cases in the Eastern US/Canada usually have several islands.

X Case Islands X Inj Groups X Super Areas X Areas X Nomograms X Interfaces X Buses									
DPT. >< +.0 +.00 .00 +.0 ABCD Records Set Columns f(x) Options									
Filter Find... Remove									
	Slack Bus Number	Slack Bus Name	Slack Bus Area Name	Total Buses	Energized	Gen MW	Gen Mvar	Load MW	Load Mvar
1	7	Seven	Right	2	YES	399.9	-10.8	400.0	0.0
2	2	Two	Top	5	YES	209.1	68.0	360.0	130.0

Simulator Options: Message Log Page

- Customize message log notation, contents, and appearance



Simulator Options: Environment Page

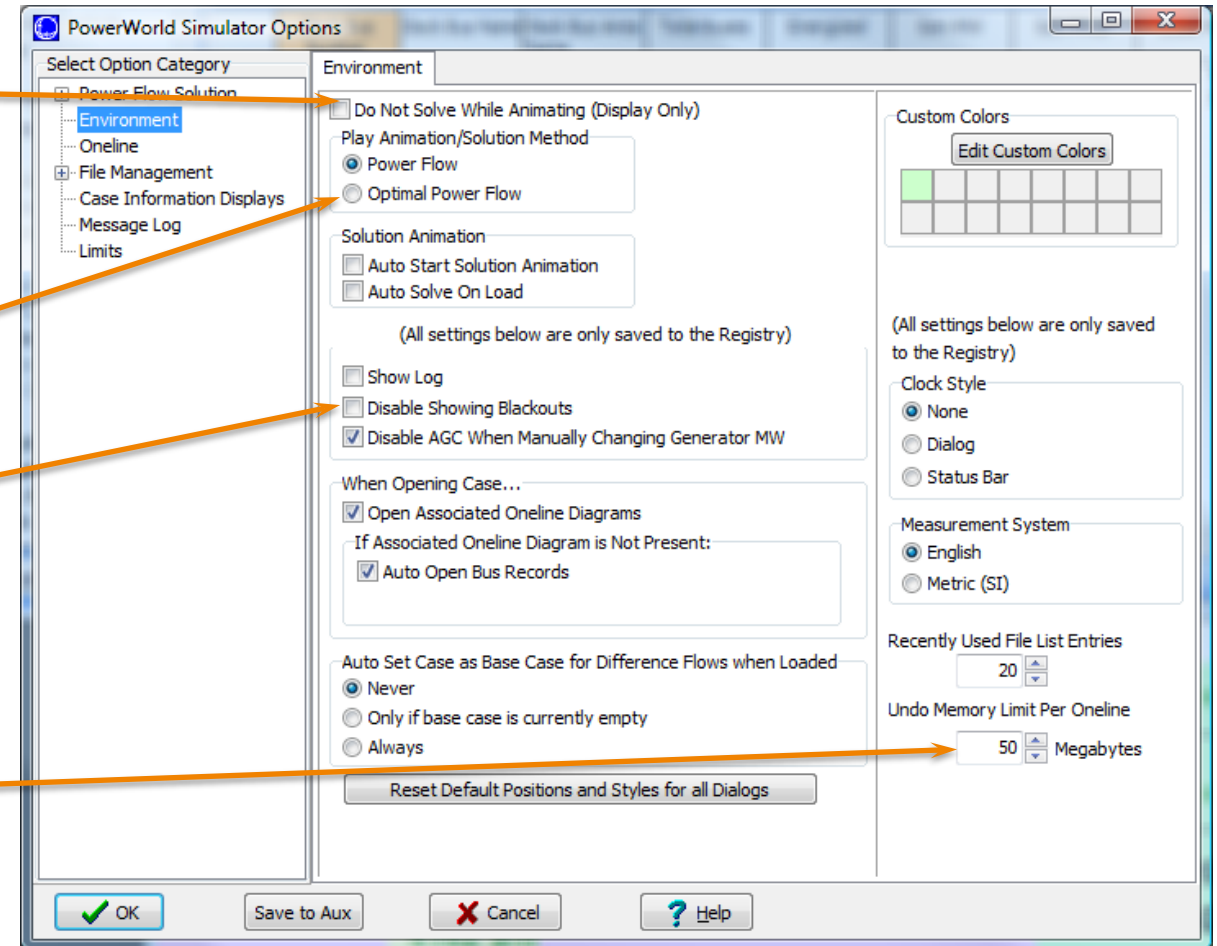


Show flow arrows only
when “Play” button is
active; no simulation

Solution method when animating

“Blackout” dialog displays if
case does not converge

Memory limit for
Online Undo feature

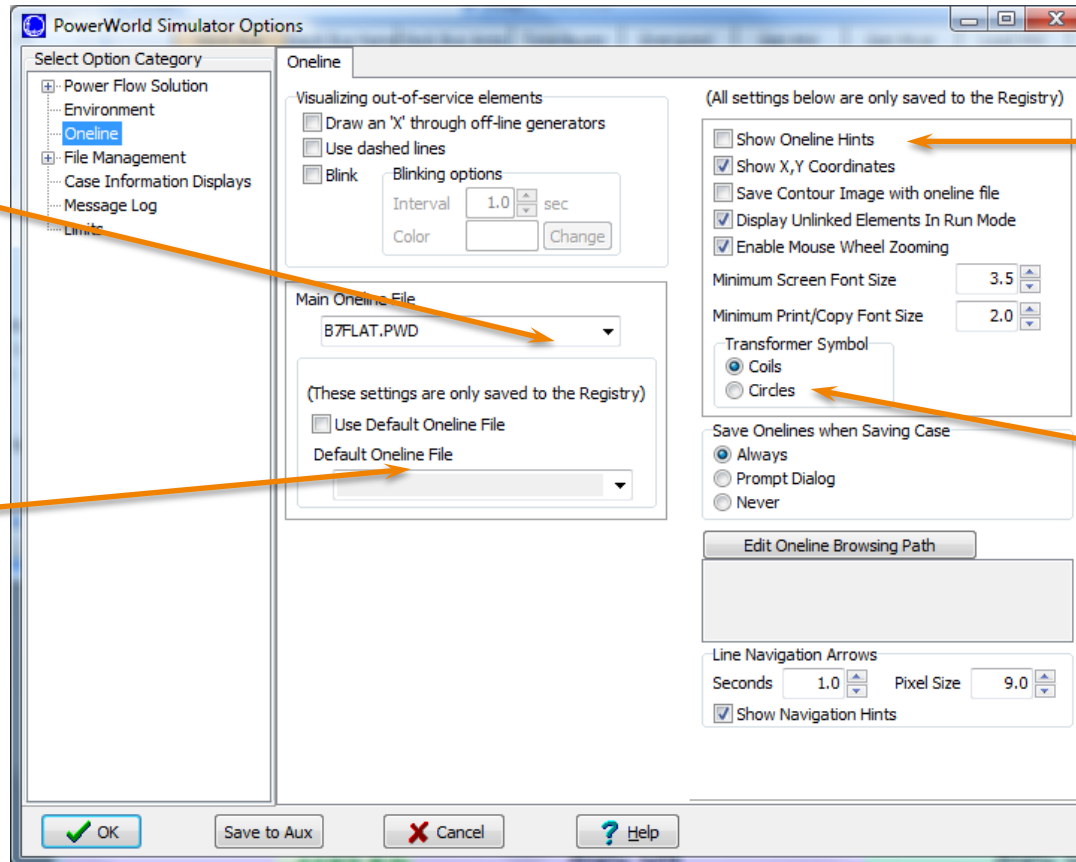


Simulator Options: Online Page



Name of main
online file for
CURRENT case

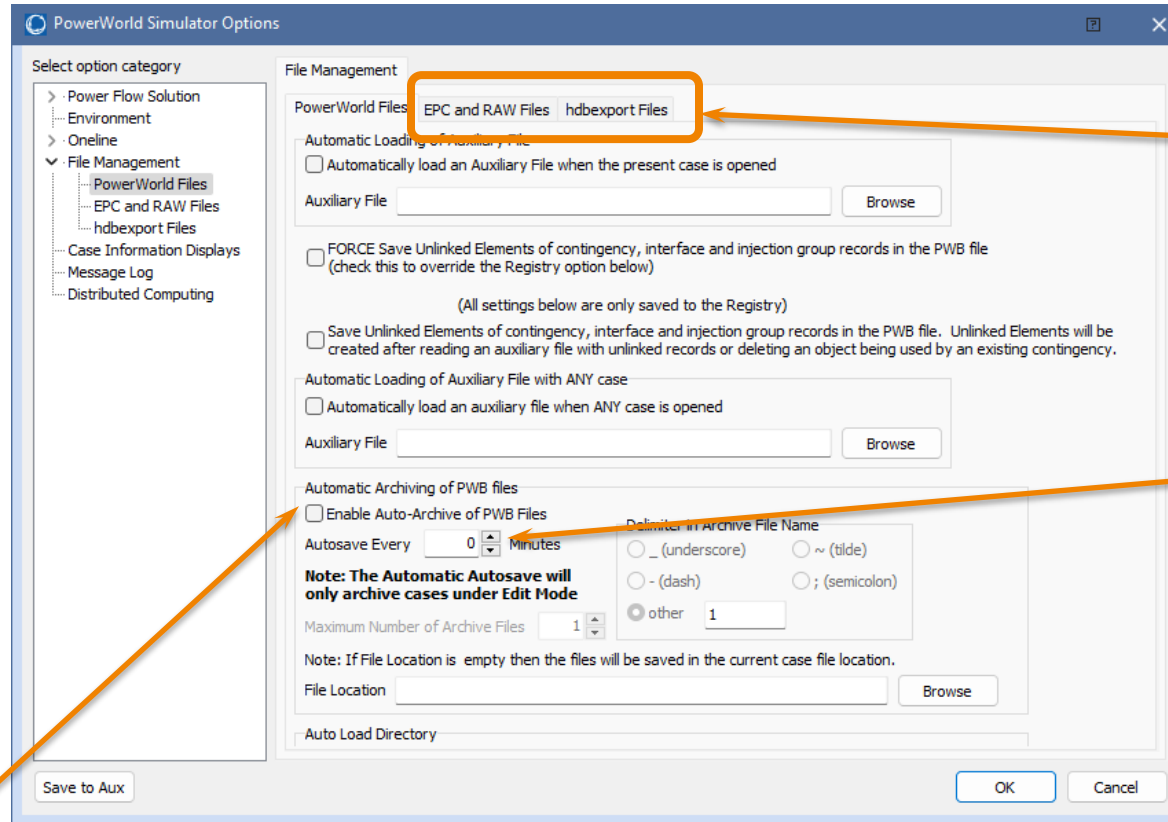
Name of default
online file to
open for ALL cases



Shows hints
when cursor
over element

Non-US style
XFR symbols

Simulator Options: File Management Page



Special options tabs for other file types

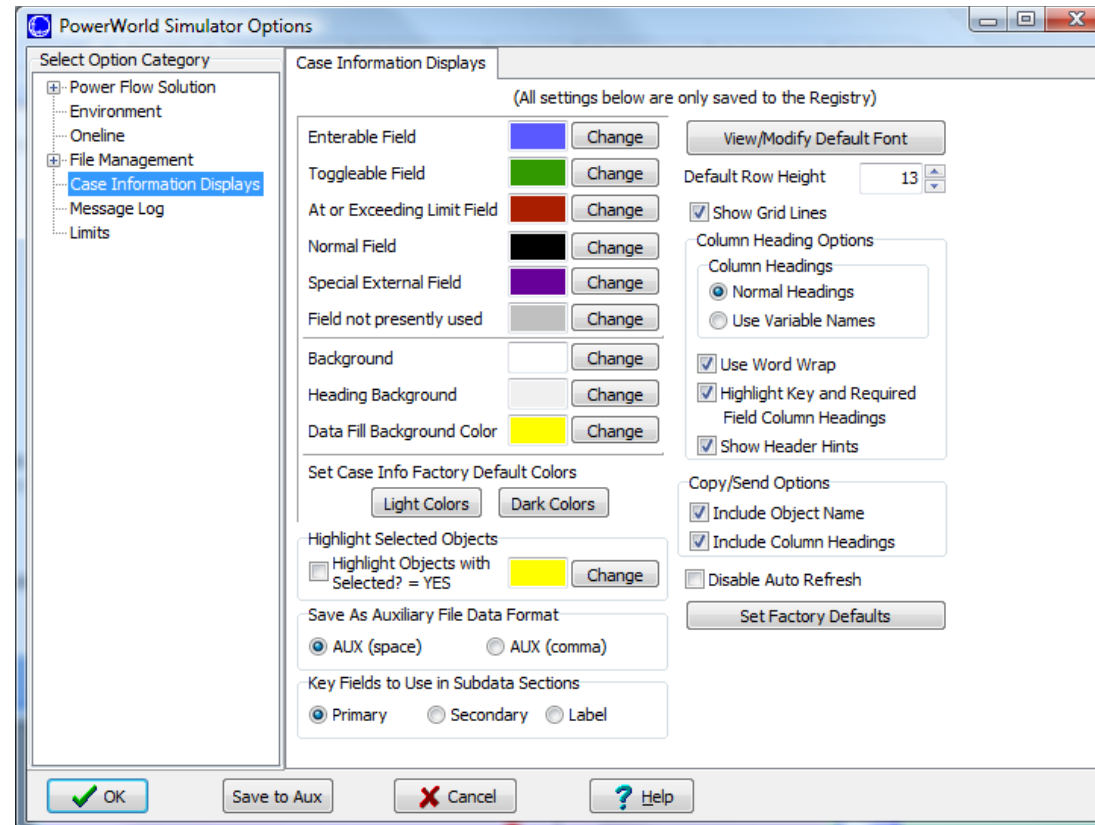
Automatically save over current PWB. “0” means do not Autosave

Enables previously saved PWB files to be automatically archived each time the file is saved with the same name

Simulator Options: Case Information Displays



- This was covered in an earlier section on Case Information Displays



Generator AVR



- Generator AVR is integrated directly into the power flow equations. (AVR creates “PV buses”)
- Generators on AVR maintain a fixed voltage magnitude at the regulated bus, provided reactive power output is within limits.
- To change options, right-click on generator symbol and select Information Dialog.

Generator Dialog (Edit Mode)



MW Control will be discussed later
Present reactive power output

Fixed reactive power limits if capability curve is not used

Check to define and use MW dependent capability curve

Generator Options

Bus Number: 1, Bus Name: One, ID: 1, Area Name: Top, Labels: no labels

Status: ☐ Open, ☒ Closed, Generator MVA Base: 100.00

Fuel Type: UN (Unknown) | [PW=0] [EPC=0], Unit Type: [dropdown]

Display: Information, Power and Voltage Control (selected), Costs, Fault Parameters, Owners, Area, etc, Custom, Stability

Power Control: MW Setpoint: 101.853, MW Output: 101.853, Min. MW Output: 100.000, Max. MW Output: 400.000, Part. Factor: 1.00

Voltage Control: Mvar Output: 5.252, Min Mvars: -9900.000, Max Mvars: 9900.000

Available for AGC: ☒ Available for AVR: ☒ Enforce MW Limits during automatic control: ☒ Use Capability Curve: ☐

Regulated Bus Number: 1, SetPoint Voltage: 1.050000, SetPoint Voltage Tol: 0.000000, Remote RegFactor: 100.0

Line Drop Compensation: Use LDC: No, Xcomp: 0.000100, Rcomp: 0.000000

Wind Control Mode: Mode: None, Power Factor: 1.0000

Voltage Droop Control: Name: [blank], Find..., Clear, Add...

OK, Save, Save to Aux, Cancel, Help

If not checked then Mvar output is fixed

Regulated Bus and voltage regulation parameters

Line Drop Compensation Options

Droop Control Scheme (not used if blank)

Remote Regulation and Var Sharing



- You may specify a regulated bus number that is not the terminal bus (commonly called “remote” regulation)
- Multiple generators may regulate the same bus
 - Generators at different buses will share the total Var requirement according to the option selected for sharing vars across groups of buses (Advanced Options Tab of Power Flow Solution Page)
 - Generators at the same bus will coordinate Var outputs so they are within the same relative location inside their Var range
 - Generators can share at the same bus and remotely regulate at the same time. In this case the “regulation percentage” refers to all the generators at the bus

Defining Reactive Capability Curve



- To use a reactive capability curve, on the Generator Dialog, check **Use Capability Curve**.
- Then use table to edit the curve. Right-click on a column of table (a point on the curve) to either
 - **insert** a new point (table column)
 - **delete** an existing point (table column)

Reactive Capability Curve



- Enter the following capability curve

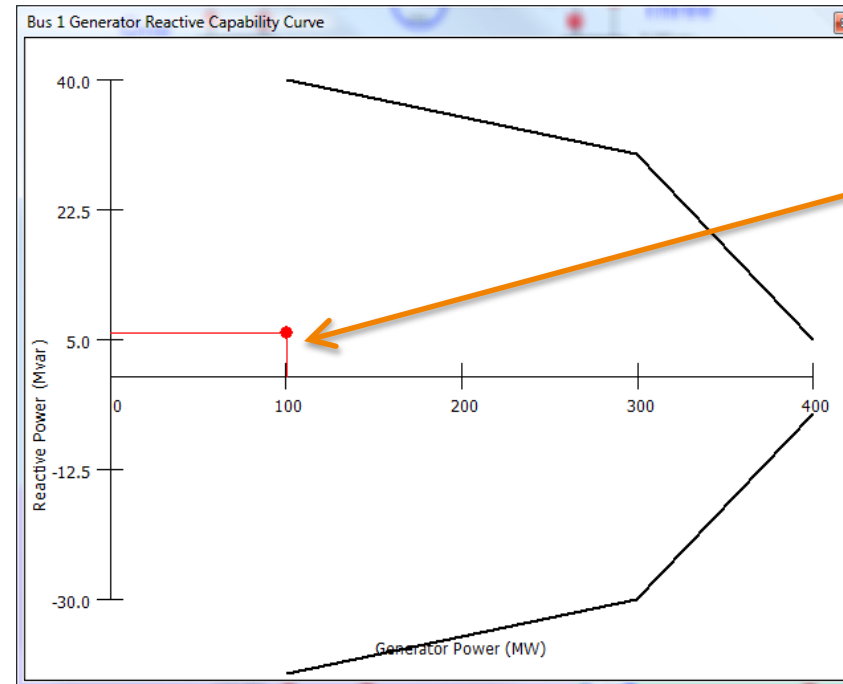
MW	100.0	300.0	400.0
Min Mvar	-40.0	-30.0	-5.0
Max Mvar	40.0	30.0	5.0

- You can view a graph of the reactive capability curve by selecting **Reactive Capability Curve** from the generator menu.

Capability Curve Graph



Right-click on generator to view its local-menu



Current MW and Mvar operating point of the generator

Play the simulation, and then use the spin button to the right of the generator to change the MW output of the generator. Notice how the operating point on the graph changes.

Saving Reactive Capability in Text File



- All power system data, including the generator reactive capability curve, is saved in PowerWorld Binary format (*.pwb) files
- Reactive capability curve data is not saved in most text-based power flow formats, such as PTI RAW or GE EPC files.
- Simulator provides the ability to save this data in text files for easy transfer between cases.

Saving in Text Files

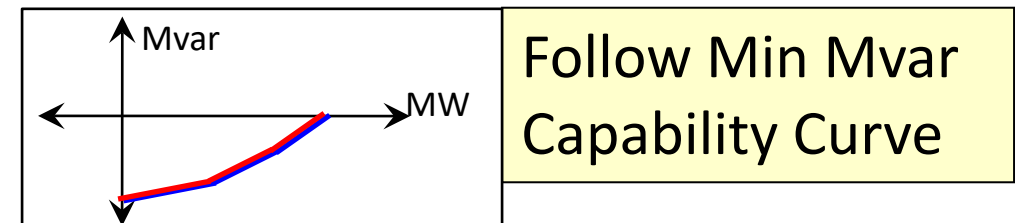
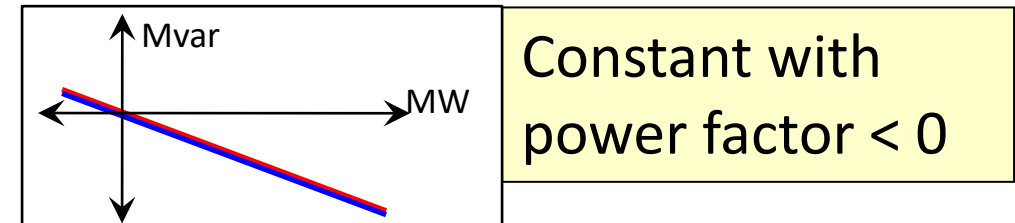
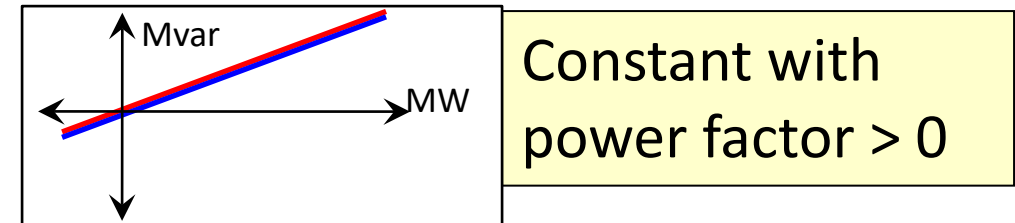
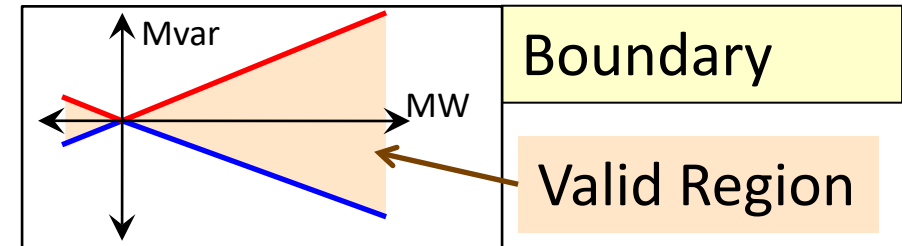
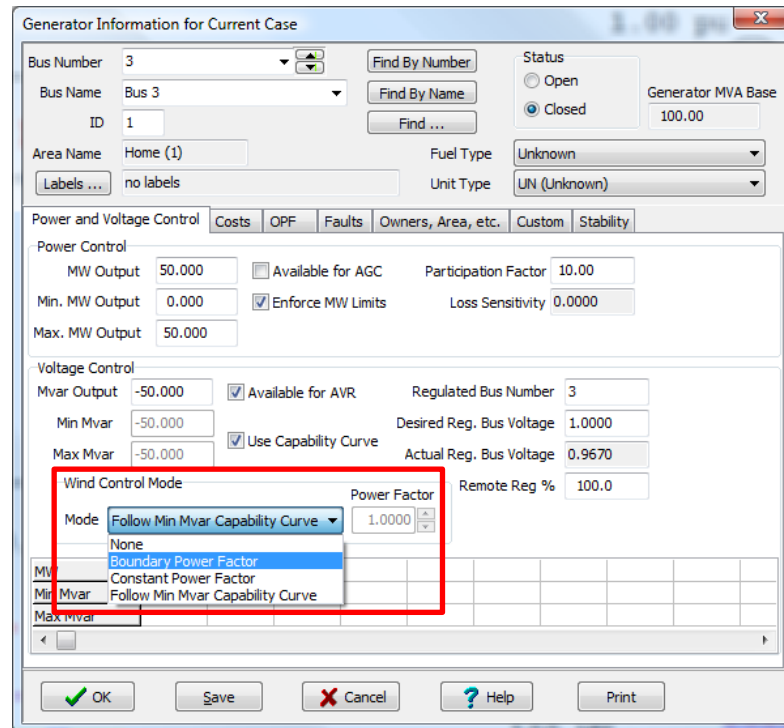


- To save reactive capability data in a text (aux) file
 - Go to the **Model Explorer** → **Network** → **Generators**
 - Right-Click and choose **Save As** → **Auxiliary File**
 - Choose the filename to save under and Click **OK**
 - You will then be prompted regarding saving the Bid Curve and Reactive Capability Curve data to the AUX file. Choose **Yes** to the Reactive Capability Curve
 - Reactive Capability Curves are stored in SUBDATA sections of the AUX file
 - *.aux file can then be manually edited

Generator Wind Control Mode



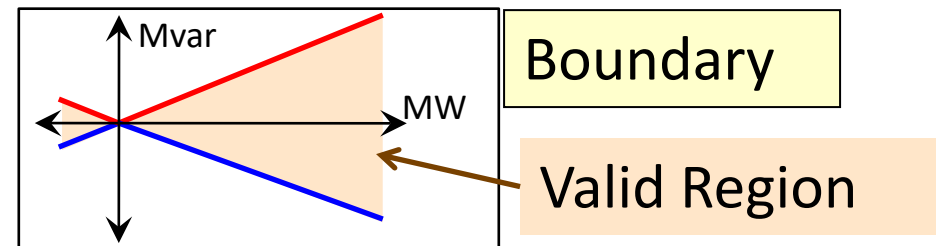
- Wind Farms often have Mvar limits that are related to a specified power factor
- This can be modeled using the Wind Control Mode Option



Wind Control Mode Options



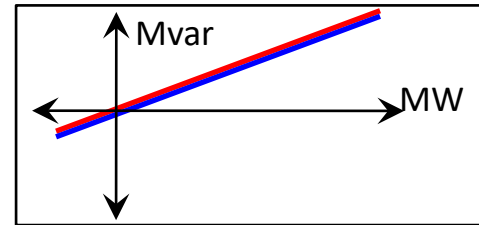
- None
 - Use default behavior with specified Max/Min Mvar or capability curve
 - Only generators without a wind control mode may be automatically chosen as a slack bus
- Constant and Boundary Power Factor
 - Mvar limit magnitudes are determined from the actual MW output and the specified power factor
 - $\text{Magnitude} = \text{MWOutput} * \tan(\arccos(\text{Power Factor}))$
 - Boundary Power Factor
 - Max Mvar output is positive
 - Min Mvar output is negative
 - Sign of power factor is not used



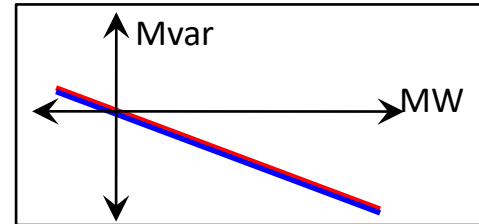
Wind Control Mode Options



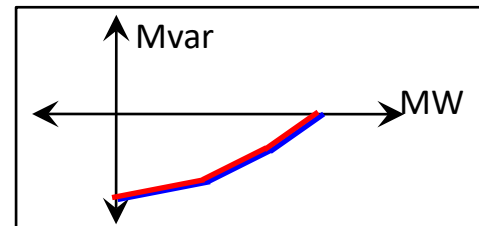
- Constant Power Factor
 - Max Mvar = Min Mvar
 - If power factor is positive, the limits have the same sign as the actual MW output
 - If power factor is negative, the limits have the opposite sign as the actual MW output
- Follow Min Mvar Capability Curve
 - Mvar output determined by a lookup of the Min Mvar value on the capability curve
 - Make generator's Mvar output a piecewise linear function of the MW output



Constant with
power factor > 0



Constant with
power factor < 0

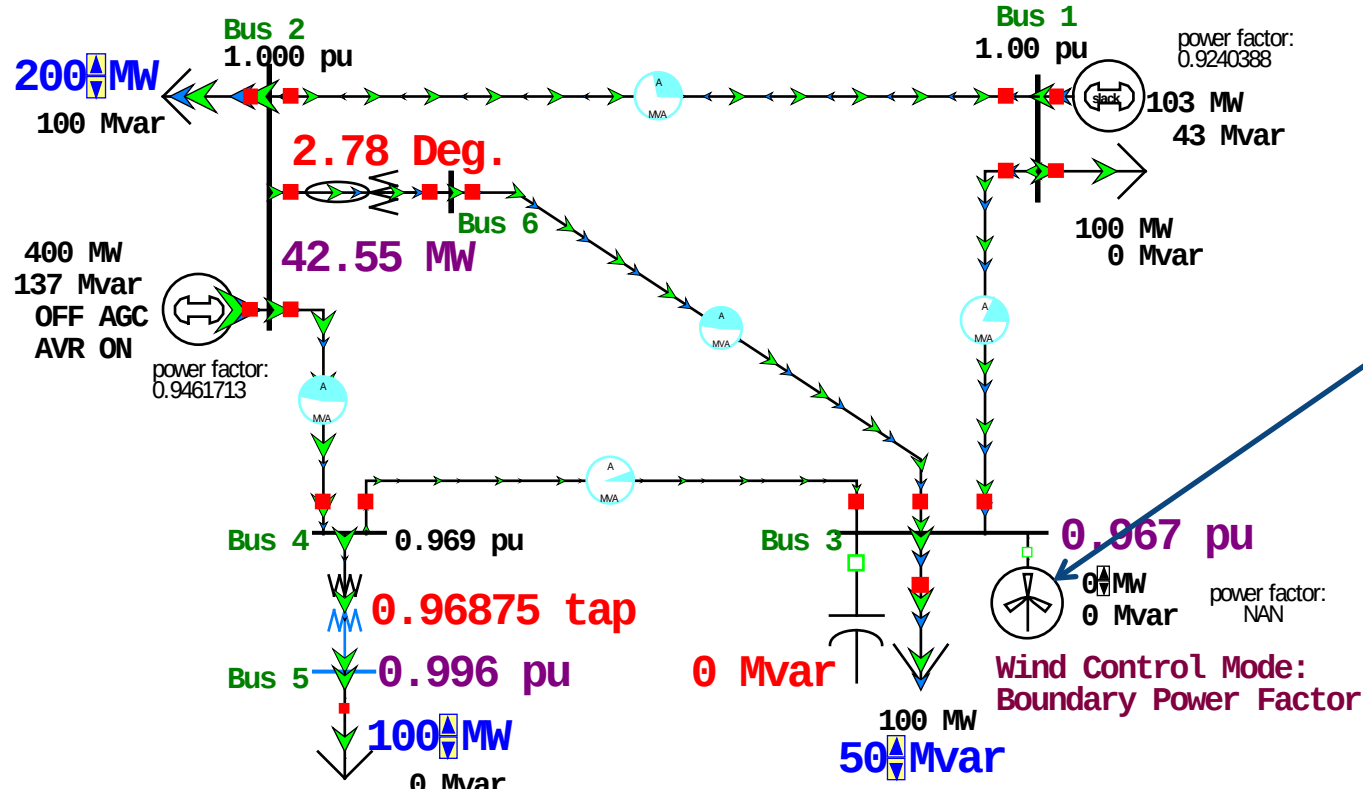


Follow Min Mvar
Capability Curve

Wind Control Modes



- Open Case B5RWind.pwb – note that Switched Shunt, LTC, and Phase Shifter control are all disabled



Check that the power factor setting for the wind plant is 0.95

Set to “Boundary Power Factor”

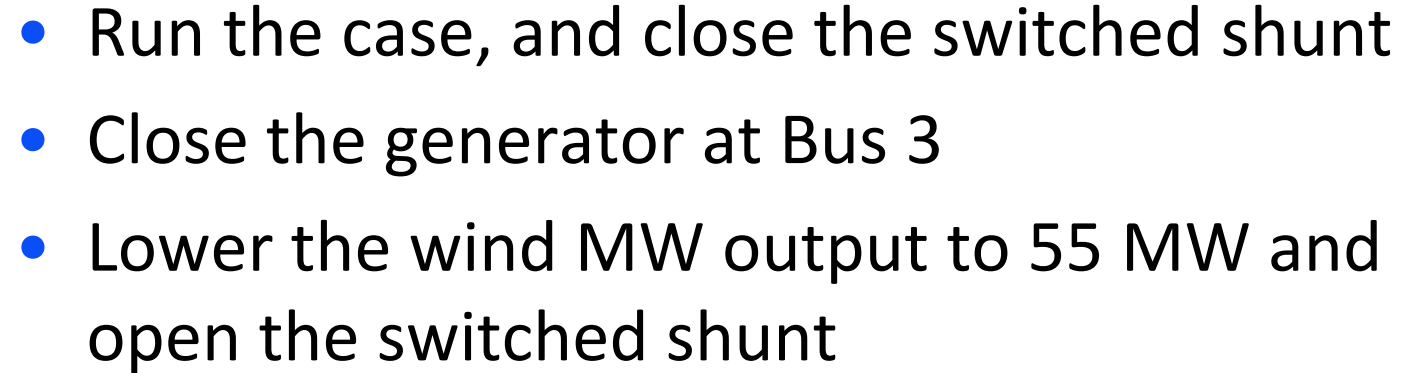
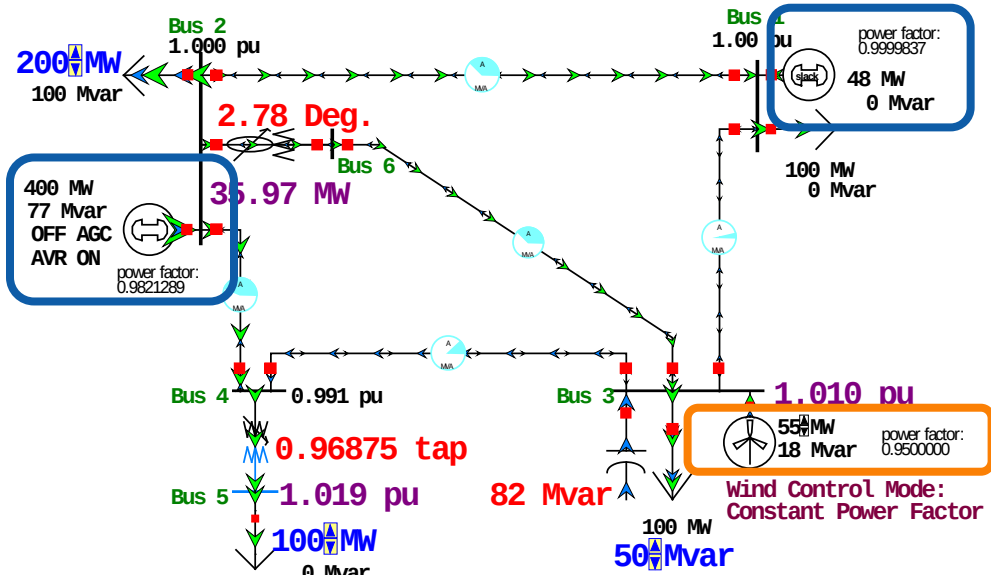


Figure 10: A detailed power system diagram showing a network of six buses (Bus 1 to Bus 6) connected by transmission lines. The diagram includes various power sources and loads. Bus 1 is connected to Bus 2 (1.000 pu) and Bus 3 (0.979 pu). Bus 2 is connected to Bus 3 (1.000 pu) and Bus 4 (0.976 pu). Bus 3 is connected to Bus 4 (0.976 pu) and Bus 5 (1.002 pu). Bus 4 is connected to Bus 5 (1.002 pu) and Bus 6 (34.82 MW). Bus 5 is connected to Bus 6 (34.82 MW) and Bus 3 (1.002 pu). Bus 6 is connected to Bus 3 (34.82 MW) and Bus 4 (34.82 MW). The diagram also shows a 200 MW generator at Bus 2, a 400 MW generator at Bus 4, a 55 MW generator at Bus 3, and a 100 MW load at Bus 3. The diagram includes various power factor and tap settings, such as 0.9578711 for the 400 MW generator and 0.96875 tap for the 100 MW load. The diagram is color-coded with blue for transmission lines, red for generators, and green for loads.

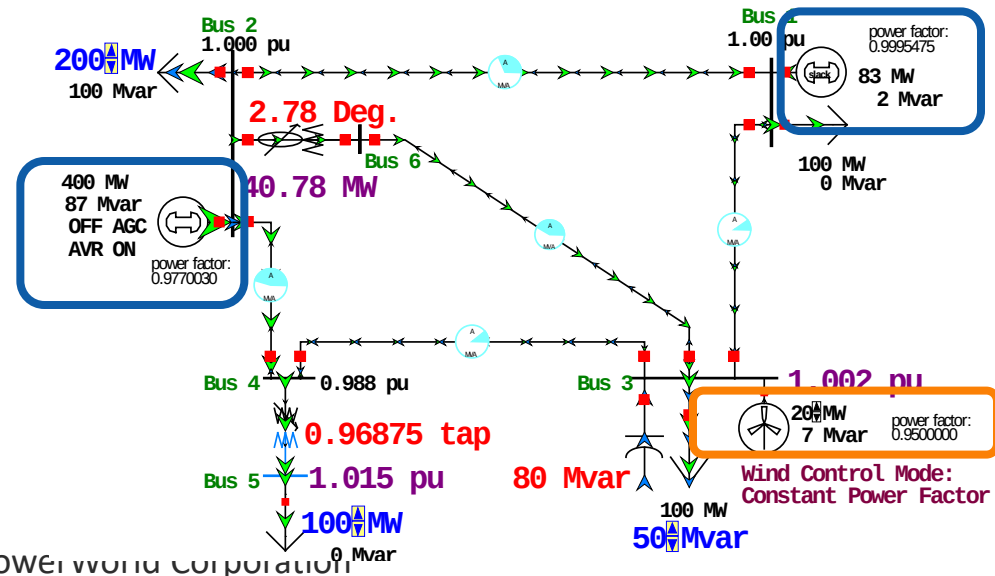
Example

Constant Power Factor



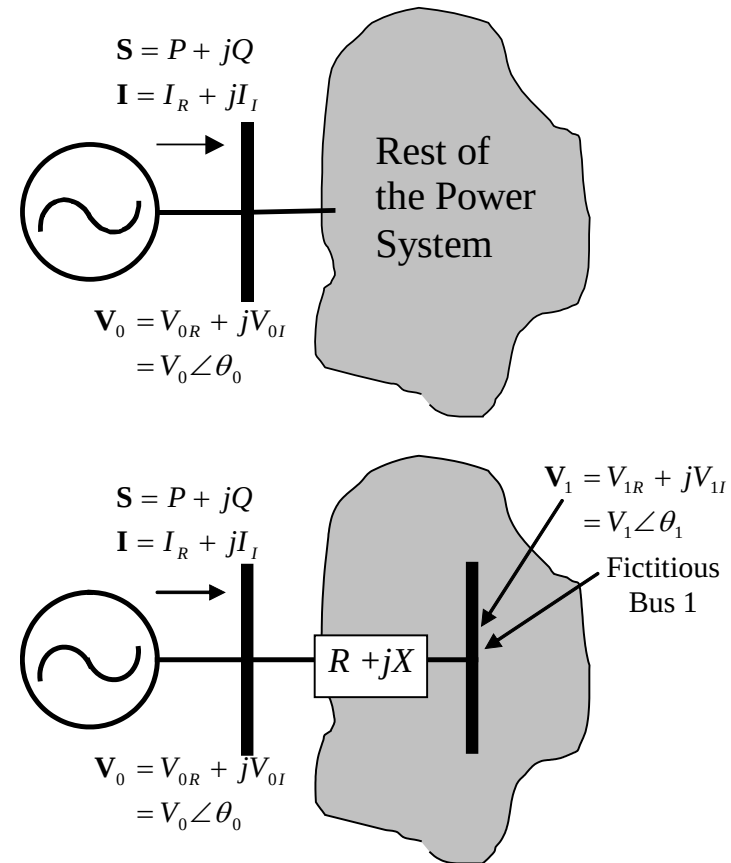
Experiment with the other wind control settings

- Change Gen 3 to Constant Power Factor
- Run the case
- Close the switched shunt
- Lower the wind to 20 MW and see the Mvar outputs adjust



Line Drop Compensation

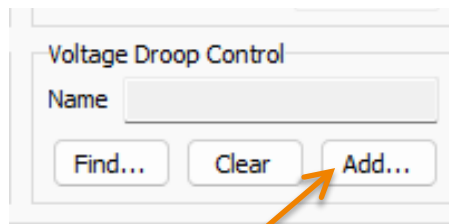
- Without LDC
 - Generator is connected to terminal and controls a bus voltage (may be terminal or remote bus)
- Generator using LDC
 - Generator controls the voltage at a “fictitious bus” some impedance away from the generator
 - This models the real-time control done at some generators
 - If Xcomp and Rcomp are both less than the ZBR Threshold (default 0.0002) the generator will regulate its own terminal
- Can be used always (Use LDC=YES) or only during Contingencies (Use LDC= PostCTG)
 - During contingencies, the voltage setpoint for the fictitious bus is set equal to the pre-contingency value at the fictitious bus



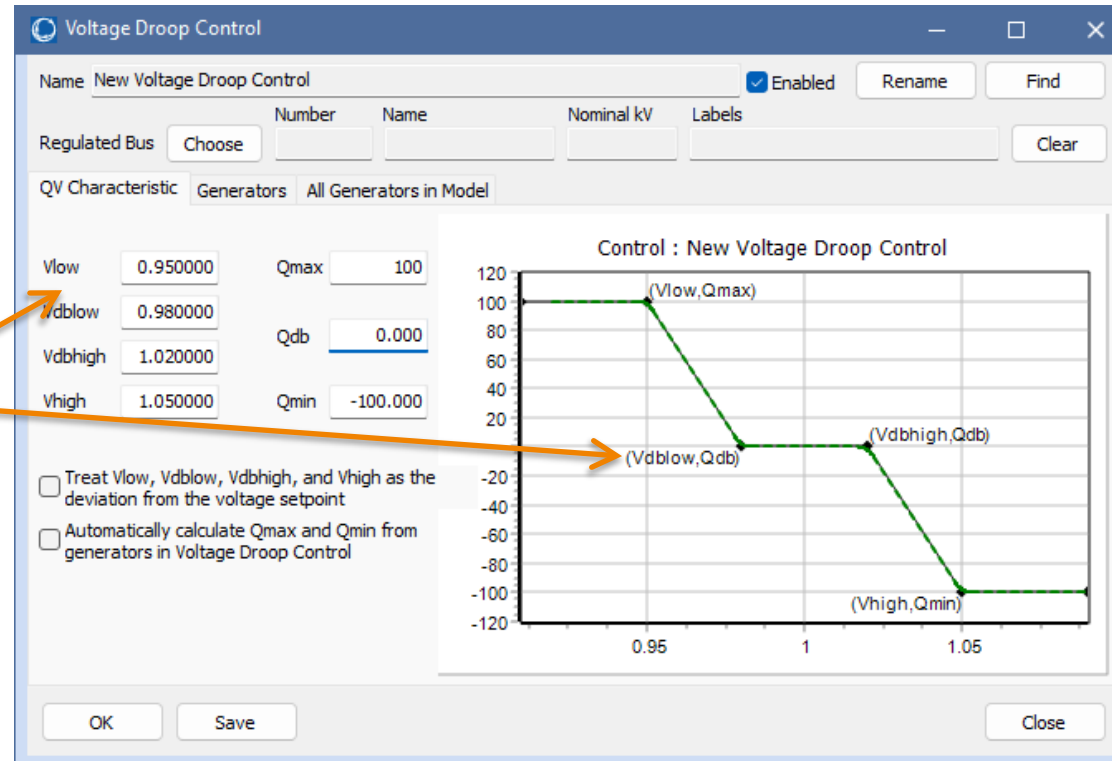
If $X < 0$: Called Reactive Current Compensation

Voltage Droop Control

- Scheme to regulate voltage within a range, rather than to a fixed setpoint



Click Add... on
Generator Dialog to
create scheme and
adjust its parameters



Switched Shunt Control

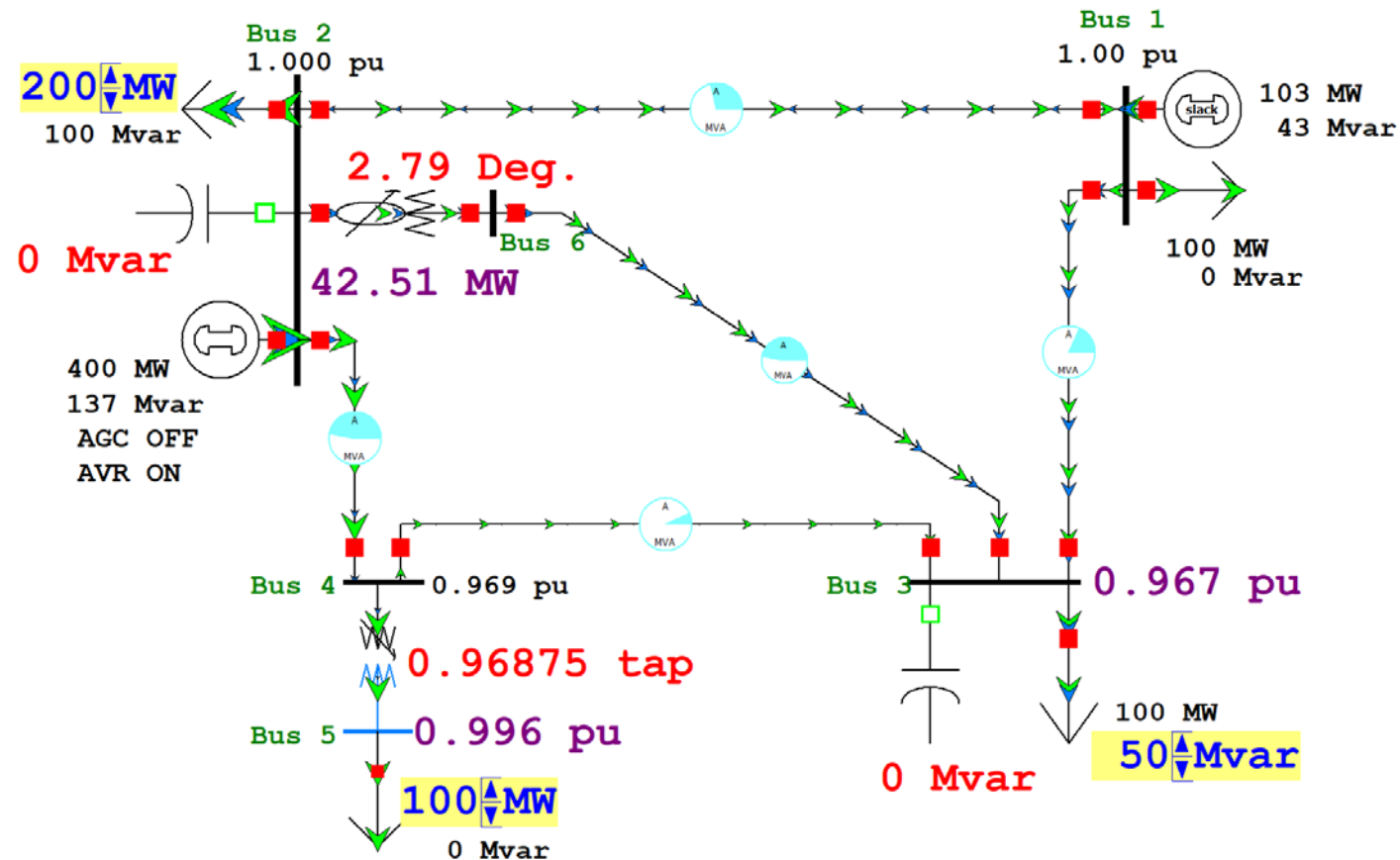


- Switched shunts can automatically change their shunt susceptance to control voltage at a regulated bus.
- Switched shunts on continuous control are integrated directly into the power flow equations. (They create “PV buses.”)
- Automatic switched shunt control can be disabled in three places
 - for entire case on Simulator Options dialog
 - for area on Area Records display
 - individually on Switched Shunt dialog
 - All three of these flags must be set to enable switched shunt control in order for a shunt to move.

Switch Shunt Control Case



- Open Case B5R.pwb



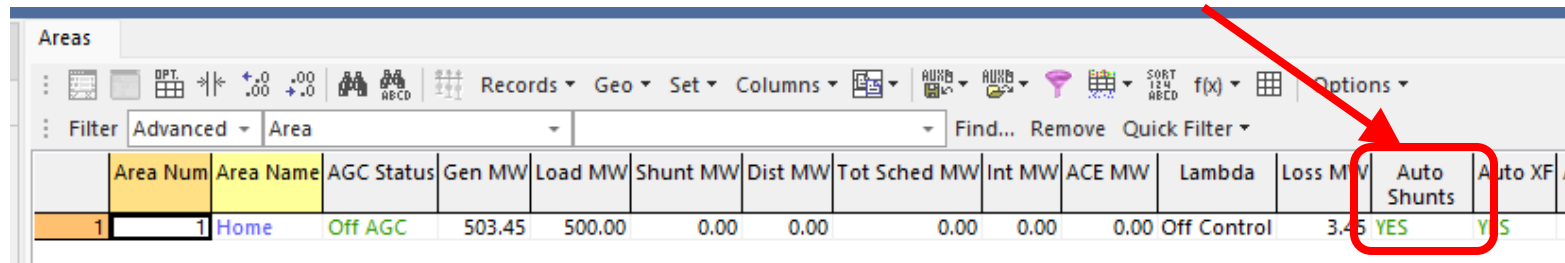
Switched Shunt Control



- Verify the switched shunt control is enabled on Power Flow Solution Options dialog

☐ Disable Switched Shunt Control

- Verify control enabled on the Area Records



Area Num	Area Name	AGC Status	Gen MW	Load MW	Shunt MW	Dist MW	Tot Sched MW	Int MW	ACE MW	Lambda	Loss MW	Auto Shunts	Auto XF
1	Home	Off AGC	503.45	500.00	0.00	0.00	0.00	0.00	0.00	Off Control	3.45	YES	YES

- Right-click on switched shunt shown at bus 3 to display the Switched Shunt dialog.

Switched Shunt Dialog



Actual Mvar will differ from Nominal if bus voltage is not 1.0 pu.

Automatic control requires the mode be either discrete, continuous, or SVC

Bus Shunt (Fixed) is the same as Fixed (flag used to support other file format)

When a value goes out of range, Simulator algorithms attempt to set the value to the target

Status must be closed to work

Specify the “blocks” of Mvar available for shunt dispatch. This example demonstrated a shunt with the ability to provide -30, -20, -10, 0, 20, 40, 60, or 80 Mvars

In discrete mode high value must be strictly greater than low value

Regulated bus - usually the terminal bus

Switched Shunt Information for Present

Bus Number: 3, Bus Name: Bus 3, Shunt ID: 1, Labels: no labels

Parameters: Nominal Mvar: 80.0, Actual Mvar: 0.0, Auto Control?: YES, Control Mode: Discrete

Control Regulation Settings: Voltage, High Value: 1.000 pu, Low Value: 0.990 pu, Target Value: 1.000 pu, Reg. Value: 0.9670 pu, Reg. Bus #: 3

Var Regulation Sharing: 1.00

Reg. Bus PU Voltage to Mvar Sensitivity: 0.000376

Voltage Control Group: Not in a Group

Mvar Blocks:

Number of Steps	Mvars per Step
3	-10
4	20

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

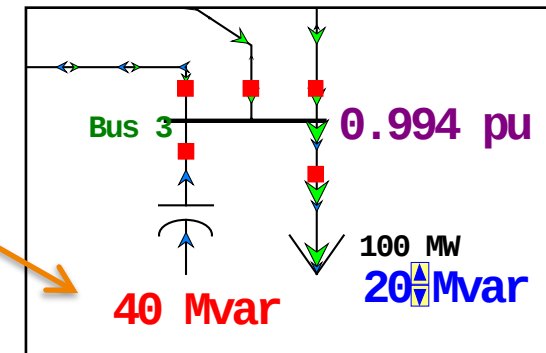
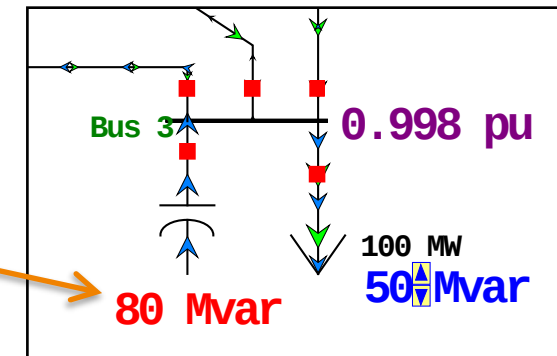
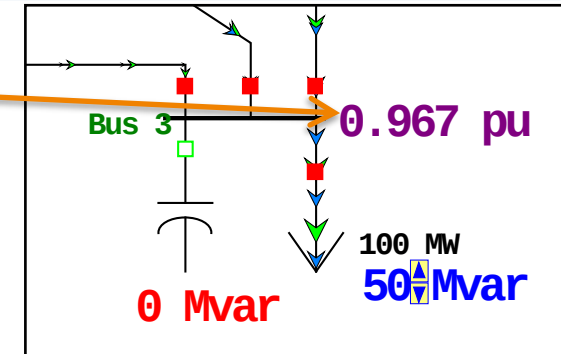
View Bus Dialog: Terminal Voltage Voltage (p.u.): 0.9670, Nom. Voltage: 138.000

Buttons: OK, Cancel, Save, Save to Aux, Help, Print

Example Shunt on B5R Case



- Bus 3 presently has a voltage of 0.967 per unit.
- From earlier slide, we set the control range for the shunt to 0.99 to 1.00 per unit, and switched in the shunt
- This results in the shunt moving to 80 Mvar nominal
- If you decrease the Mvar load at the bus, the voltage increases, and the shunt eventually reduces

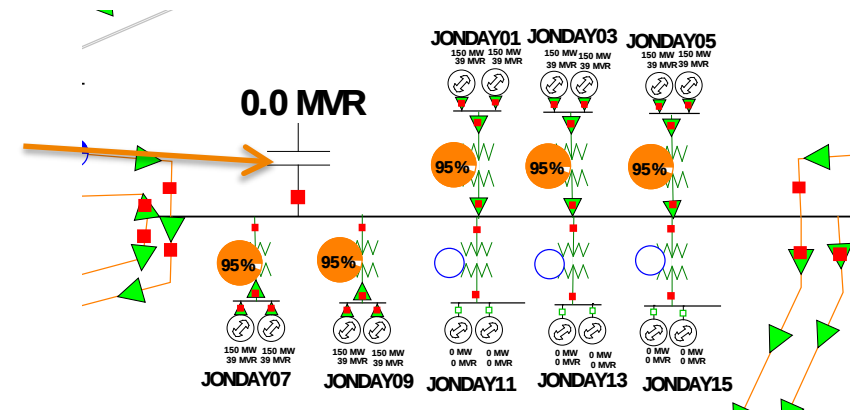


Switched Shunt Control of Generator Mvar Outputs



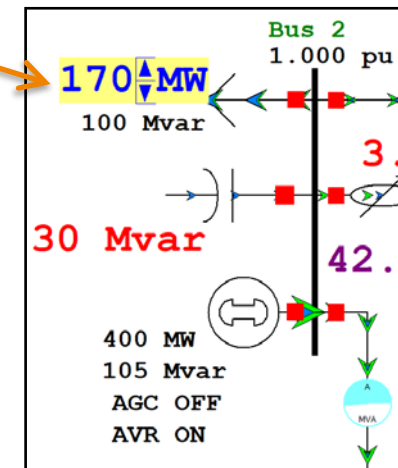
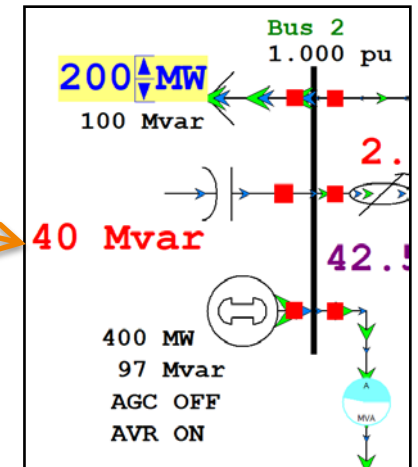
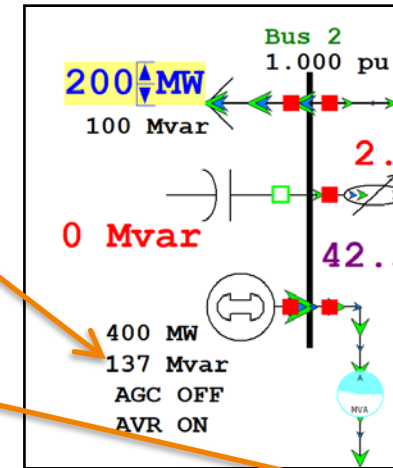
- Switched Shunts may be used to control the Mvar output of generation
- To do this, change the **Control Regulation Settings** to *Generator Mvar*
 - Setting **Reg. Bus** now means to control the total generator Mvar output for generators which control the voltage at the bus specified.
- Switched Shunts can also regulate *Wind Mvar* or to a Model Expression (*Custom Control*)

You could set this shunt to control the total generator Mvar output of all 16 generators controlling its terminal bus



Example Generator Mvar Control

- Bus 2 generator provides 137 Mvar to control to 1.00 pu.
- Close the shunt at Bus 2; it regulates the Gen to 95-105 Mvar, causing the shunt to move to 40 Mvar nominal
- If you vary the load at the bus, the voltage starts to change, prompting the generator Mvar to change; when it goes out of range, the shunts responds





SVC Control Mode



Special options
available on subtabs
of Control Options

Options for SVC Type

Can control up to 8
fixed shunts

Check to enable
Slow B Control
Options

Additional details available in Online Help documentation

Transformer Tap Control



- Some transformers can automatically change either their tap ratio or their phase angle to control either
 - voltage - Load Tap Changing (LTC) transformer
 - MVAR flow - LTC transformer
 - MW flow - phase shifter
- Again, Automatic control can be disabled in three places
 - for entire case on **Simulator Options** dialog
 - for area on **Area Records** display
 - individually on **Transmission Line/Transformer** dialog
 - All three of these flags must be set to enable switched shunt control in order for a shunt to move.

Transformer Control

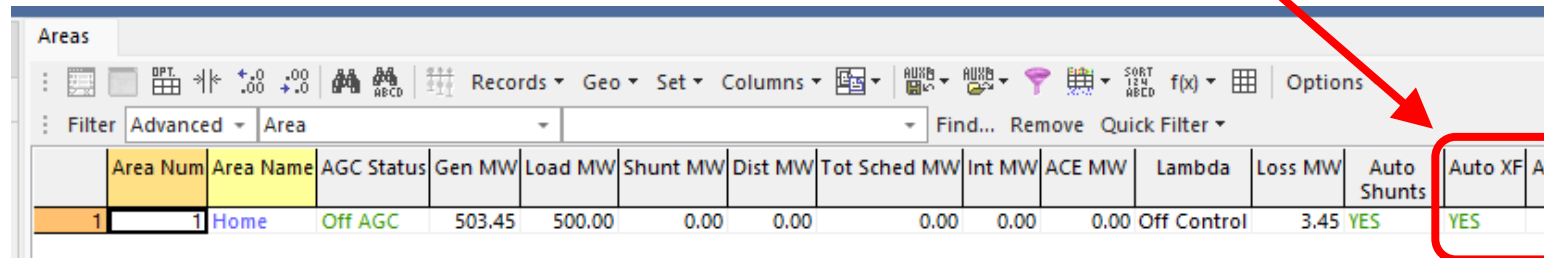


- Verify the transformer control is enabled on Power Flow Solution Options dialog

☐ Disable LTC Transformer Control
Min. Sensitivity for LTC Control

☐ Disable Phase Shifter Control
☐ Model Phase Shifters as Discrete Controls

- Verify control enabled on the Area Records



Area Num	Area Name	AGC Status	Gen MW	Load MW	Shunt MW	Dist MW	Tot Sched MW	Int MW	ACE MW	Lambda	Loss MW	Auto Shunts	Auto XF	A
1	Home	Off AGC	503.45	500.00	0.00	0.00	0.00	0.00	0.00	Off Control	3.45	YES	YES	

- Right-click on transformer shown between buses 4-5 to display the transformer dialog.

LTC Transformers



Right-click on transformer symbol to view the Branch Options dialog

Present off-nominal turns ratio and phase shift

Must be checked to enable control

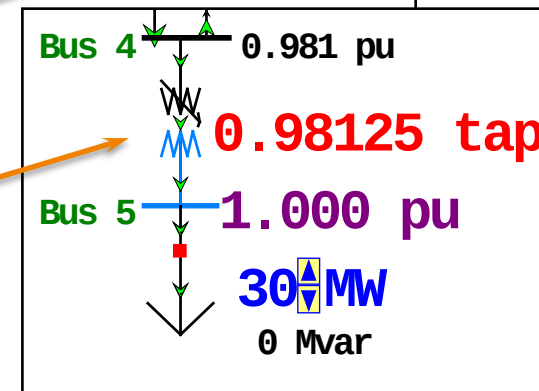
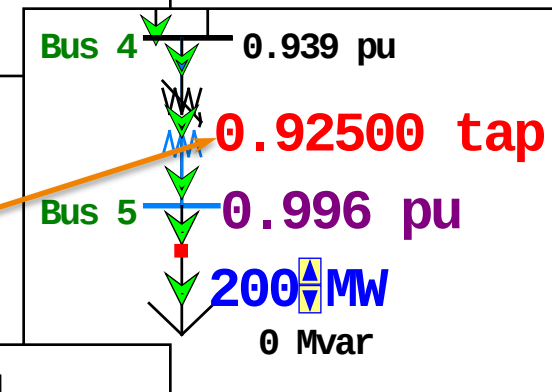
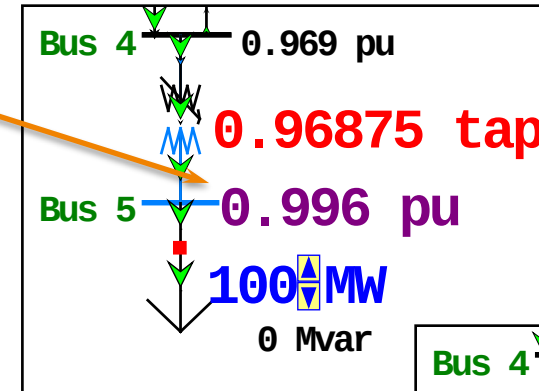
Select to view LTC options

The image shows two overlapping dialog boxes from a software application. The background dialog is the 'Branch Information Dialog' for a transformer connecting Bus 4 to Bus 5. It displays various parameters like nominal kV, voltage angle, and labels. The 'Transformer Information' tab is active, showing the 'Off-nominal Tap Ratio' as 0.96875 and 'Phase Shift Degrees' as 0.00. A checkbox for 'Automatic Control Enabled' is checked. An orange arrow points from the text 'Must be checked to enable control' to this checkbox. Another orange arrow points from the text 'Select to view LTC options' to the 'Change Automatic Control Options ...' button. The foreground dialog is the 'Transformer Control Info' box, which provides detailed settings for the automatic control. It shows 'Automatic Control Type' set to 'Voltage Regulation (AVR)' and 'Automatic Control Enabled' checked. It also displays 'Regulation Minimum Voltage' (0.990000), 'Regulation Maximum Voltage' (1.000000), and 'Regulation Target Type' set to 'Middle'. Other parameters like 'Present Tap Ratio', 'Minimum Tap Ratio', 'Maximum Tap Ratio', and 'Tap Step Size' are also visible. An orange arrow points from the text 'Present off-nominal turns ratio and phase shift' to the 'Off-nominal Tap Ratio' field in the background dialog.

Example LTC on B5R Case



- Bus 5 starts with a voltage of 0.996 per unit
- On previous slide we showed that tap (on the bus 4 side) was set to control voltage at bus 5 between 0.99 and 1.00
- As we increase load tap moves
- As we decrease load tap moves



Phase-Shifting Transformers



Right-click on phase-shifter symbol to view the Branch Information dialog

The Branch Information Dialog box displays the following information:

Transformer	From Bus	To Bus	Circuit
Number 2	6	1	
Name Bus 2	Bus 6		
Area Home (1)	Home (1)		
Nominal kV 138.0	138.0		
Voltage Angle 1.00000 4.0150	0.98944 -0.0046		
Labels ... no labels			

Buttons: Find By Number, Find By Name, Find ...

From End Metered ☒

Parameters Transformer OPF Fault Info Area, Zone, Owner, Sub, PTDF Custom Stability Geography GIC

Transformer Information

Off-nominal Tap Ratio 1.00000

Phase Shift Degrees 2.79

Edit Integer Tap Positions

Automatic Control Type transformer control is Phase Shift Control

Change Automatic Control Options ...

Area and Case Control Options

- ☒ Area Transformer Control Enabled
- ☒ Case LTC Transformer Control Enabled
- ☒ Case Phase Shifter Control Enabled

Automatic Control Enabled

- ☐ Not Enabled
- ☒ Enabled for Power Flow
- ☐ Enabled for OPF

(Note, tap and/or phase shift is always on the From Bus side)

Specify Transformer Bases and Impedances...

Buttons: OK, Save, Save to Aux, Cancel, Help, Print

Present phase shift angle

Must be selected to enable control

Select to view Phase-Shifter options

The Transformer Control Info dialog box displays the following information:

Common Options Time Step Options

Automatic Control Type

- ☐ No Automatic Control
- ☐ Voltage Regulation (AVR)
- ☐ Reactive Power Control
- ☒ Phase Shift Control

Regulation Minimum MW Flow 40.0

Regulation Maximum MW Flow 45.0

Regulation Target Type ☒ Middle ☐ Max/Min

Present Phase Angle (degrees) 2.789

Minimum Phase Angle -30.000

Maximum Phase Angle 30.000

Tap Size (degrees) 0.006

Values above are on System Voltage Base

Impedance Correction Table 0

Insert Transformer Correction Table

Automatic Control Enabled

- ☐ Not Enabled
- ☒ Enabled for Power Flow
- ☐ Enabled for OPF

Regulated Bus Number 2

Present MW Flow 42.5

MW Error 0.0

MW Flow to Phase Sensitivity -7.37

☐ Use Line Drop Compensation

Line Drop Compensation Resistance (R) 0.000000

Line Drop Compensation Reactance (X) 0.000100

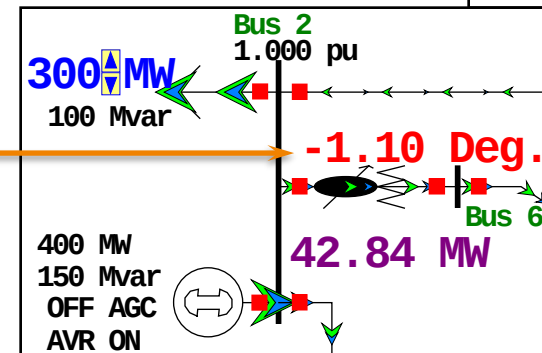
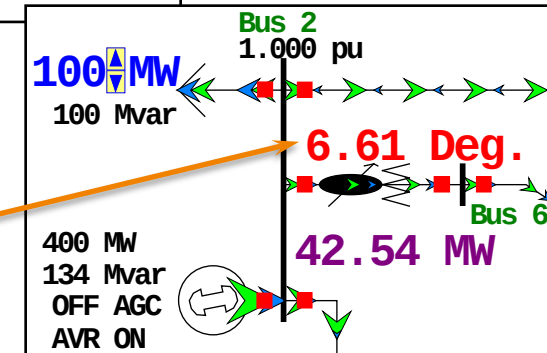
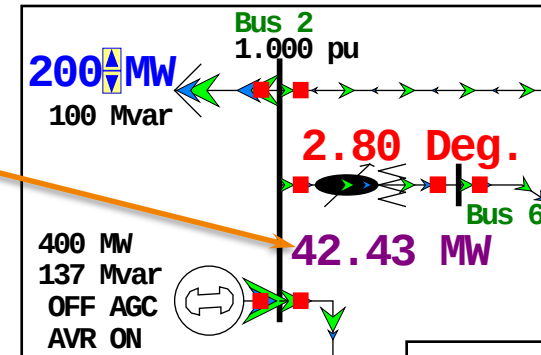
Line Drop Impedances are given on the system MVA Base

Buttons: OK, Cancel, Help

Example Phase-Shifters on B5R Case



- Flow from Bus 2 to Bus 6 starts at 42.43 MW
- On previous slide we showed that phase shifter was set to control flow to between 40 and 45 MW
- As we increase load, the phase shift moves
- As we decrease load, the phase shift moves





Overview of PowerWorld's Solve Power Flow



- What does Solve Power Flow do?
 - Solve Power Flow should not be confused with a single Newton-Raphson (or other technique) power flow
 - Simulator's "Solve Power Flow" 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 Solve Power Flow 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 also
covered in this
section

MW Control Loop also covered later

Example Message Log 1/2



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.

Estimation of Generation

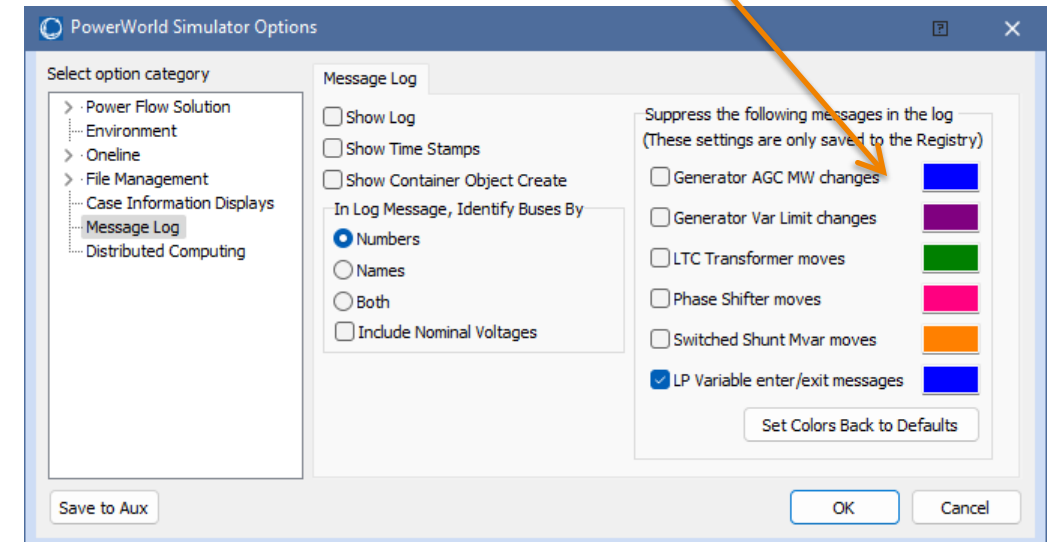
Inner Power Flow

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
in **Simulator Options** →
Message Log



Example Message Log 2/2



3 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 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
Voltage 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 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
2 Inner Iterations	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	Inner Power Flow
Voltage Loop Iteration #4	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 18239 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 62046 gen by -3.6MW AGC changed area PACE slack bus 66055 gen by -12.5MW Generation Adjustment Completed.	Area Automatic Generation Control Iteration
Voltage Loop Iteration #5	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 18239 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
Area Loop Iteration #1	Number: 0 Max P: 0.398 at bus 18239 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	Inner Power Flow
2 Inner Iterations	Solution Finished In 4.522 Seconds Simulation: Successful Power Flow Solution Starting Solution using Rectangular Newton-Raphson	