

# Steady-State Power System Security Analysis with PowerWorld Simulator

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## S6: Voltage Stability Using PV Curves



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# Voltage Stability Concepts

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- Voltage stability is the ability of a power system to maintain acceptable voltage at all buses under normal operating conditions and after being subjected to a contingency
- Voltage stability is a local phenomenon, but its consequences may have a widespread impact
  - A local voltage collapse can and does lead to a widespread collapse of the power system

# Voltage Stability Studies

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- Characteristics of interest are the relationships between transmitted power ( $P$ ), receiving end voltage ( $V$ ), and reactive power injection ( $Q$ )
- Traditional forms of displaying these relationships are PV and QV curves obtained through steady-state analysis
- V-Q sensitivities can also be used as indicators of voltage stability

# PV Study



- The “PV” (Power-Voltage) analysis process involves using a series of power flow solutions for increasing transfers of MW and monitoring what happens to system voltages as a result
- Relationship of voltage to MW transfer is non-linear, which requires the full power flow solutions

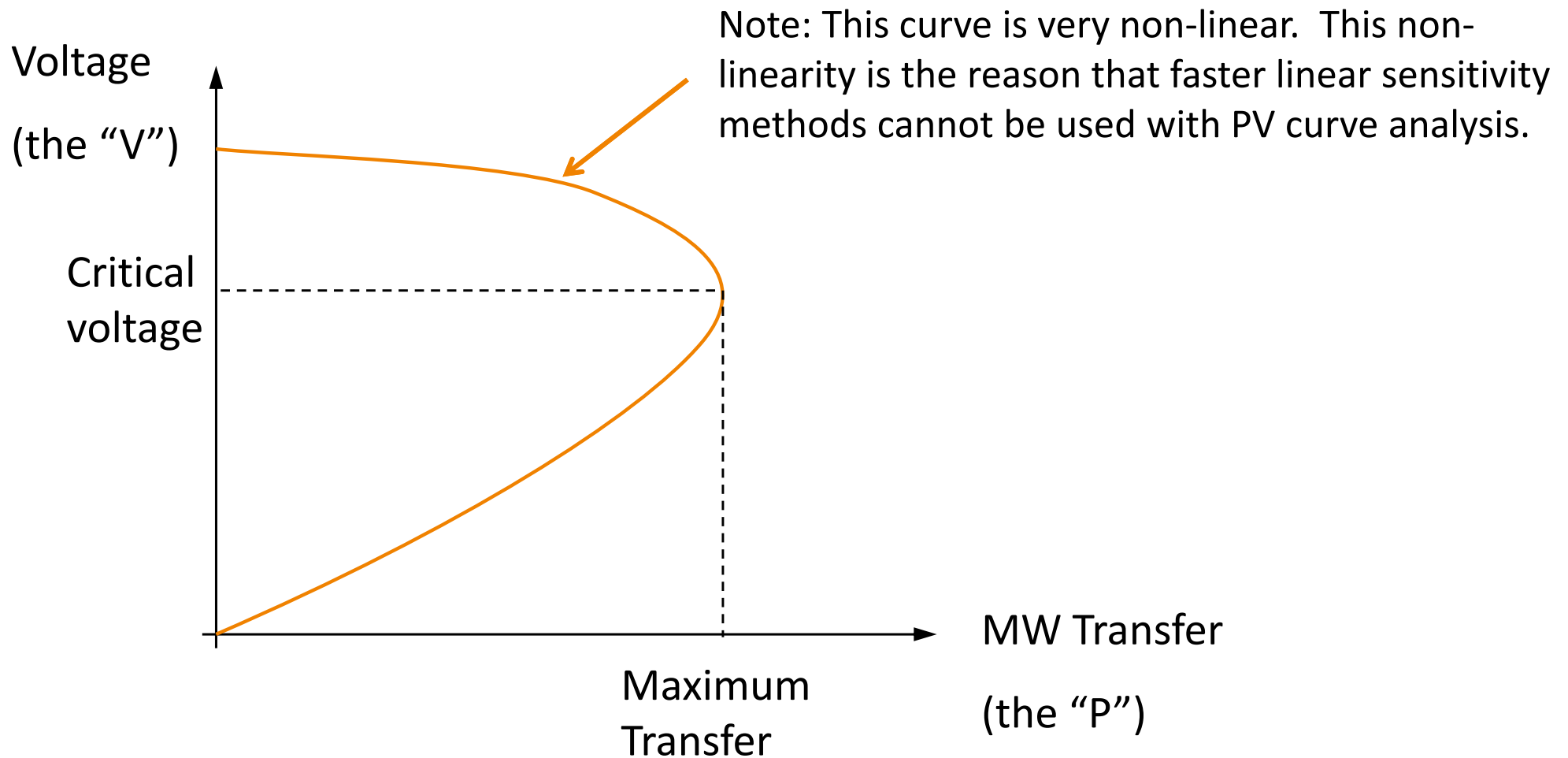
# PV Study

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- Traditionally, MW transfer is designed to model increasing load in a part of the system
- Specific buses must be selected for monitoring and PV curves are plotted for each bus

# Typical PV Curve Plot



# PV Curve Results



- At the “knee” of the PV curve, voltage drops rapidly with an increase in MW transfer
- The power flow solution fails to converge beyond this limit, which is indicative of instability
  - You may remember the term “Maximum Power Transfer” from electrical engineering courses. This is the same topic.
- Operation at or near the stability limit risks a large-scale blackout
  - A satisfactory operating condition is ensured by allowing sufficient “power margin”

# PV Curve Example



- Use the Synthetic 10,000 bus example
  - *ACTIVSg10k.pwb*
  - *ACTIVSg10k PV Injection Groups.aux*
  - *ACTIVSg10k PV Options.aux*
  - *KlamathFallsCTG.aux*
- We will study a transfer of power from generators in Washington State to an increasing Southern California load
- First step - define an injection group containing WA generators to serve as the source



# Injection Groups

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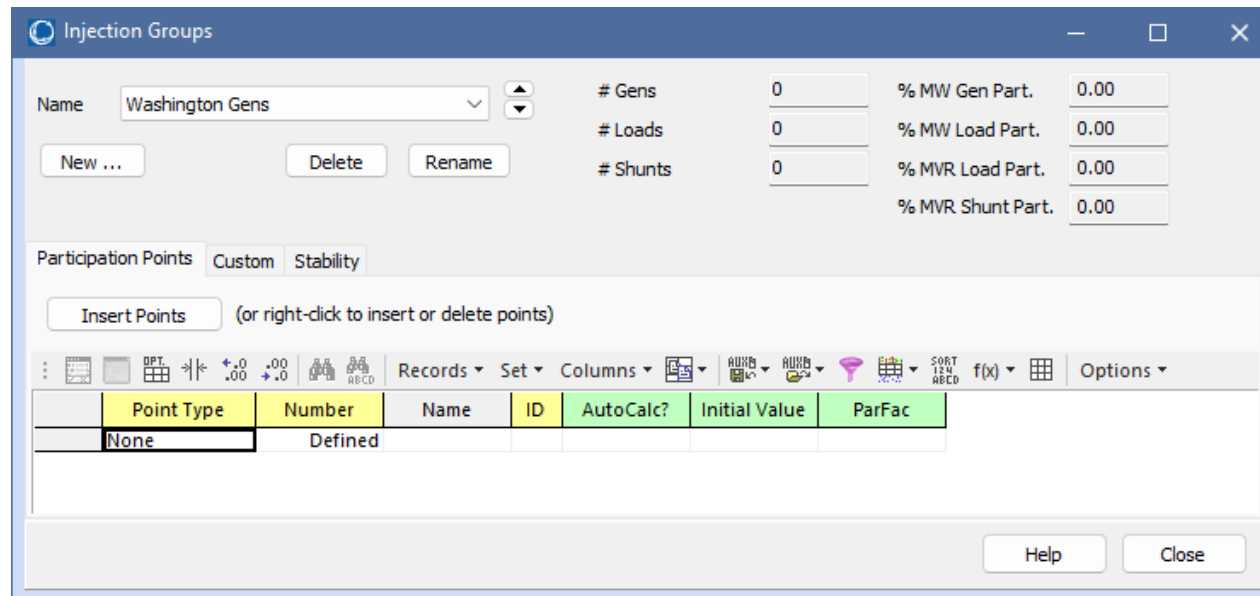


- *Injection Groups* in Simulator PVQV define which region or regions will import the transfer and which region or regions will supply it
- These are discussed in section 15: Data Aggregation
- The groups will act in unison to implement a power transfer
- One side is the source - the other is the sink

# Defining Injection Groups



- Select **Aggregations** → **Injection Groups** from the Model Explorer
- Presently reads *None Defined*. Right click and select **Insert** from the local menu.
- Provide Group name *Washington Gens*
- This opens the following display



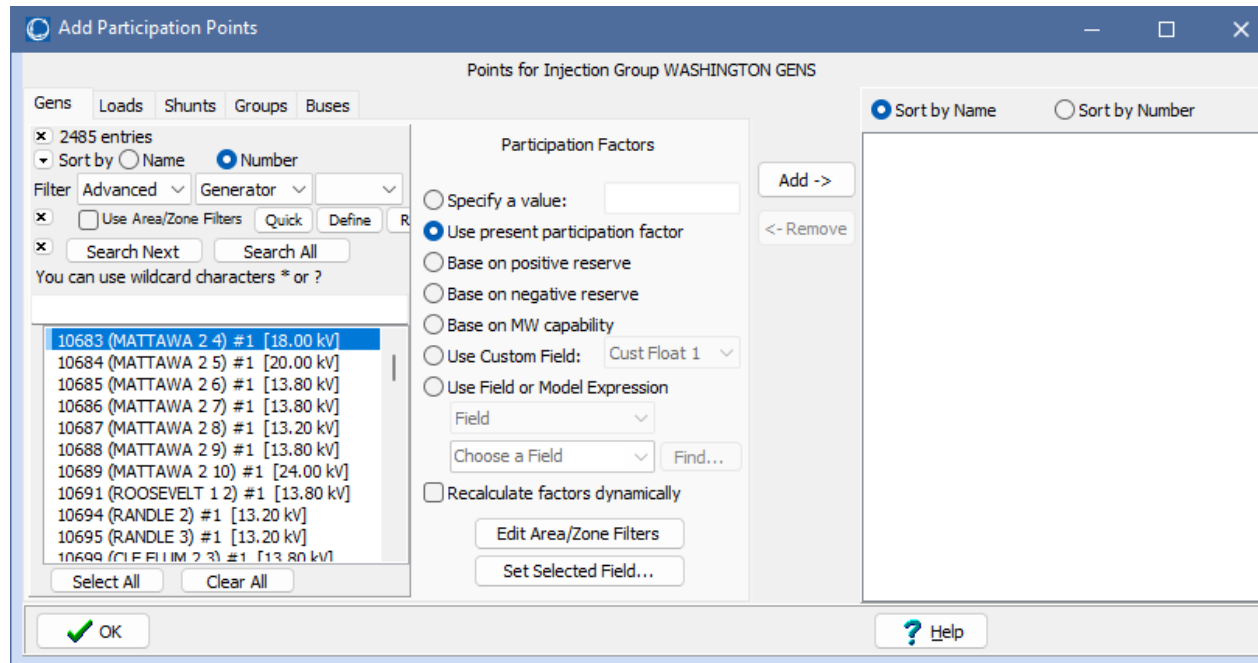
The screenshot shows the 'Injection Groups' dialog box. The 'Name' field is set to 'Washington Gens'. The 'Participation Points' section is set to 'Custom'. The 'Insert Points' button is visible. The table below shows the current state of the injection group.

Point Type	Number	Name	ID	AutoCalc?	Initial Value	ParFac
None	Defined					

# Defining Participation Points



- Now add the points of injection to the group
- To do this, click **Insert Points** or choose **Records** → **Insert** on the Participation Points list
- This opens the dialog below



# Use Filters to Choose Points

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- Click the button **Edit Area/Zone Filters**
- Set all areas to *No* except Washington
- Close the Area/Zone Filters display
- Check the box **Use Area/Zone Filters**
- The list of generators will now only show those generators which are in Washington

# Defining Participation Points

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- Select all the generators in the list by clicking the button **Select All**
- For this example, assume all generators will participate proportional to their MW reserves
  - Therefore, select **Base on Positive Reserve**
- Use **Add ->** key to move the selected generators into the participation point list

# Defining Participation Points

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- Each generator will have a participation factor calculated for it based on the method of calculation selected, or will use the pre-defined values
- In this case, the participation factors will be proportional to the MW reserves
- Hit **OK** to add points to injection group

# Define the Sink Group

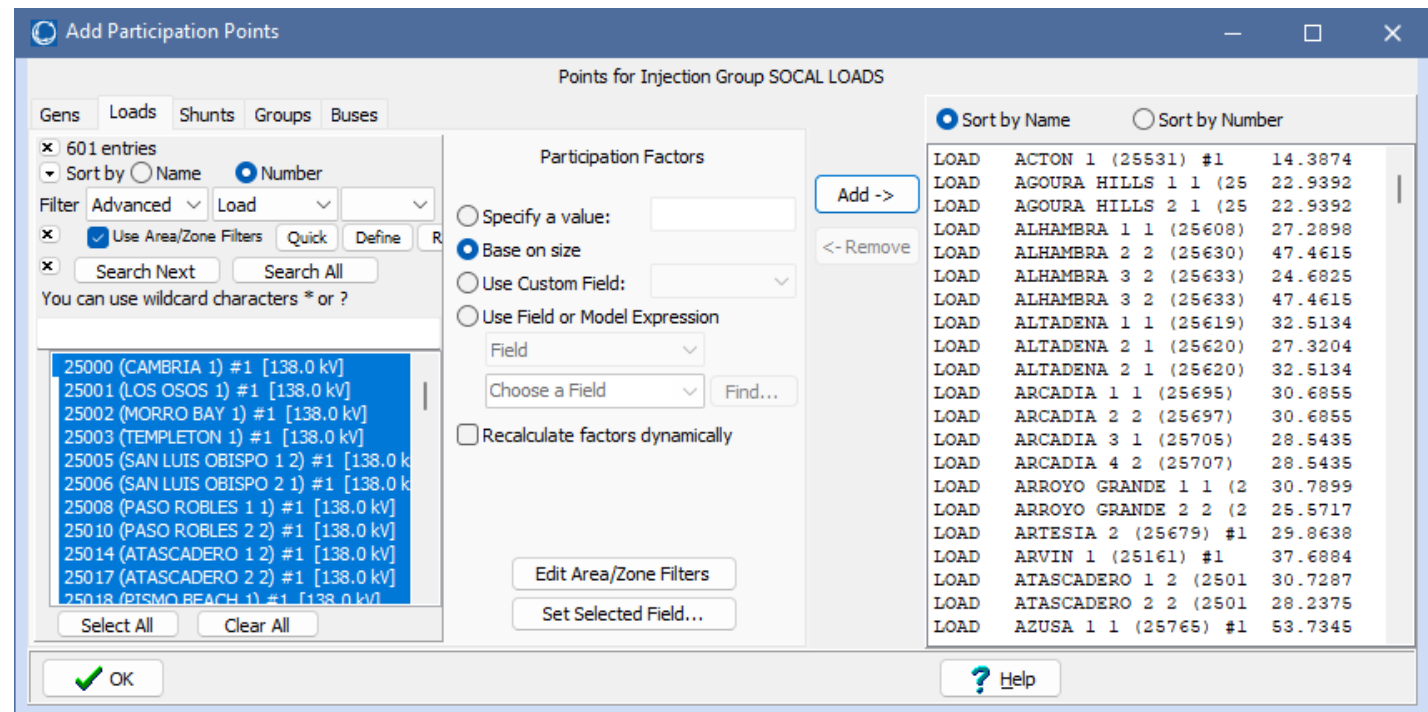


- Process is very similar
- Change area/zone filters so that only area 6 (Southwest California) is set to YES
- Open Injection Groups display again. Select **Records → Insert**
- Call this group *SoCal Loads*
- Choose **Insert Points** or **Records → Insert**
- Switch to Load Tab, because we want the loads to serve as injection points

# Define the Sink Group



- Select all the loads in the list
- Use **Base on Size** to calculate the participation factor, so that the larger loads will participate more heavily in the transfer
- Click the **Add ->** button to move loads into the list





# Saving the groups



- We have now defined a set of source and sink points. The PV study will model an increasing transfer from source to sink.
- This procedure involved a lot of steps, so you don't want to have to redefine the groups for a slightly different case



To save the injection groups, select an injection group and use the Save Auxiliary Menu

- This will save the groups in a text file along with any other auxiliary data you may have
- The data can then be loaded into a different case as needed

# Contingency Definition

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- In addition to analyzing the system for its current topology, you may want to examine a specific set of contingencies
- Simulator's contingency analysis is fully integrated into the PVQV package to allow you to gauge the impact of contingencies
- To define a contingency list, go to **Tools** → **Contingency Analysis**

# Contingency Definition

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- For this example, we will use a pre-defined contingency called *OPEN Klamath Falls 765*
- The file *KlamathFallsCTG.aux* contains the contingency definition

# Performing a PV Curve Study: Open the PV Study

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- We are finally ready to perform the PVQV study. Select **Add Ons** ribbon tab → **PV Curves**.
- This form is organized in a series of pages, that are arranged in the order they should be considered
- The options on the following slides are stored in *ACTIVSg10k PV Options.aux*

# Setup: Common Options

## Transfer Definition

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- Under Source, click on the drop-down box and select *Washington Gens*, our predefined injection group
- Under Sink, select *SoCal Loads*
- You can also define these groups from this dialog by selecting **View/Define Groups**

# Setup: Common Options



The screenshot displays the 'PV CURVES' software interface. The 'Setup' window is open, and the 'Common Options' tab is selected. The interface includes a left-hand navigation tree with categories like 'Setup', 'Quantities to track', 'Limit violations', 'PV output', 'QV setup', 'PV Results', and 'Plots'. The main area shows the 'Setup' configuration for power transfer between injection groups. The 'Ramping Method' is set to 'Injection Group Source/Sink'. The 'Source' is 'Washington Gens' and the 'Sink' is 'SoCal Loads'. A 'View / Define Injection Groups' button is present. Below this, there are tabs for 'Common Options', 'Injection Group Ramping Options', 'Interface Ramping Options', and 'Advanced Options'. The 'Common Options' section includes: 'Critical Scenarios' with a value of 1; 'Base Case and Contingencies' with 'Run base case to completion' checked; and 'Vary the transfer as follows:' with step size values of 200.00, 10.00, 2.00, and 0.00.

**PV CURVES**

Setup

Ramping Method

Injection Group Source/Sink

Interface MW Flow

Transfer power between the following two injection groups:

Source: Washington Gens

Sink: SoCal Loads

View / Define Injection Groups

Common Options | Injection Group Ramping Options | Interface Ramping Options | Advanced Options

Critical Scenarios

Stop after finding at least 1 critical scenarios

Base Case and Contingencies

Skip contingencies

Manage contingency list ...

Run base case to completion

Base Case Solution Options ...

Vary the transfer as follows:

Initial Step Size (MW): 200.00

Minimum Step Size (MW): 10.00

When convergence fails, reduce step by a factor of 2.00

Stop when transfer exceeds 0.00

Save Auxiliary ... Load Auxiliary ... Launch QV curve tool ... ? Help Close

# Setup: Common Options

## Vary transfer options



- Initial Step Size
  - The rate at which transfer will increase initially
  - **200 MW for example**
- Minimum Step Size
  - Whenever Simulator fails to converge at a particular transfer level, it will return to the previous one and use a smaller increase. This is the minimum.
  - **10 MW for example**
- Reduce step by a factor of
  - Amount Simulator will reduce the transfer by in case of non-convergence (Not MWs)
  - **2 for example**
- Stop when transfer exceeds
  - When checked, the PV analysis will stop after a specified MW transfer level has been achieved
  - **Unchecked for example**

# Setup: Common Options



- Stop after finding at least ... critical scenarios
  - Minimum number of critical scenarios that will be found
  - **1 for example**
- Skip Contingencies
  - Check this box to run the analysis for the base case only
  - **Unchecked for example**
- Run Base Case to Completion
  - When checked, the critical transfer point is found for the base case in addition to the number of specified critical scenarios
  - **Checked for example**



# Setup: Injection Group Ramping Options



The screenshot displays the 'PV CURVES' software interface. On the left is a navigation tree with 'Setup' expanded to 'Injection Group Ramping Options'. The main window has a 'Setup' tab and a sub-tab 'Injection Group Ramping Options'. It features a 'Ramping Method' section with 'Injection Group Source/Sink' selected. A 'Transfer power between the following two injection groups:' section shows 'Source' as 'Washington Gens' and 'Sink' as 'SoCal Loads', with a 'View / Define Injection Groups' button. Below are 'Injection Group Options' including 'Island-Based AGC Tolerance' (5.0000) and three unchecked checkboxes: 'Allow only AGC units to vary', 'Enforce unit MW limits', and 'Do not allow negative loads'. A 'Ramping Method' table is also present.

Ramping Method	Source	Sink
Proportional	<input checked="" type="radio"/>	<input checked="" type="radio"/>
Merit Order	<input type="radio"/>	<input type="radio"/>
Economic Merit Order	<input type="radio"/>	<input type="radio"/>
Merit Order Close	<input type="radio"/>	<input type="radio"/>

(Enabled injection group-specific scaling options will override these options. Injection group-specific options do not include the AGC Tolerance.)

Buttons at the bottom: Save Auxiliary, Load Auxiliary, Launch QV Curve Tool, Help, Close.

# Setup:

## Injection Group Ramping Options

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- Island-Based AGC Tolerance
  - Tolerance used in the MW control loop when solving the power flow during implementation of the transfer
  - General rule of thumb is that Minimum Step Size should be at least 1 to 2 times larger than this value
  - Simulator will modify this so that MVA convergence tolerance < AGC Tolerance < Minimum Step Size
  - **5 MW for example**
- Allow only AGC units to vary
  - In Simulator each unit may be on or off AGC. If this box is checked only those set on AGC can vary.
  - **Unchecked for example**

# Setup:

## Injection Group Ramping Options

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- Enforce unit MW limits
  - When checked generators will only participate in the transfer if they are within their min/max MW limits
  - **Unchecked for example**, so we may examine the transfer capacity regardless of reserve in Washington
- Do not allow negative load
  - When this box is checked, loads will be prevented from being set below zero
  - **Unchecked for example**
- Ramping Method
  - Merit Order method: individual generators and loads will be moved to their min/max in succession in order of descending participation factor (as set in its injection group participation point)
  - Economic Merit Order: maintains generators within an Economic Min/Max
  - Can select separately for the source and sink
  - **Source and Sink are Proportional for this example**

# Setup: Advanced Options



**PV CURVES**

Setup

Ramping Method

- Injection Group Source/Sink
- Interface MW Flow

Transfer power between the following two injection groups:

Source: Washington Gens

Sink: SoCal Loads

View / Define Injection Groups

Common Options | Injection Group Ramping Options | Interface Ramping Options | **Advanced Options**

How should reactive power load change during ramping?

- Maintain the MW/MVAR ratio at each load, but then scale MVAR by a factor of 1.0000
- As MW changes, change the MVAR at a power factor of 1.0000

(If enabled, injection group specific scaling options will override these options.)

Reverse Transfer

- Apply Reverse Transfer
- Maximum Reverse Transfer (MW > 0): 1000.00

Load Component Variation

- All changes apply to constant power (S MW, S MVAR)
- Vary in proportion to existing Z,I,P ratios
- Vary using proportions specified below:

	P (MW)		Q (MVAR)	
	Source	Sink	Source	Sink
Power (S)	1.00	1.00	1.00	1.00
Current (I)	0.00	0.00	0.00	0.00
Impedance (Z)	0.00	0.00	0.00	0.00

Save Auxiliary ... Load Auxiliary ... Launch QV curve tool ... ? Help Close

*pfQMult*

*Pf<sub>specified</sub>*

Each column must sum to 1

# Setup: Advanced Options



- How should reactive power load change during ramping?
  - Maintain the MW/MVAR ratio at each load, but then scale MVAR by a factor of

$$pf = \cos \left( \tan^{-1} \left( \frac{Q_{Existing}}{P_{Existing}} \right) \right)$$

$$\Delta Q = \tan \left( \cos^{-1} ( pf ) \right) * \Delta P * pfQMult$$

- As MW changes, change the MVAR at a power factor of

$$\Delta Q = \tan \left( \cos^{-1} \left( pf_{specified} \right) \right) * \Delta P$$

# Setup: Advanced Options



- Load Component Variation
  - Total load (P,Q) at a load can be specified as the sum of constant power (S), constant current (I), and constant impedance components (Z)
  - Constant current and constant impedance components are both functions of voltage at the bus
  - These options determine the proportion of the load change that each component receives

# Setup: Advanced Options



- Load Component Variation

- All changes apply to constant power (S MW, S MVAR)

$$\Delta P_S = \Delta P, \Delta P_I = 0, \Delta P_Z = 0, \Delta Q_S = \Delta Q, \Delta Q_I = 0, \Delta Q_Z = 0$$

- Vary in proportion to existing Z,I,P ratios

- Existing ratios determined based on the existing total nominal load ( $P_{nom}, Q_{nom}$ ) prior to any change due to the transfer

$$k_{PS} = \frac{P_{nomS}}{P_{nom}}, k_{PI} = \frac{P_{nomI}}{P_{nom}}, \dots, k_{QS} = \frac{Q_{nomS}}{Q_{nom}}, \dots, k_{QZ} = \frac{Q_{nomZ}}{Q_{nom}}$$

- Ratios are multiplied by the total nominal load change to calculate the nominal load change for each component

$$\Delta P_{nomS} = k_{PS} * \Delta P_{nom}, \Delta P_{nomI} = k_{PI} * \Delta P_{nom}, \dots, \Delta Q_{nomS} = k_{QS} * \Delta Q_{nom} \dots$$

# Setup: Advanced Options



- Load Component Variation

- Vary in proportion to existing Z,I,P ratios

- The total nominal power change is determined based on the total real power change required due to the transfer, the calculated ratios, and present voltage at a bus

$$\Delta P_{nom} = \frac{\Delta P}{k_{PS} + k_{PI} * V + k_{PZ} * V^2}$$

- Change in nominal reactive power is determined based on the option selected for how reactive power should change during the transfer



# Setup: Advanced Options



- Load Component Variation
  - Vary using proportions specified below
    - Proportions are grouped by real and reactive power and then source or sink
    - Proportions for each group must sum to 1 so that component changes sum to the total load change
    - Same calculations as option to use existing Z,I,P ratios except that the ratios are user-specified
- Apply Reverse Transfer
  - For any contingency that does not solve in the base case, apply a transfer from the Sink to the Source in an attempt to find a solution
  - Must specify the Maximum Reverse Transfer because it is possible that a solvable point will not be found

# Interface MW Flow Ramping Method



The screenshot displays the 'PV CURVES' software window. On the left is a tree view with the following items: Setup (expanded), Common Options, Injection Group Ramping Options, Interface Ramping Options (highlighted), Advanced Options, Quantities to track, Limit violations, PV output, QV setup, PV Results, and Plots. The main area shows the 'Setup' tab with the following settings:

- Ramping Method:**  Injection Group Source/Sink,  Interface MW Flow
- Interface X:** AEP-CIN (with 'Find...' button)
- Use Interface Y:**
- Interface Y:** AEP-CIPS (with 'Find...' button)
- Angle:** 0.00

Below these are four tabs: Common Options, Injection Group Ramping Options, **Interface Ramping Options** (selected), and Advanced Options. The 'Interface Ramping Options' tab contains:

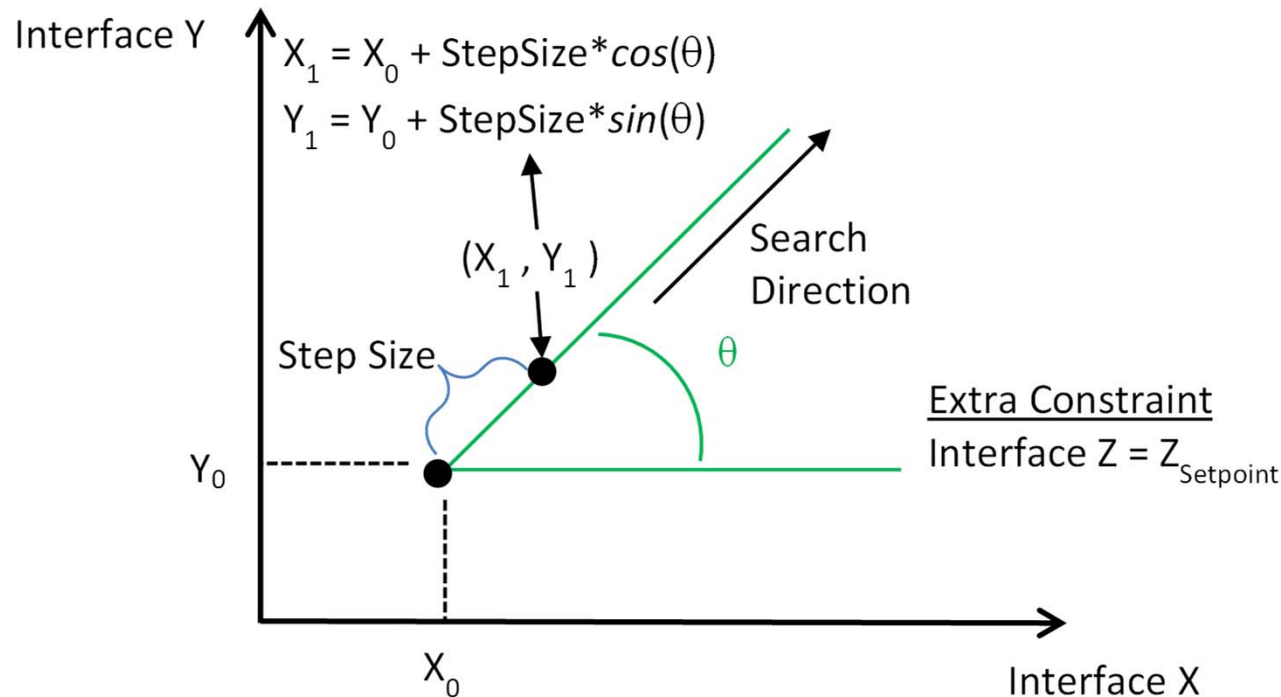
- Use Interface Z:**
- Interface Z:** AEP-IP (with 'Find...' button)
- MW Setpoint:** 100

At the bottom of the window are buttons for 'Save Auxiliary ...', 'Load Auxiliary ...', 'Launch QV curve tool ...', 'Help', and 'Close'.

# Interface MW Flow Ramping Method



- Requires the OPF add-on
- Ramps transfer by increasing flow on 1 or 2 interfaces
  - Search direction determined by **Step Size** and **Angle**
- Optional constraint to maintain flow on a third interface



# Quantities to Track



- On the **Quantities to track** page, there are several sub pages that allow you to track values for various devices



- Let's monitor bus 20005 (Crescent City 1, 345 kV):
  - voltage
  - $dV/dQ$
- And Mvar Reserve (Max-MVR) for Injection Group Washington Gens
- Search for the fields and toggle to change values

# Quantities to Track



**PV CURVES**

Quantities to track

Note: Any quantities which are defined as part of a plot on the New Plots area will also result in that quantity being tracked.

Buses Generators Injection Groups Lines Transformers Shunts Interfaces Case Devices At Limits

	Number	Name	Nom kV	Volta	kV Voltage?	Angle?	MW Load?	Mvar Load?	dV/dQ?	VP Sensitiv
1	20005	CRESCENT CITY 1	345.00	YES	NO	NO	NO	NO	YES	NO
2	10003	OCEAN SHORES 1	138.00	NO	NO	NO	NO	NO	NO	NO
3	25490	LOS ANGELES 54 2	138.00	NO	NO	NO	NO	NO	NO	NO
4	10005	WESTPORT 2	138.00	NO	NO	NO	NO	NO	NO	NO
5	10006	LONG BEACH 1 1	138.00	NO	NO	NO	NO	NO	NO	NO
6	10007	LONG BEACH 1 2	138.00	NO	NO	NO	NO	NO	NO	NO
7	20265	FORESTHILL 1 1	138.00	NO	NO	NO	NO	NO	NO	NO
8	10009	OCEAN PARK 2	138.00	NO	NO	NO	NO	NO	NO	NO
9	10010	HOQUIAM 1	138.00	NO	NO	NO	NO	NO	NO	NO
10	10011	PORT ANGELES 1 1	138.00	NO	NO	NO	NO	NO	NO	NO
11	10012	ABERDEEN 1 1	345.00	NO	NO	NO	NO	NO	NO	NO
12	10013	ABERDEEN 1 2	138.00	NO	NO	NO	NO	NO	NO	NO
13	10014	MONTESANO 1	138.00	NO	NO	NO	NO	NO	NO	NO
14	10015	MONTESANO 2	138.00	NO	NO	NO	NO	NO	NO	NO
15	11024	GRAND COULEE 14	13.80	NO	NO	NO	NO	NO	NO	NO

Modify Existing Bus Tracking to Track Only Single Bus Per Super Bus

Note: The active defined contingencies affect the selection of super buses and resulting tracked buses.

Include ATC Extra Monitors

Warning: Do not track too many quantities. Simulator stores all the data in memory in your computer. If you track too much you will run out of memory causing Simulator to halt.

Save Auxiliary ... Load Auxiliary ... Launch QV curve tool ... ? Help Close

# Quantities to Track: Devices At Limits



- Can track devices that hit or back off limits during the analysis
  - Limits are only tracked during the base case ramping and not during contingencies
  - Generator var, switched shunt var, LTC transformer tap, line thermal, and interface thermal limits can be tracked
- Limit the amount of elements that are tracked by defining filters for each type of element tracked
- Optionally track “Generators Var Limits” for the filter “COB In-service” (loaded with *ACTIVSg10k PV Options.aux*)

# Limit Violations → Critical Scenarios



The screenshot displays the 'PV CURVES' software window with the 'Limit Violations' settings panel open. The left sidebar shows a tree view with 'Limit Violations' expanded to 'Critical Scenarios' and 'Monitor Only' selected. The main panel is titled 'Limit Violations' and has two tabs: 'Critical Scenarios' and 'Monitor Only'. The 'Monitor Only' tab is active.

**Inadequate Voltage Level**

- Stop when voltage becomes inadequate
- Apply to Which Voltage Level:
  - Low Voltage:  Log inadequate voltages,  Interpolate inadequate voltages
  - High Voltage:  Log inadequate voltages,  Interpolate inadequate voltages
- Voltage Level to Consider Inadequate:
  - Specify voltage for all buses in pu: 0.9000
  - Use Low Voltage Violation Limits for each bus
  - Use a specified Low Voltage Limit Set: A
- High Voltage Level to Consider Inadequate:
  - Specify voltage for all buses in pu: 1.1000
  - Use High Voltage Violation Limits for each bus
  - Use a specified High Voltage Limit Set: A
- Do not consider radial buses to have inadequate voltage (including buses that become radial due to a contingency)

**Branch and Interface Violations**

- Branch Violations:
  - Ignore
  - Log Only
  - Stop When Violated
  - Stop in Base Case Only
- Interface Violations:
  - Ignore
  - Log Only
  - Stop When Violated
  - Stop in Base Case Only

**Limit Monitoring Settings**

- Negative dV/dQ Sensitivities
- Stop when dV/dQ sensitivities become negative

Buttons at the bottom: Save Auxiliary, Load Auxiliary, Launch QV Curve Tool, Help, Close.

# Limit Violations → Critical Scenarios



- Inadequate voltage level
  - Stop when voltage becomes inadequate
    - A scenario will be judged critical once any monitored voltage falls below the inadequate voltage level
  - Log inadequate voltages
    - Keeps track of inadequate voltages without considering a scenario to be critical
  - Interpolate inadequate voltages
    - Allows linear estimation of where a voltage becomes inadequate without having to reduce the step size in order to exactly determine when a voltage becomes inadequate
- **Limit Monitoring Settings** determine which buses are monitored and how high and low voltage violations are identified for each bus



# Limit Violations → Critical Scenarios



- Inadequate Voltage Level
  - Specify voltage level to consider inadequate
    - Specify voltage for all buses
    - Use Low Voltage Violation Limits for each bus
    - Use a specified Low Voltage Limit Set
  - Do not consider radial buses to have inadequate voltage
    - Buses that are connected by only a single in-service branch are considered radial. If buses are connected by more than one branch, all but one of the branches is open.
    - Buses that are radial for a given scenario, even those that become radial due to a contingency, will not be monitored
    - Limit Monitoring Settings option to not monitor radial lines and buses will exclude from monitoring those buses that are connected by a single branch in the base case

# Limit Violations → Monitor Only



The screenshot shows the 'PV CURVES' software interface. On the left is a tree view with categories: Setup, Quantities to track, Limit Violations, PV output, QV setup, PV Results, and Plots. Under 'Limit Violations', 'Monitor Only' is selected. The main panel displays the 'Limit Violations' settings for the 'Monitor Only' scenario. It includes options to 'Identify bus voltages with ...' and checkboxes for 'Low Voltage Violations' (with a sub-option 'Always Report Lowest Voltage') and 'High Voltage Violations'. A button labeled 'Limit Monitoring Settings' is present. At the bottom of the window are buttons for 'Save Auxiliary', 'Load Auxiliary', 'Launch QV Curve Tool', 'Help', and 'Close'.

# Limit Violations → Monitor Only

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- Use the **Identify Bus Voltages with...** section to tell the PV tool to keep track of buses that violate their voltage limits as of the last successful solution for each scenario
  - Low Voltage Violations
    - “Always Report Lowest Voltage” will report a voltage even if it does not violate a low voltage limit
  - High Voltage Violations
- Selecting either one of the two voltage violation boxes will make available a few tools and fields on the **Overview** table on the **PV Results** page

# PV Output

## Save results to file



- Simulator records the value of each monitored quantity at each transfer level for each contingency being studied
- Data only present in memory unless storage file and location specified
- Save results to file
  - Check and specify the file path and name
  - Results stored with transfer level in rows and tracked quantities in columns
  - Comma-separated file regardless of file extension chosen
  - For this example, choose file *PVResults.csv* in current directory
- Transpose results
  - Results stored with tracked quantities in rows and transfer levels in columns
- Single Header File
  - Only a single header is shown at the top of the file rather than repeating the header at the start of each scenario section

# PV Output State Archiving



- Entire system can be saved during the analysis
- Directory and prefix must be specified to help in distinguishing between separate PV runs
- Can save as PWB, AUX, or both
- This can require significant disk space, but can be quite helpful to examine a particular transfer level
- Save only the base case for each critical contingency
  - Base case without contingency but with critical transfer level implemented will be saved for each critical scenario
- Save all states
  - All states at each valid transfer will be saved
  - Non-critical states will be saved with contingency implemented. Only base case saved at the critical transfer level.
  - Base case state without contingency implemented will be saved for all scenarios at all transfer levels at which that scenario will solve

# Save/Load Auxiliary Options

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- This form has a large number of options
- These do not have to be set every time - just use the **Save Auxiliary** button at the bottom of the form to transfer options between cases
- Options are saved in Simulator's Auxiliary File format
- You may also load options back in by choose the **Load Auxiliary** button
- The options on these slides are stored in *ACTIVSg10k PV Options.aux*

# PV Results

## Performing the Analysis



- Go to the PV Results page to initiate the PV Curve analysis. Click **Run** to begin.

The screenshot shows the 'PV CURVES' software window. The left sidebar contains a tree view with the following items:

- Setup
  - Common Options
  - Injection Group Ran
  - Interface Ramping (
  - Advanced Options
- Quantities to track
  - Buses
  - Generators
  - Injection Groups
  - Lines
  - Transformers
  - Shunts
  - Interfaces
  - Case
  - Devices At Limits
- Limit violations
- PV output
- QV setup
- PV Results**
  - Overview
  - Legacy Plots
  - Track Limits
  - Plots

The main area is titled 'PV Results' and contains the following elements:

- Buttons: Run, Stop, and a checkbox for 'Restore Initial State on Completion of Run'.
- Message: 'Nominal shift set to 1650.000.'
- Input fields: Present nominal shift (1650.000) and Present step size (50.000).
- Data Table:

	Gen MW	Load SMW	Load IMW	Load ZMW
Source	20748.47	0.00	0.00	0.00
Sink	0.00	23504.73	0.00	0.00

Buttons: View detailed results, Other actions >>

Message: No limiting cases found yet.

Navigation tabs: Overview, Legacy Plots, Track Limits

Toolbar: Includes icons for grid, zoom, and other functions.

	Scenario	Critical?	Critical Reason	Max Shift	Max Export
1	base case	NO			
2	OPEN Klamath Falls 765	NO			

Bottom bar: Save Auxiliary ..., Load Auxiliary ..., Launch QV curve tool ..., Help, Close

# PV Results

## Overview, Plot

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- When the PV run is completed, the **Overview** list display will show a summary of the results
- Critical scenarios (contingencies) are identified along with information about the critical buses and maximum achieved transfer levels
- Plots of tracked quantities can be made from the **Legacy Plots** tab or **Plots** page
- System state is left at the transfer level of the last studied critical scenario with any contingency restored



# PV Results

## Legacy Plots Tab



- Once the PV tool has completed running, you may plot the results using the **Legacy Plots** tab of the **PV Results** page

The screenshot shows the 'PV Results' window with the 'Legacy Plots' tab selected. The interface includes a 'Run' button, a 'Stop' button, and a checkbox for 'Restore Initial State on Completion of Run'. A red error message states 'Base case could not be solved'. Below this, there are input fields for 'Present nominal shift' (7800.000) and 'Present step size'. A table shows power flow data for 'Source' and 'Sink' across 'Gen MW', 'Load SMW', 'Load IMW', and 'Load ZMW'. The 'Found 2 limiting cases.' section is visible. The 'Legacy Plots' section has tabs for 'Overview', 'Legacy Plots', and 'Track Limits'. It features dropdowns for 'Horizontal axis value' (set to 'Nominal Shift') and 'Vertical axis value type' (set to 'PU Volt'). A table lists 'Plot values for these elements...' with a 'Description' column and a 'Plot?' checkbox. A 'Contingency Scenario' table is also present. At the bottom, there is a 'Plot title' input field, 'Clear' and 'Plot' buttons, and 'Load Auxiliary' and 'Launch QV Curve Tool' buttons.

Source	Gen MW	Load SMW	Load IMW	Load ZMW
26948.47	0.00	0.00	0.00	0.00
Sink	0.00	28127.41	0.00	0.00

Contingency Scenario	Critical	Plot?
Base Case	YES	YES
OPEN Klamath Falls 765	YES	YES

Description	Plot?
CRESCENT CITY 1_345.0 (20005)	YES

Choose Horizontal Axis and Vertical Axis values

For vertical axis, choose which elements to plot with selected values

Enter a title for the plot

Choose which contingencies to include on the plot

Click to show the plot

# PV Results

## Legacy Plots Tab

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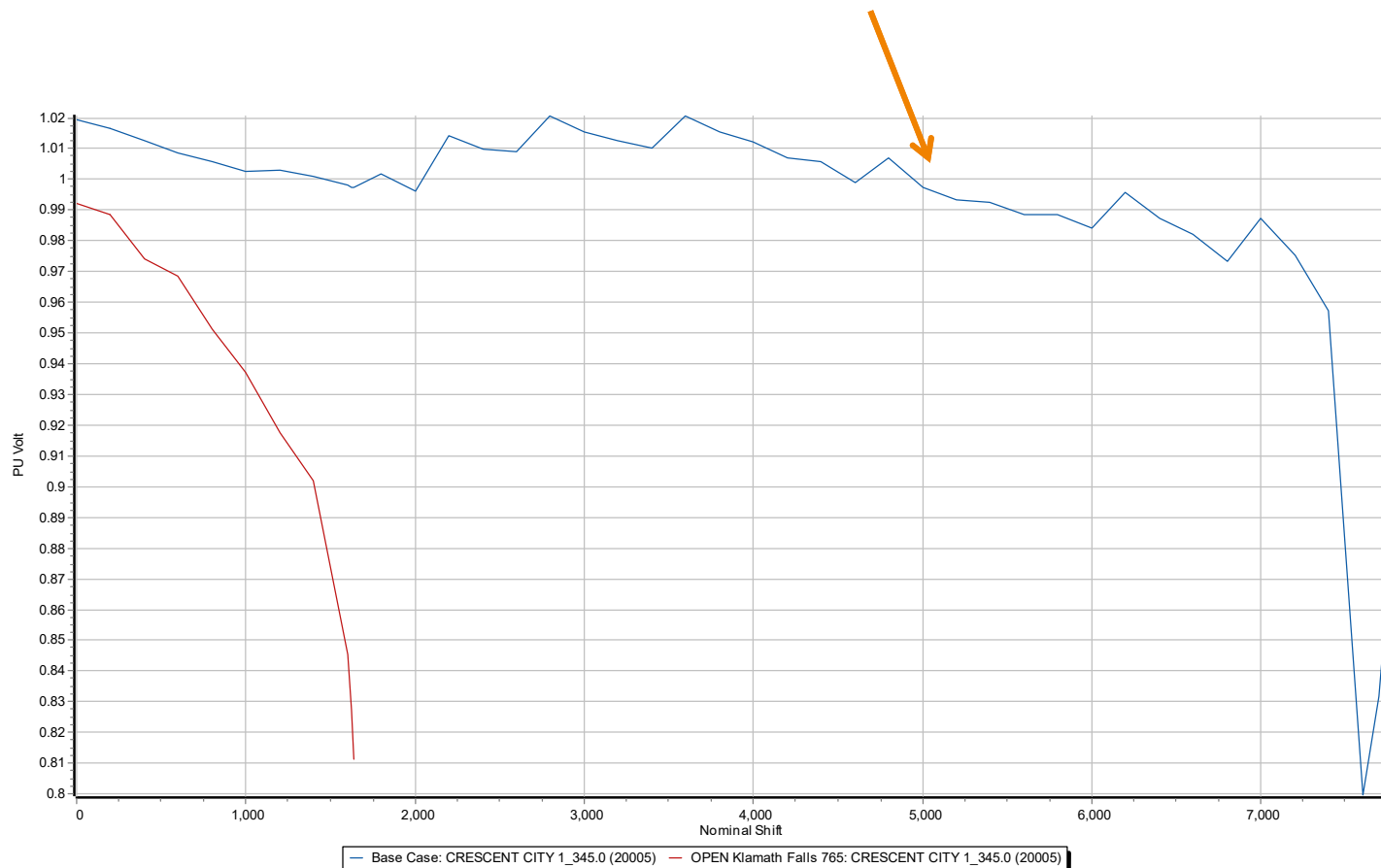
- The plot tab allows the user to plot all of the values that were designated to be monitored during the analysis
- For example, we can plot the bus voltages vs. the size of the transfer
- For Horizontal-Axis, select *Nominal Shift*
- For Vertical-Axis, select *PU Volt*
- Select all the Crescent City bus as elements
- Select all PV Scenarios
- Add title (optional)

# PV Results:

## Example PV Curve

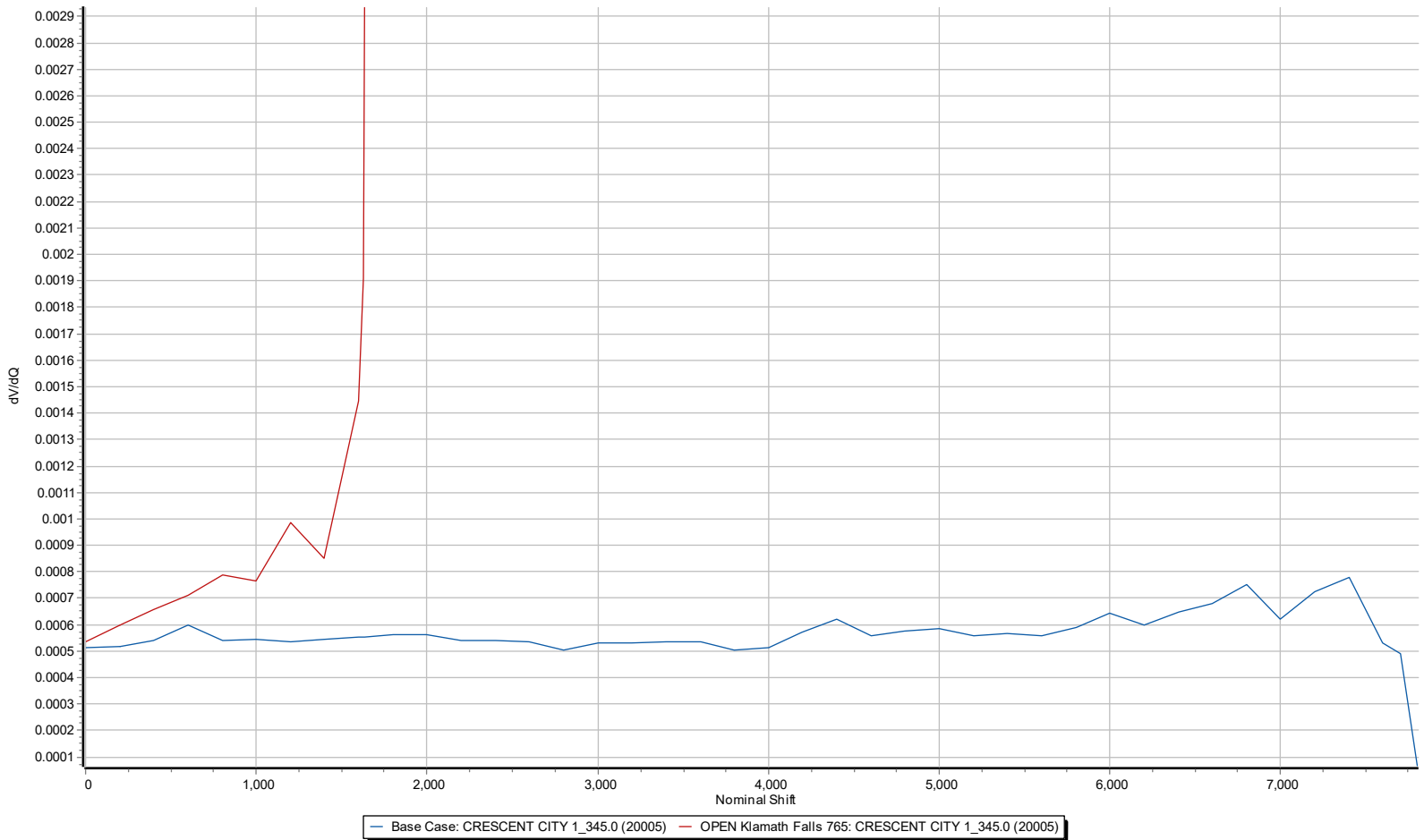


Note the “jaggedness”, especially for the Base Case plot. This is caused by the switched shunt and LTC transformer control actions trying to pull voltages up. Disable control switching to reduce this effect.



Right-click on the plot to Save it as a bitmap, metafile, or JPEG, or to copy or print the plot

# PV Results: dV/dQ plot



Build Date: June 7, 2023

# PV Results: csv file



Tracked  
Quantities  
stored at each  
solution step

The screenshot shows an Excel spreadsheet with the following data:

	A	B	C	D	E	F	G	H	I	J	K
1	RESULTS FOR PV STUDY ""										
2	**Scenario** "Base Case"										
3	Nominal	Export	"Import"	Bus 20005	Bus 20005	InjectionC	Newly Critical				
4	0	0	0	1.01954	5.13E-04	6171.389					
5	200	199.997	-175.116	1.01668	5.16E-04	6094.321					
6	400	399.997	-349.735	1.01279	5.42E-04	6006.029					
7	600	599.9985	-522.89	1.00862	5.98E-04	5920.751					
8	800	800.0046	-697.267	1.00567	5.40E-04	5843.27					
9	1000	1000.005	-869.357	1.00275	5.42E-04	5766.665					
10	1200	1200.005	-1042.55	1.00308	5.35E-04	5733.854					
11	1400	1400	-1213.04	1.00102	5.45E-04	5700.343					
12	1600	1600	-1382.11	0.99798	5.52E-04	5650.678					
13	1625	1624.999	-1403.71	0.99744	5.53E-04	5643.462					
14	1637.5	1637.508	-1413.17	0.99717	5.53E-04	5639.922	OPEN Klamath Falls 765 (Reached Nose)				
15	1800	1800	-1552.75	1.0017	5.62E-04	5630.666					
16	2000	2000	-1721.63	0.99614	5.63E-04	5563.683					
17	2200	2200.001	-1892.75	1.01429	5.38E-04	6035.164					
18	2400	2400.003	-2054.01	1.00986	5.42E-04	5925.212					

# PV Results Track Limits



Tracked Generators reveal some devices that hit Max Mvar during the transfer

**PV CURVES**

Setup  
 Common Options  
 Injection Group Ran  
 Interface Ramping (0  
 Advanced Options

Quantities to track  
 Buses  
 Generators  
 Injection Groups  
 Lines  
 Transformers  
 Shunts  
 Interfaces  
 Case  
 Devices At Limits

Limit violations  
 PV output  
 QV setup  
 PV Results  
 Overview  
 Legacy Plots  
 Track Limits  
 Generator Var L  
 Shunt Var Limits  
 LTC Var Limits  
 Line Thermal Lin  
 Interface Therm

Plots

**PV Results**

Run Stop  Restore Initial State on Completion of Run

Base case could not be solved

Present nominal shift 7710.000  
 Present step size

Source	Gen MW	Load SMW	Load IMW	Load ZMW
	26858.47	0.00	0.00	0.00
Sink	0.00	28075.09	0.00	0.00

View detailed results  
 Other actions >>

Found 2 limiting cases.

Overview Legacy Plots Track Limits

Filter out devices that never hit or backoff a limit during the PV run

Generator Var Limits Shunt Var Limits LTC Var Limits Line Thermal Limits Interface Thermal Limits

	Number of Bus	Name of Bus	ID	0.00	200.00	400.00	600.00	800.00	1000.00	1200.00	1400.00	1600.00
1	10683	MATTAWA 2 4	1	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range
2	10684	MATTAWA 2 5	1	Within Range	At Max	At Max	At Max	At Max	At Max	At Max	At Max	At Max
3	10685	MATTAWA 2 6	1	Within Range	At Max	At Max	At Max	At Max	At Max	At Max	At Max	At Max
4	10686	MATTAWA 2 7	1	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range
5	10687	MATTAWA 2 8	1	Within Range	At Max	At Max	At Max	At Max	At Max	At Max	At Max	At Max
6	10688	MATTAWA 2 9	1	Within Range	At Max	At Max	At Max	At Max	At Max	At Max	At Max	At Max
7	10689	MATTAWA 2 10	1	At Max	At Max	At Max	At Max	At Max	At Max	At Max	At Max	At Max
8	10691	ROOSEVELT 1 2	1	At Max	At Max	At Max	At Max	At Max	At Max	At Max	At Max	At Max
9	10694	RANDLE 2	1	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range
10	10695	RANDLE 3	1	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range
11	10699	CLE ELUM 2 3	1	At Min	At Min	At Min	At Min	At Min	At Min	At Min	At Min	At Min
12	10703	GOLDENDALE 2 2	1	Within Range	At Max	At Max	At Max	At Max	At Max	At Max	At Max	At Max
13	10710	WENATCHEE 3 4	1	At Min	At Min	At Min	At Min	At Min	At Min	At Min	At Min	At Min
14	10711	WENATCHEE 3 5	1	At Min	At Min	At Min	At Min	At Min	At Min	At Min	At Min	At Min
15	10712	WENATCHEE 3 6	1	At Min	At Min	At Min	At Min	At Min	At Min	At Min	At Min	At Min
16	10713	WENATCHEE 3 7	1	At Min	At Min	At Min	At Min	At Min	At Min	At Min	At Min	At Min
17	10714	WENATCHEE 3 8	1	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range	Within Range

Save Auxiliary ... Load Auxiliary ... Launch QV curve tool ... ? Help Close

# PV Results

## Other actions



- View activity log
  - Outlines step-by-step the activities the PV tool performed during the run
- View detailed results
  - Opens a text file that contains the detailed results including the values of the tracked quantities at each step for each scenario
- Clear results
  - Purges the currently stored results from memory
- Restore Initial State
  - Brings back the case that was in memory prior to the PV run
- Restore Last Solved State
  - Brings back the solved power flow model that depicts the system at the largest transfer level that was studied. This is a base case state with no contingency implemented.

# PV Results

## Other actions



- Save critical contingencies
  - Saves contingency settings and records in an auxiliary file for each scenario where a critical state was reached
- Set current state as initial
  - Removes the case that was in memory at the beginning of the PV run and replaces it with what is currently in memory
- Start Over
  - Removes all results from memory, restores the initial case, and removes all entries from the activity log
- Run QV tool
  - Launches the QV tool using the case that is currently in memory as its basis



# Time Saving Measures

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- Only define a few contingencies - each contingency monitored can add significant time to the PV study
- Try to limit the number of Quantities to Track. There is no hard limit on this, but the amount of computer memory can become substantial if you try to monitor too much.

# Plot Designer



- A general-purpose tool with more flexibility and options than **Legacy Plots**
  - Presents a complete list of PV track-able objects and variables, but only those selected on **Quantities to track** will have actual data to plot
  - **Legacy Plots** presents a reduced set of options, specific to PV curve plotting and the quantities tracked
- Saving plot options
  - **Save Auxiliary...** always visible on the PV Curves dialog
  - **Save Plot Definitions to Auxiliary File** on the Plot Designer

# Plot Designer



- Replicate PV plot drawn with the Legacy Plot tool
  - Device Type: Bus
  - Choose Fields: PU Volt
  - Choose Object: 20005
  - Click the Add >> button (or drag them to the Plots, Subplots, Axis Groups) window
- These settings and those on following slides are in *ACTIVSg10k PV Plot Definition.aux*
- More details on the Plot Designer tool are in training topic **T7: Plot Definitions**

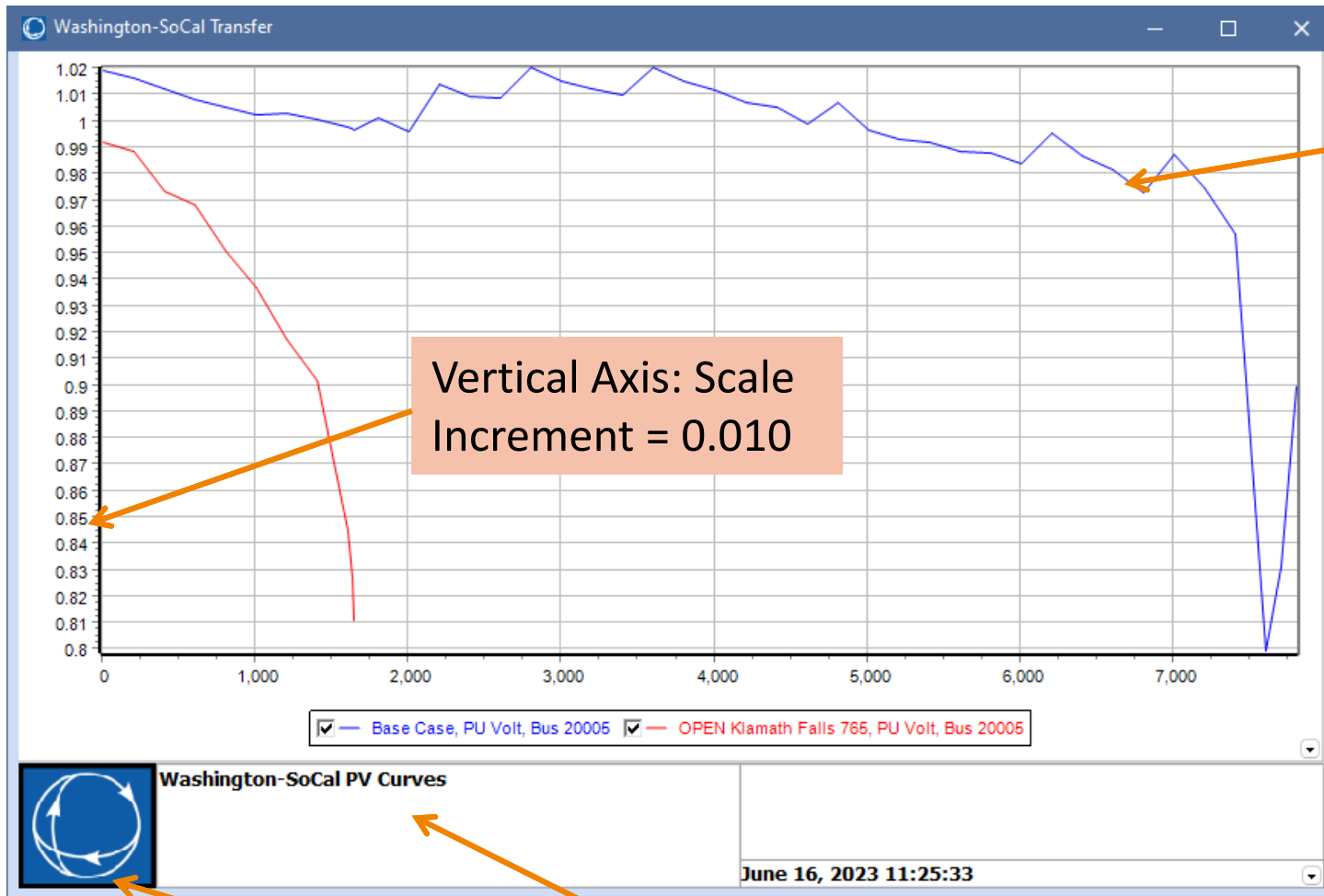
# Plot Designer



To show only certain PV Scenarios (base case, contingencies), click **Choose PV Scenarios to Plot**

Optionally rename the plot

# Plot Designer



Vertical Axis: Scale Increment = 0.010

Plot Series List: set color, thickness, style, etc.

To vary them for each scenario, open "Choose PV Scenarios to Plot"

Title Block: Logo Image, Left Memo, Right Memo

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