Linear Analysis

- Power Transfer Distribution Factors (PTDFs)
- Transmission Load Relief (TLRs) and Generation Shift Factors (GSFs)
- Multiple Direction PTDFs
- Multi-Element TLR/GSFs
- Line Outage Distribution Factors (LODFs)
- Outage Transfer Distribution Factors (OTDFs)
- Other Sensitivities
  - Line Flows, Interface Flows, Bus Voltages, Losses
- Line Loading Replicator
- Connections Menu

Power Transfer Distribution Factors (PTDFs)

- PTDF is a term defined by NERC to indicate the incremental impact a transfer of power between areas has on system flows.
- PTDFs can be calculated in Simulator by selecting **Tools** ribbon tab → **Sensitivities** → **Power Transfer Distribution Factors (PTDFs)**.
- PTDFs can be visualized on the onelines.

PTDF Calculation

- PTDFs show the linear impact of a power transfer
  - They show what percent of a transfer would appear on each transmission line in the power system
- PTDFs calculated using the factored power flow Jacobian
  - $\mathbf{\Delta x} = [J(x^*)]^{-1}\,\mathbf{\Delta P}$
  - $\mathbf{\Delta P}$ = change in power injections associated with power transfer
  - $\mathbf{\Delta x}$ = change in system voltages, from which flows can be derived

Specifying Transfer Direction for PTDF Calculation

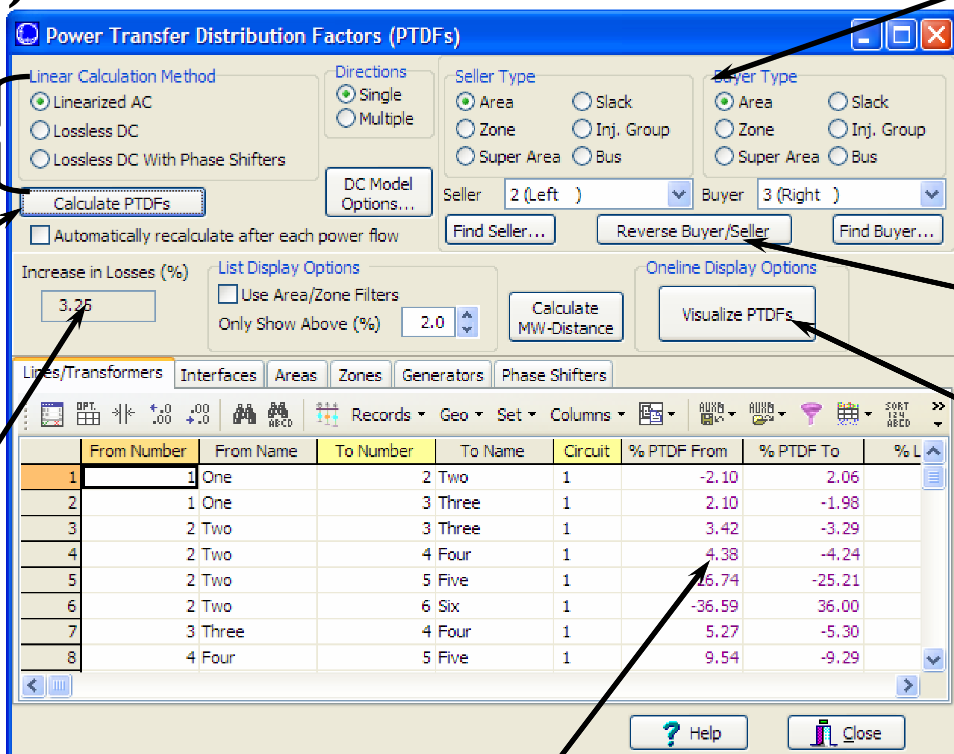
- Must specify a buyer (sink) and a seller (source) of power – a transfer direction
- Options for Buyer and Seller
  - Area, Zone, or Super Area
    - The PTDF calculation will assume that the generators in this region participate according to their participation factors
  - Slack
    - Means all power will come from or go to the slack bus
  - Injection Group
    - Injection groups can include loads and/or generation. Participation is specified for each element of the group
  - Bus
    - All power will come from or go to this bus.

Calculation Method for PTDF Calculation

- Must specify a calculation method
  - Linearized AC – includes the full Jacobian in the calculation, and thus includes losses
    - Note: the PTDF calculation assumes that all losses are made up for by the buyer
    - Exception: if the seller contains the slack bus, then the seller will make up for all losses.
  - Lossless DC – only uses the DC power flow equations, so losses not included
  - Lossless DC with phase shifters – modification to previous that forces change in flow across operating phase shifters to be zero.
  - For a highly detailed explanation of the PTDF calculation, see the section at the end of this binder

PTDF Display

- Choose **Tools** ribbon tab → **Sensitivities** → **Power Transfer Distribution Factors (PTDFs)**



Select Calculation Method to Use

Select to calculate the PTDFs

Percentage change in system losses

User selects seller and buyer

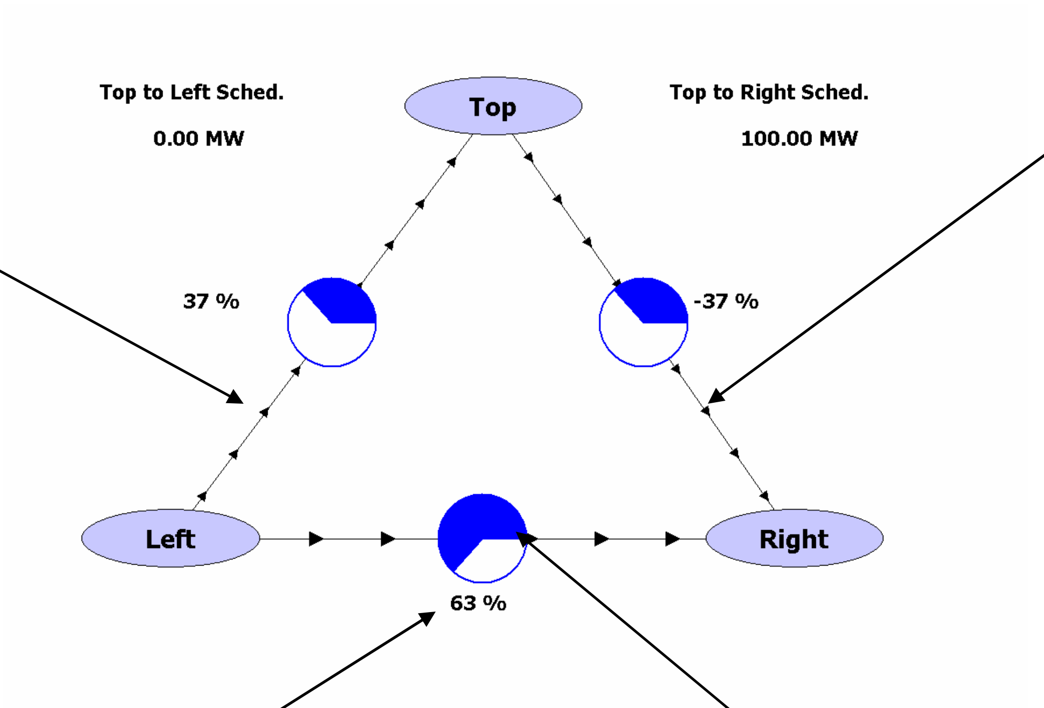
Switches buyer and seller

Used to visualize PTDFs on oneline. Only available if only one oneline is open.

Results are expressed as a percentage of the power transfer

PTDFs on the Onelines

Animated arrows used to indicate percentage of transfer flowing on the interface



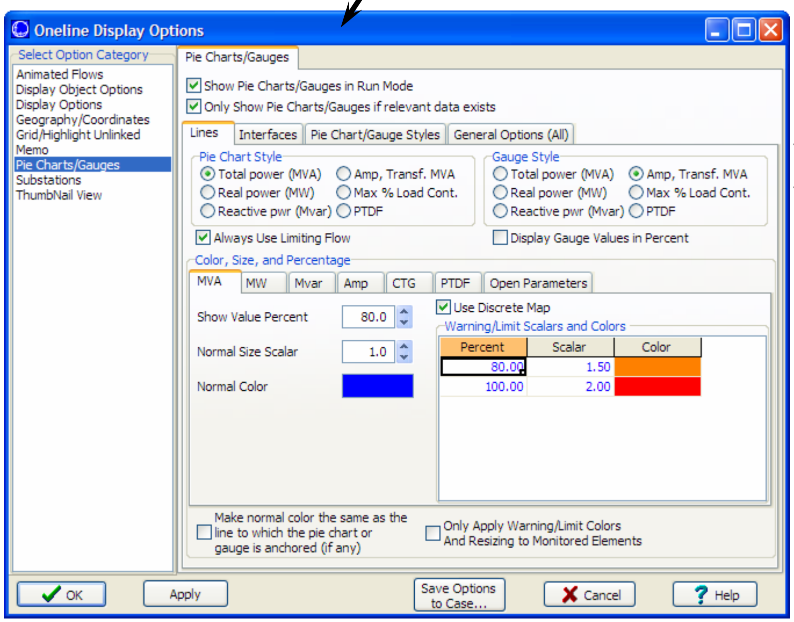
Different colors can be used to high-light counter-flows

Fields now show percentage of specified transaction flowing through the interface

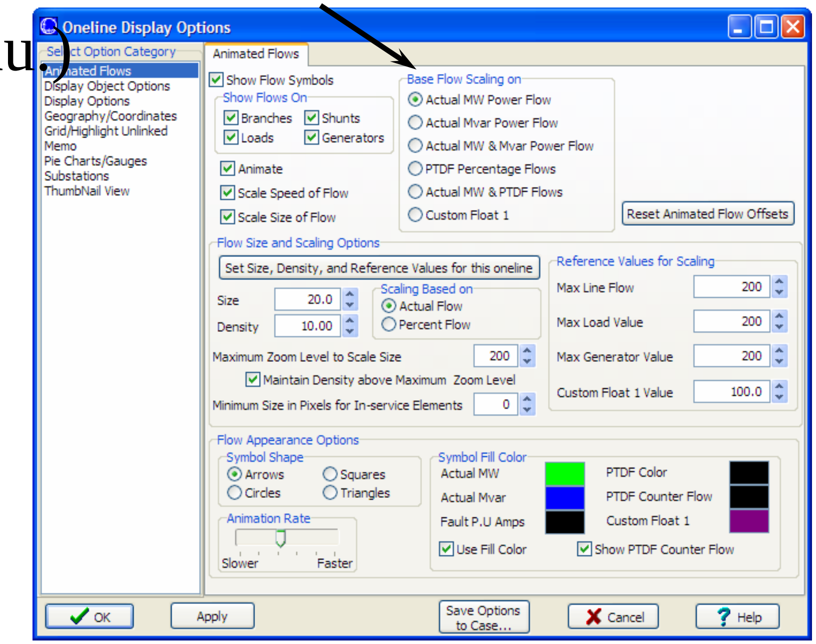
Pie charts indicate %

PTDFs on the Onelines

Using the Oneline Display Options dialog, the size/color of the pie charts (both line and interface) can be conditional, based upon percentage flow through the device

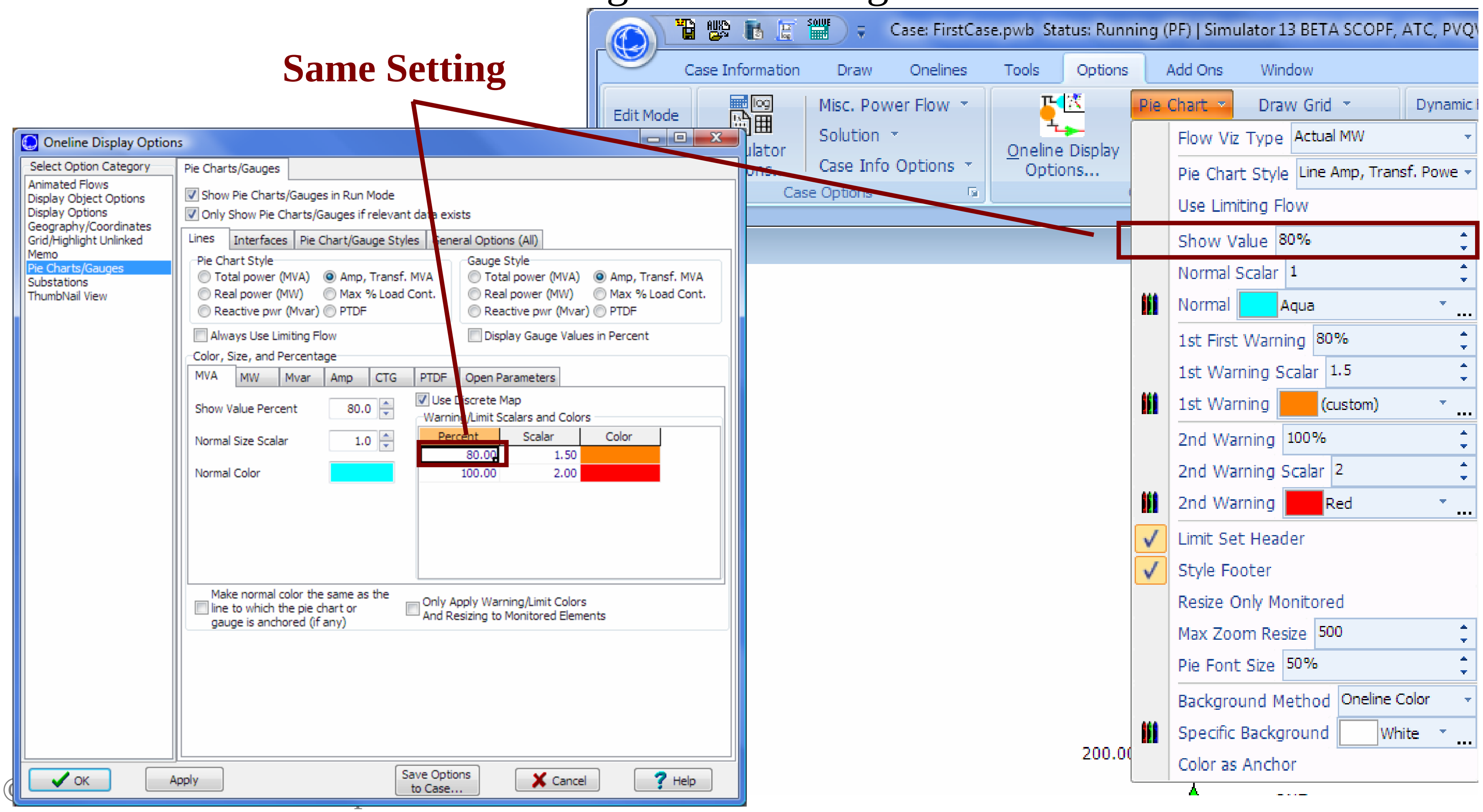


Use to toggle between actual flows and PTDFs (you can also use the oneline local-menu)



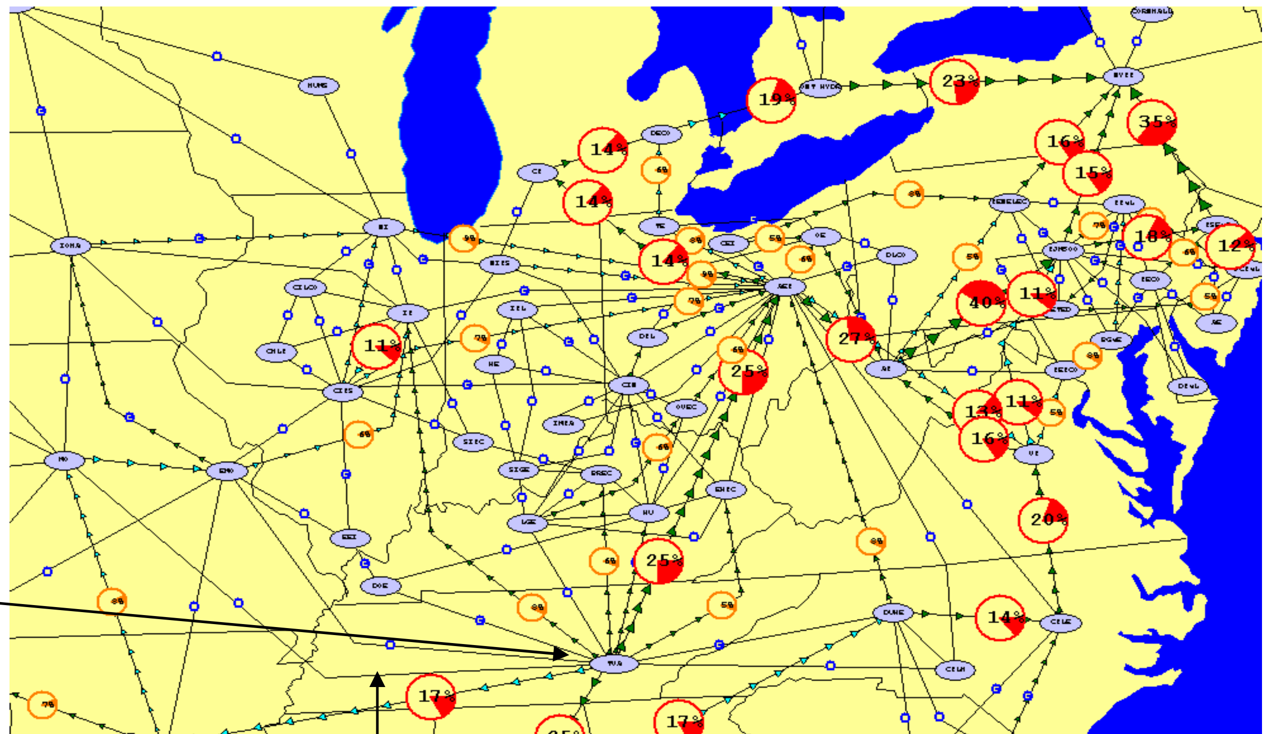
Remember: Pie Charts Options Toolbar

- Available in **Options** ribbon tab → **Pie Chart**
- Notice that all the settings on the dialog are available



PTDFs for a Large Case

The PTDFs were calculated using a 23,000 bus FERC 715 case for the SERC region



Simulated transfer is from TVA to NYPP

Pie charts dynamically increase in size/change color for different PTDF values

Transmission Loading Relief (TLR) and Generation Shift Factors (GSF)

- PTDF calculation determine the impact of ONE transfer on MANY lines
- The TLR calculation is exactly the same mathematically, but it determines the impact of MANY transfers on ONE line
- Think about building a table
  - Columns represent many different transfer directions
  - Rows represent many different branches
  - Then the table entry at Row N, Column M is the distribution factor of the Mth transfer on the Nth branch
  - The PTDF calculation determine a column of this table
  - The TLR calculation determines a row of this table

TLR/GSFs versus PTDFs: Table of Distribution Factors

List of Transfer Directions

List of Lines

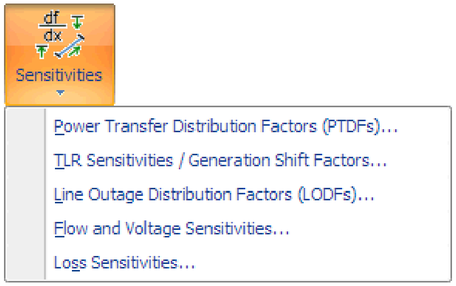
	Dir_1		Dir_N	$\cdots$	Dir_{n_d}
Line_1	DF_{11}	$\cdots$	DF_{1N}	$\cdots$	DF_{1n_d}
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
Line_M	DF_{M1}	$\cdots$	DF_{MN}	$\cdots$	DF_{Mn_d}
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
Line_{n_l}	$DF_{n_l 1}$	$\cdots$	$DF_{n_l N}$		$DF_{n_l n_d}$

TLR or GSF Calculation For Line M

PTDF Calculation for Direction N

Options for TLR/GSF Calculation

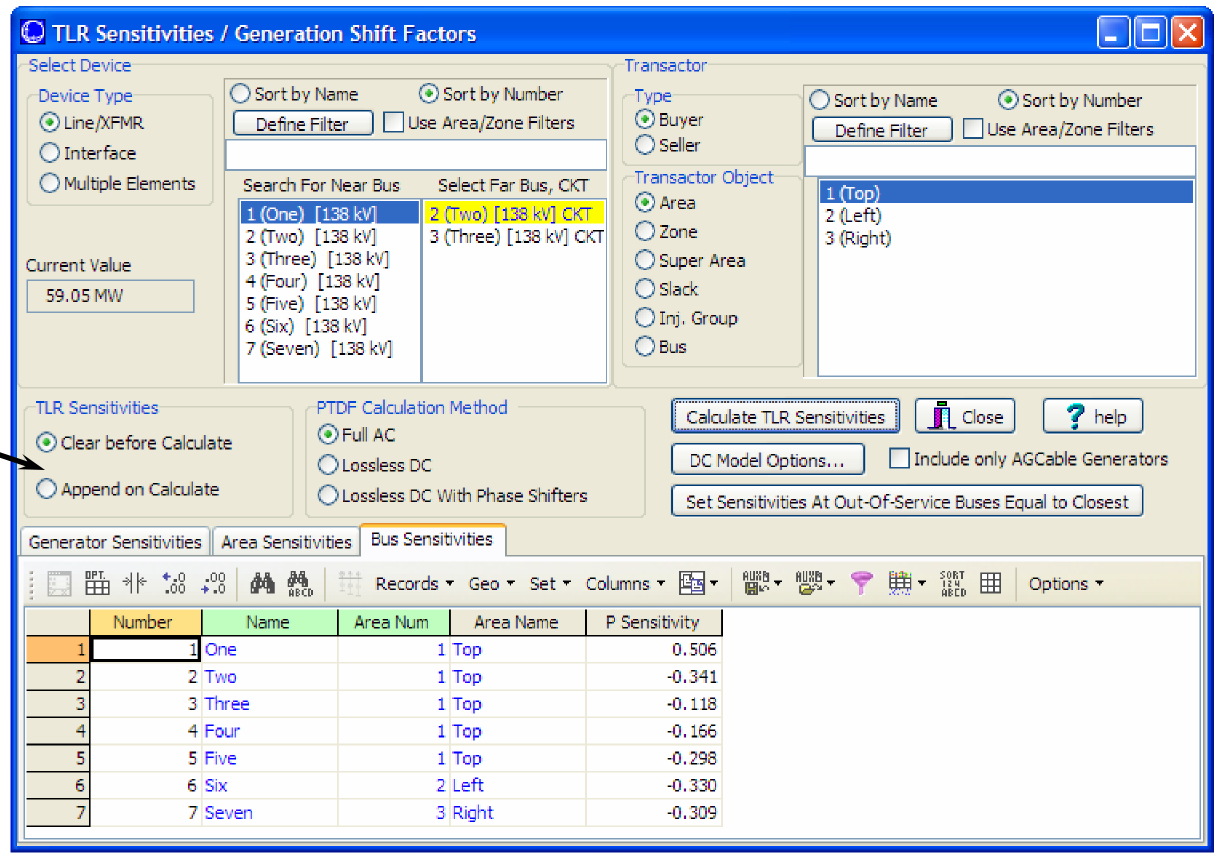
- Specify a transmission line or interface
- Specify a calculation method (same as for PTDF)
- To narrow down the choices for directions, specify one end of the transfer (buyer or seller)
  - TLR calculates the impact of transferring power between each bus and the specified end of the transfer.
  - The Area Sensitivities determined will just be a weighted average of the sensitivities for each generator bus in the area (weighted by Participation Factors)
- GSF versus TLR
  - The generation shift factor calculation is a specific kind of TLR calculation.
  - GSF implies that the buyer is the Slack bus



TLR/GSF Dialog

- Choose **Tools** ribbon tab → **Sensitivities** → **TLR Sensitivities / Generation Shift Factors**

When you **Append on Calculate**, Simulator will keep the highest distribution factor calculated for each bus or area after each calculation



Calculating the whole Table Multiple Direction PTDF

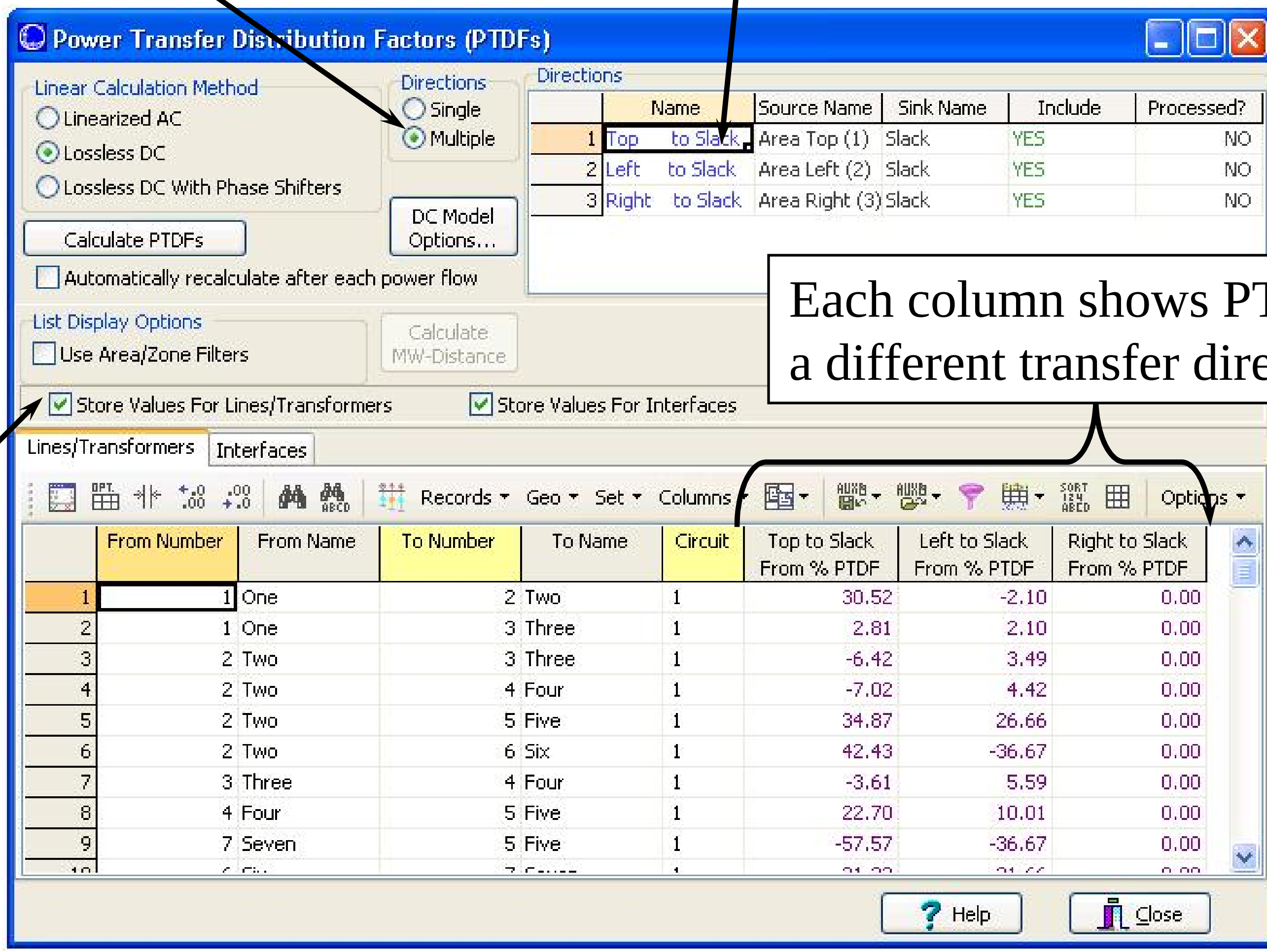
- Simulator also allows you to calculate the entire distribution factor table
- Specify a list of directions
  - Simulator will calculate the PTDFs for each of these transfer directions and display them
  - Must be VERY careful. You may ask Simulator to calculate two many numbers for your computer to hold.
    - 20,000 transmission lines and 500 transfer directions means that you must calculate 10 million values (actually it's 20 million because simulator calculate the PTDF for both directions of flow on the transmission line)
    - Assuming about 20 bytes per value, that's around 400 MB of computer memory

	Dir_1		Dir_N	$\cdots$	Dir_{n_d}
Line_1	DF_{11}	$\cdots$	DF_{1N}	$\cdots$	DF_{1n_d}
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
Line_M	DF_{M1}	$\cdots$	DF_{MN}	$\cdots$	DF_{Mn_d}
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
Line_{n_l}	$DF_{n_l 1}$	$\cdots$	$DF_{n_l N}$		$DF_{n_l n_d}$

PTDF Display for Multiple Directions

Choose Multiple Directions

Right-click on list display and choose insert or Auto-Insert to specify directions



Each column shows PTDF for a different transfer direction.

To save memory, you can specify whether to store values for only lines or only interfaces

Calculating the whole Table TLR/GSF Multiple Elements

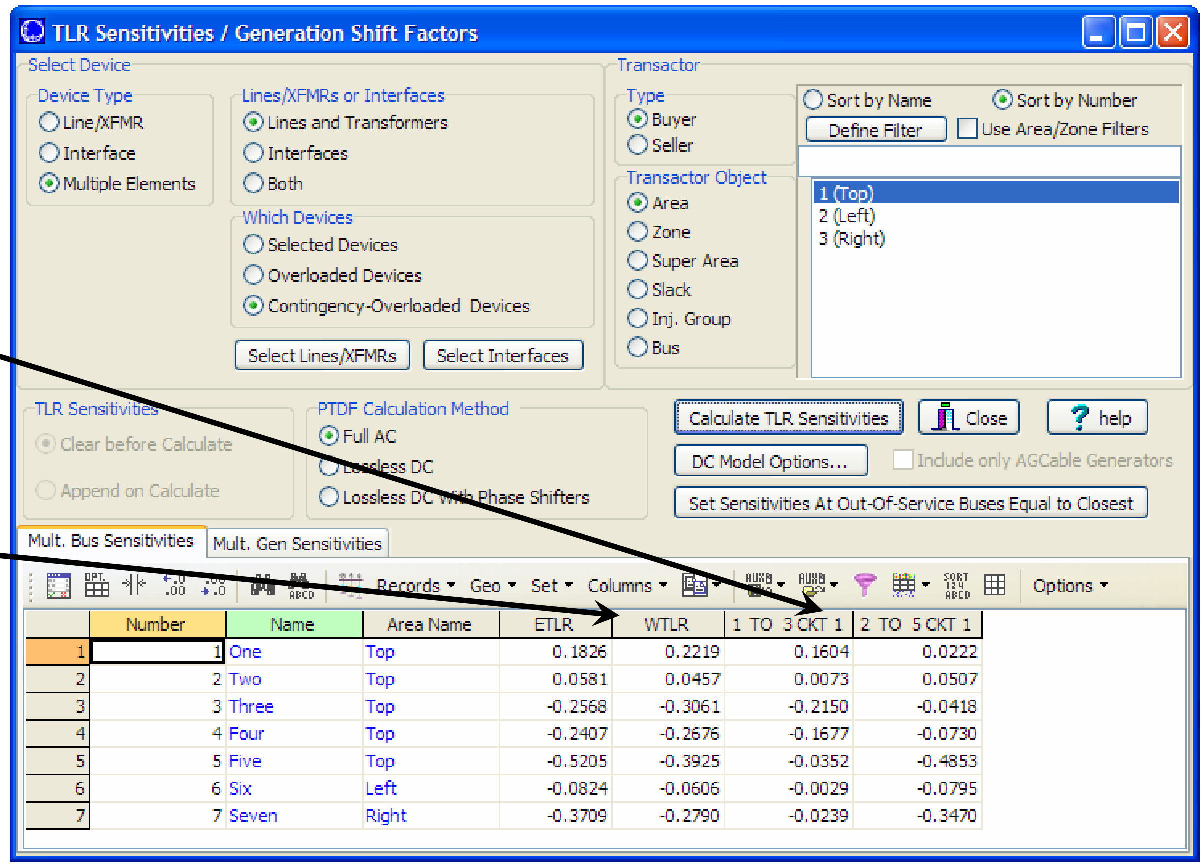
- Multiple Direction PTDFs work best for
  - A small number of Directions
  - A large number of lines/interfaces
- TLR/GSF Multiple Elements work best for
  - A large number of Directions/Buses
  - A small number lines/interfaces

TLR/GSF Multiple Elements

- Allows Calculation of TLR for specified branches or interfaces

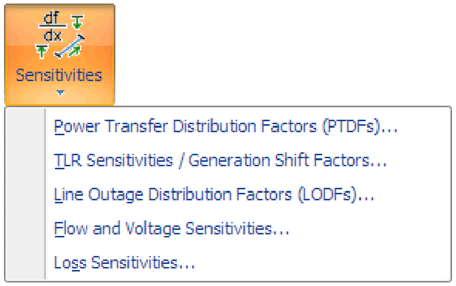
TLRs with respect to individual elements

Weighted TLR (WTLR) shows sensitivity as a weighted sum of MW relief over all overloaded elements



Line Outage Distribution Factors (LODFs)

- LODFs are another linearized calculation
  - Calculate the impact of opening (outaging) a transmission branch on all the other branches in the case.
  - Also can calculate the impact of closing in a branch (could call this called a Line Closure Distribution Factor or LCDF)
- Specify a transmission branch, and the calculation determines what percent of the flow on that line will appear on all other transmission lines
  - If the branch was initially open, then the LCDF will calculate what percent of the post-closure flow on the line will appear on other lines



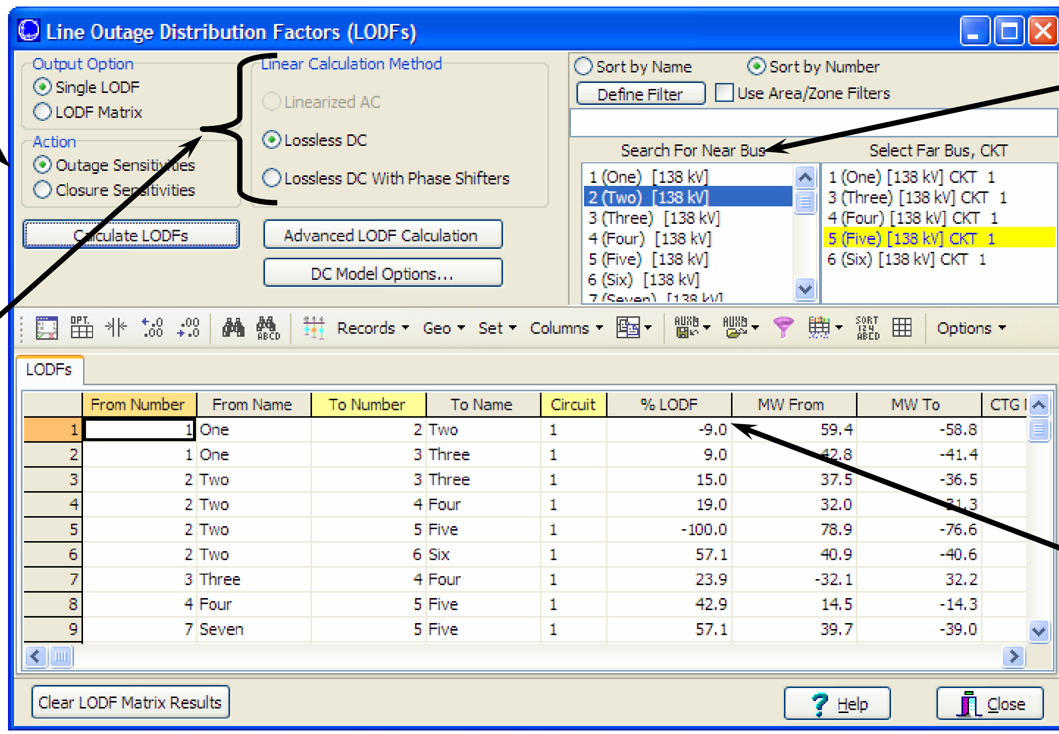
LODF Dialog

- Choose **Tools** ribbon tab → **Sensitivities** → **Line Outage Distribution Factors (LODFs)**

Action will actually be determined for you

(If the line is presently closed, then it will automatically do an outage sensitivity)

Select the transmission branch



Select Calculation Method to Use

LODF values in percent (or LCDF)

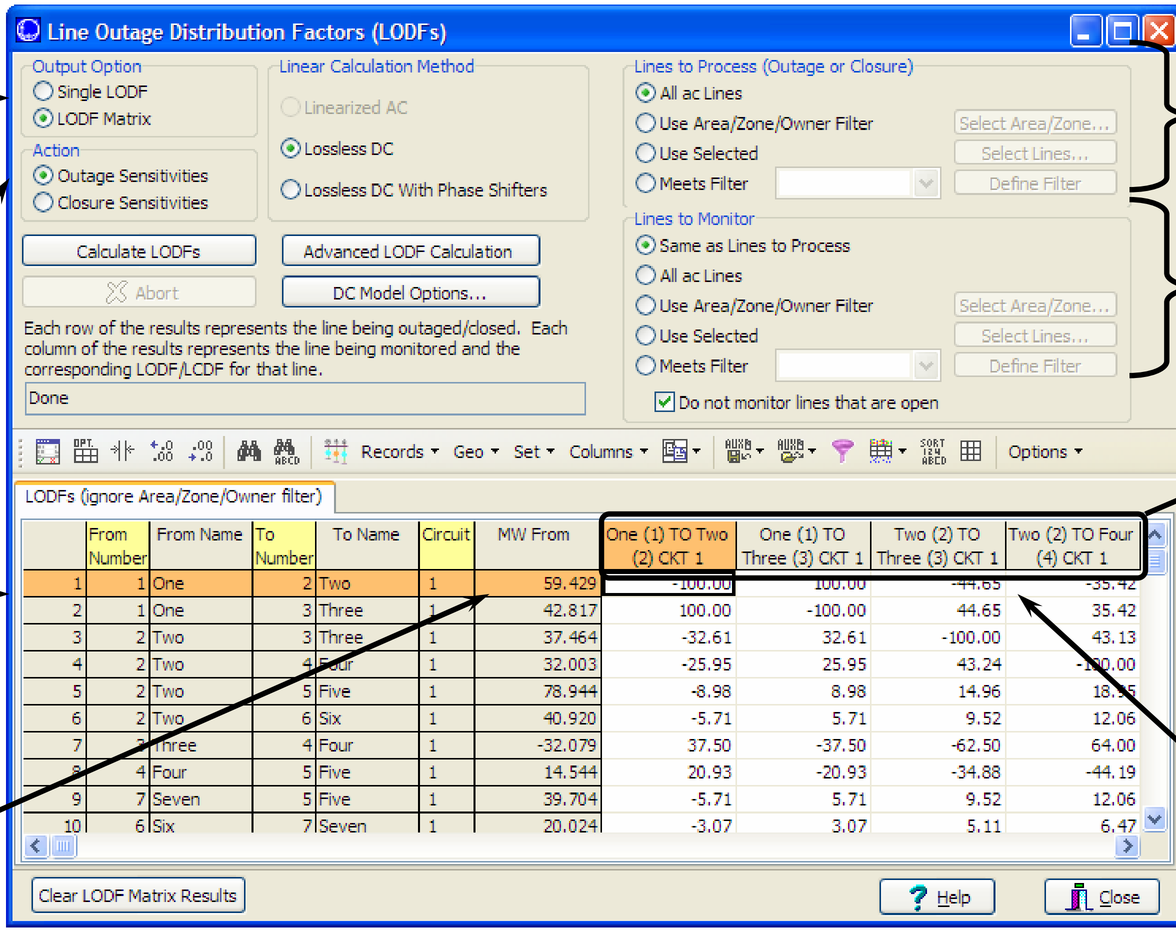
LODF Matrix

Select LODF Matrix

Select type of sensitivity

Line to outage/ close

Present MW flow on line



Select lines to outage/close

Select lines to monitor

Lines to monitor

LODF on Line 2-3 for outage of Line 1-2

Outage Transfer Distribution Factors (OTDFs)

- Simulator finds these during ATC Calculations
- The setup for the calculation
  - Studying a transfer between a seller and buyer
  - Monitoring the flow on line M
  - Studying what happens after an outage of line C
- OTDF
  - the percent of the transfer that will flow on Line M AFTER the outage of line C
- Outage MW (OMW)
  - The MW flow on line M after line C is outaged
- Calculate OMW and OTDF from by using the present flow on the lines and PTDFs and LODFs

OTDF, OMW Calculation

- Values we already know

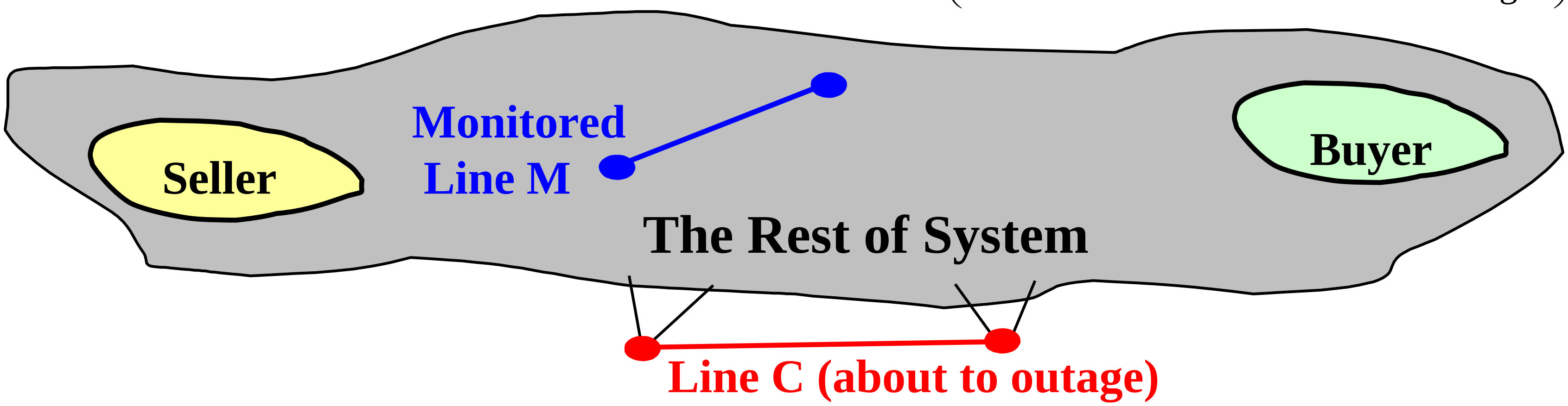
$PTDF_M$ = PTDF for the transfer direction on line M

$PTDF_C$ = PTDF for the transfer direction on line C

$MW_M = $ (present MW flow on monitored line M)

$MW_C = $ (present MW flow on contingent line C)

$LODF_{M,C} = $ (the percent of flow on line C that will move over to line M if Line C is outaged)



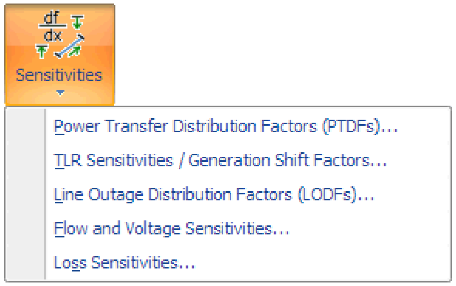
- Calculate the OTDF and OMW values from this

$$OMW_{M,C} = MW_M + LODF_{M,C} * MW_C$$

$$OTDF_{M,C} = PTDF_M + LODF_{M,C} * PTDF_C$$

OTDF and OMW calculation for multiple line outages

- A similar calculation can be done when trying to include multiple-line outage OTDFs
  - Finds the percent of a transfer that will flow on Line M AFTER the outage of lines 1, 2, …
- Simulator handles these multiple outages internally
- For more details, see the section near the end of this binder on Linear Analysis Techniques.



Flows and Voltage Sensitivities

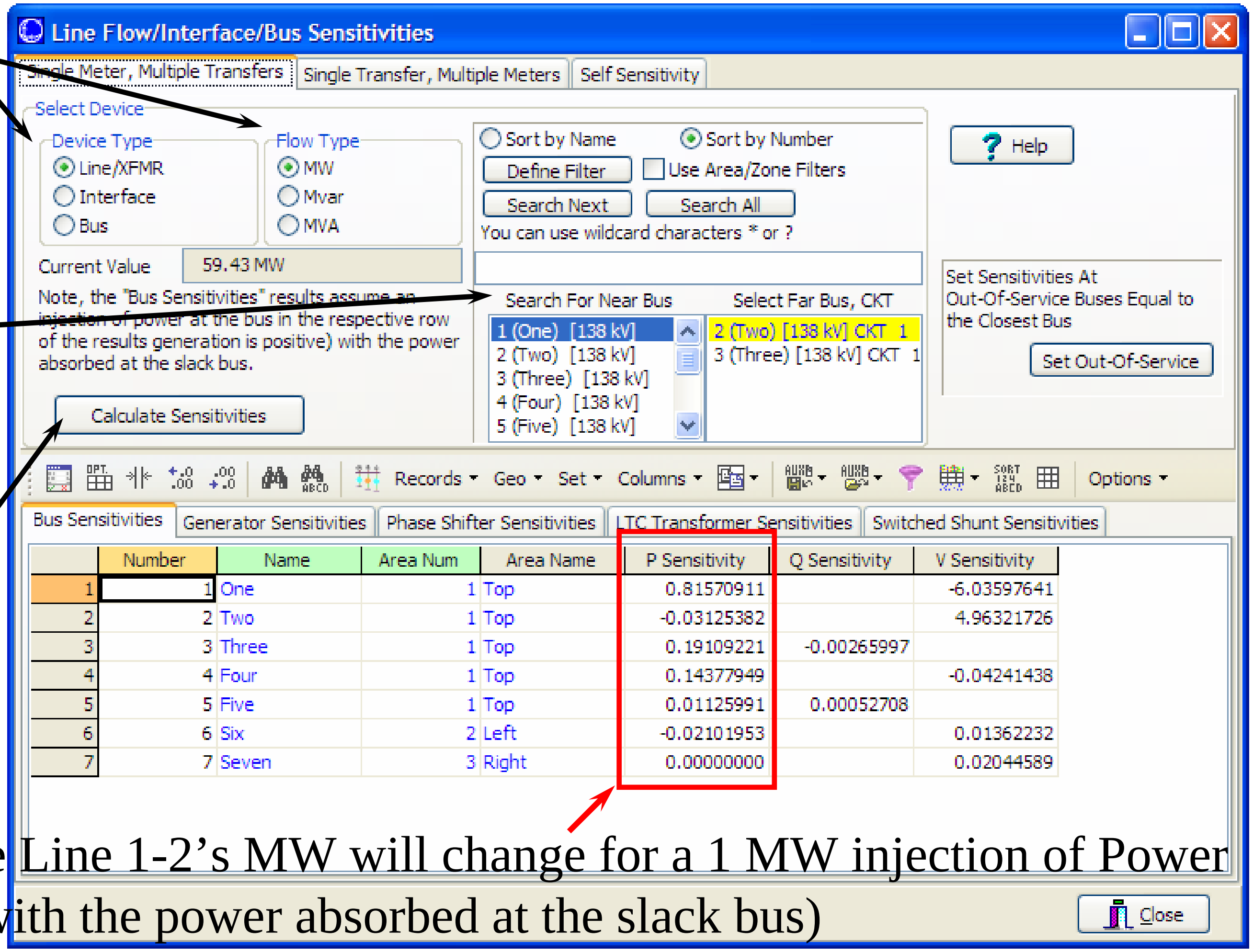
- Choose **Tools** ribbon tab → **Sensitivities** → **Flow and Voltage Sensitivities t**o bring up the Line Flow/ Interface/Bus Sensitivities dialog
- Calculates the sensitivity of various valuesto an injection of real or reactive power
  - If not specified, these calculations assume that the absorption of MW/Mvars occurs at the ***island slack bus***
  - Line or Interface MW flow sensitivities → $\dfrac{dP_{Flow}}{d\mathbf{P}_{\mathbf{injection}}}, \dfrac{dP_{Flow}}{d\mathbf{Q}_{\mathbf{injection}}}$
  - Line or Interface MVAR flow sensitivities → $\dfrac{dQ_{Flow}}{d\mathbf{P}_{\mathbf{injection}}}, \dfrac{dQ_{Flow}}{d\mathbf{Q}_{\mathbf{injection}}}$
  - Line or Interface MVA flow sensitivities → $\dfrac{dS_{Flow}}{d\mathbf{P}_{\mathbf{injection}}}, \dfrac{dS_{Flow}}{d\mathbf{Q}_{\mathbf{injection}}}$
  - Bus voltage sensitivities → $\dfrac{dV_{Bus}}{d\mathbf{P}_{\mathbf{injection}}}, \dfrac{dV_{Bus}}{d\mathbf{Q}_{\mathbf{injection}}}$

Flows and Voltage Sensitivities

Select Device and Flow or Voltage Type

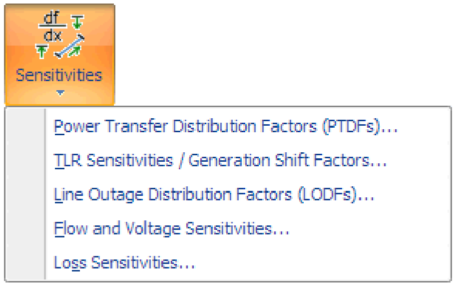
Select Device

Click Calculate Sensitivities



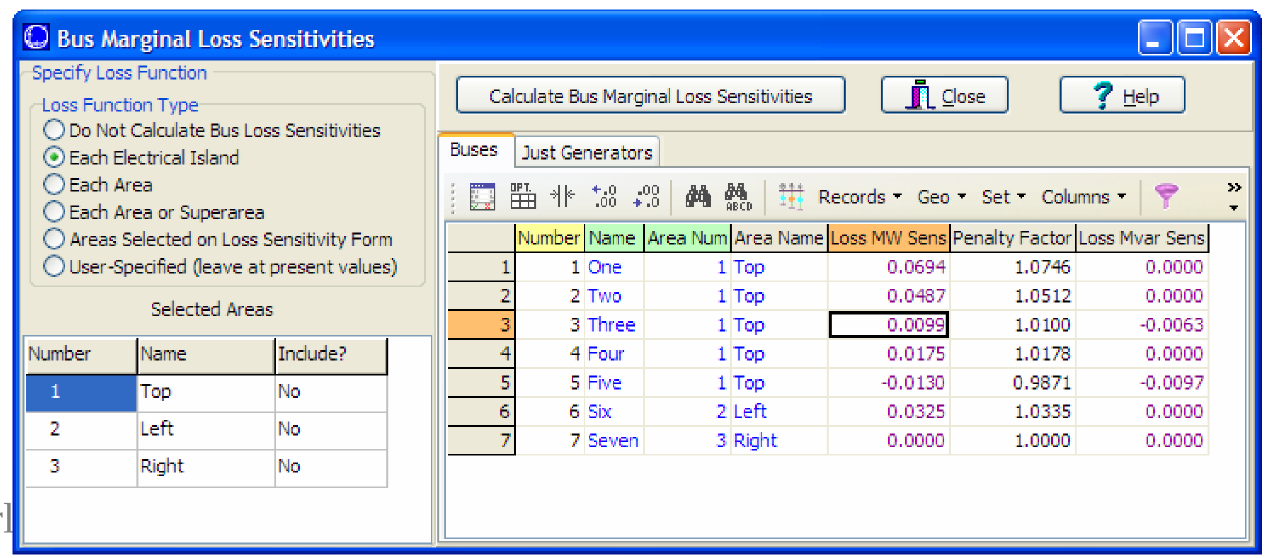
	Number	Name	Area Num	Area Name	P Sensitivity	Q Sensitivity	V Sensitivity
1	1	One	1	Top	0.81570911		-6.03597641
2	2	Two	1	Top	-0.03125382		4.96321726
3	3	Three	1	Top	0.19109221	-0.00265997	
4	4	Four	1	Top	0.14377949		-0.04241438
5	5	Five	1	Top	0.01125991	0.00052708	
6	6	Six	2	Left	-0.02101953		0.01362232
7	7	Seven	3	Right	0.00000000		0.02044589

Represents how the Line 1-2's MW will change for a 1 MW injection of Power at respective bus (with the power absorbed at the slack bus)



Loss Sensitivities

- Choose **Tools** ribbon tab → **Sensitivities** → **Loss Sensitivities** to bring up the Bus Marginal Loss Sensitivities dialog
- This models an injection of 1.0 MW at a bus with this power being absorbed at the *island slack bus*
- The **Loss MW Sens** value for each bus represents how much the losses as specified by the **Loss Function Type** will increase for the 1 MW injection at the respective bus



Loss Sensitivities

- Penalty Factor Column equals 1/(1 – Loss MW Sens)
- Loss Function Types
  - Do not calculate – All Loss MW Sens values will be zero
  - Each Electrical Island – how do losses change in the island
  - Each Area – For each bus it calculates how the losses in the bus' area will change (Note: this means that sensitivities at buses in two different areas can not be directly compared because they are referenced to different losses)
  - Each Area or Super Area – same as Each Area, but if a Super Area exists it will use this instead (Note: this means that sensitivities at buses in two different areas can not be directly compared because they are referenced to different losses)
  - Areas Selected on Loss Sensitivity Form – Calculates how the losses in the selected areas will change
  - User-Specified – Values will never be recalculated. Also the Loss MW Sens column will become enterable (blue) on the bus displays.

Line Loading Replicator

- Available from **Tools** ribbon tab → **Line Loading Replicator**
- Uses linear transfer sensitivities to calculate injection changes required to achieve desired MW flow on a selected line
- Injection groups used to select the generators and loads that can participate in the injection changes
- Net injection change is zero; same amount of MW injected into the system as taken out of the system
- Generator and load min and max always enforced
- Injection changes can be implemented in the power flow case to determine the actual impact of the changes

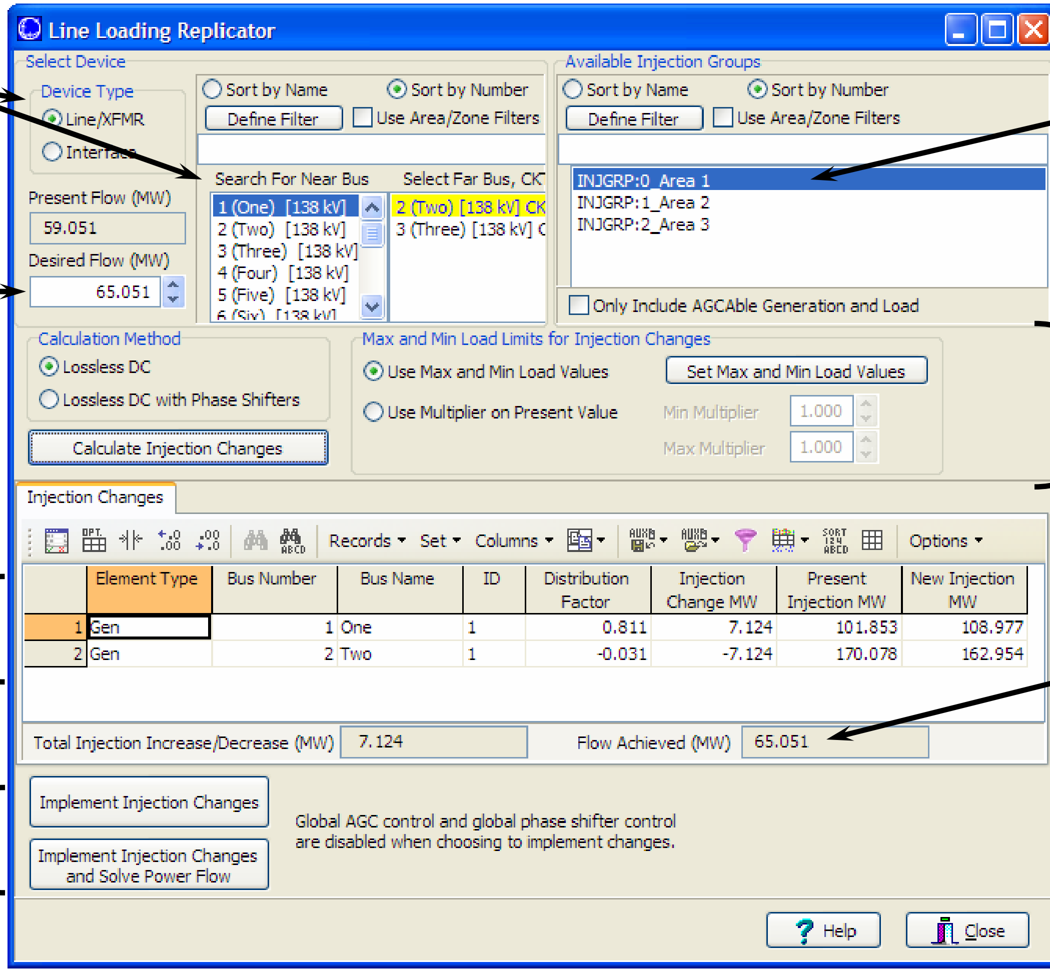
Line Loading Replicator Dialog

Choose the device

Set the Desired Flow

Participating elements and required injection changes

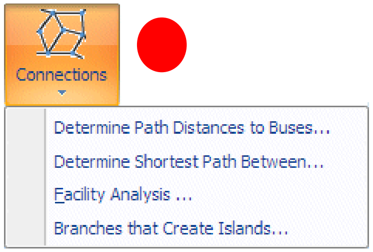
Implement injection changes in the case



Select the injection group that determines participants

Define Max and Min load limits

MW Flow value that can be achieved on selected device

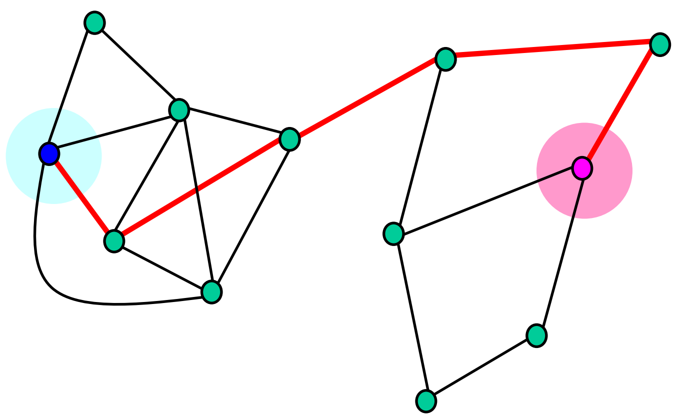


Tools: Other Ribbon Group Connections Menu

- Features in this menu analyze the connectivity of the power system model
  - Determine Path Distances to Buses…
    - Determine the path distance at each bus to a particular part of the system
  - Determine Shortest Path Between…
    - Find the shortest path between points in the network
  - Facility Analysis…
    - Find the minimum number of branches to remove to separate two parts of the network
  - Branches that Create Islands…
    - Find a list of branches that if removed will split the network into two islands.

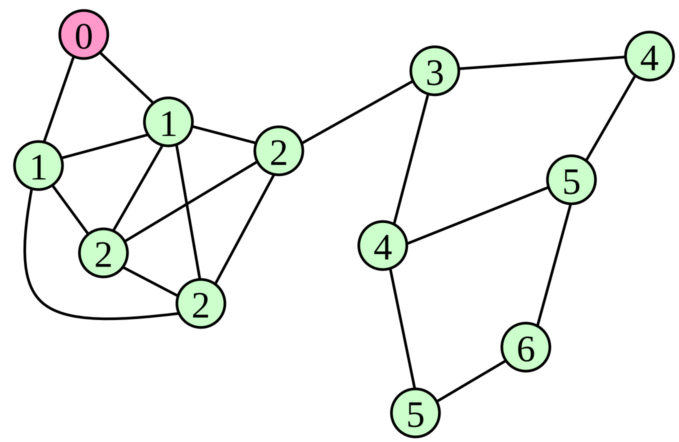
Tools in Connections Menu: Are Graph Analysis Tools

Determine Shortest Path Between



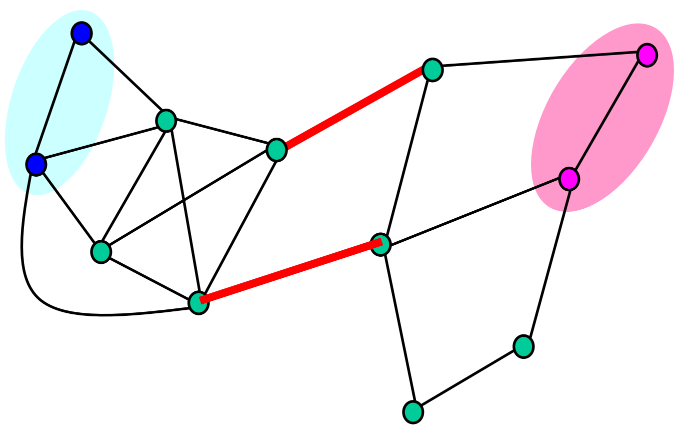
Result: Returns a list of branches

Determine Path Distances to Buses



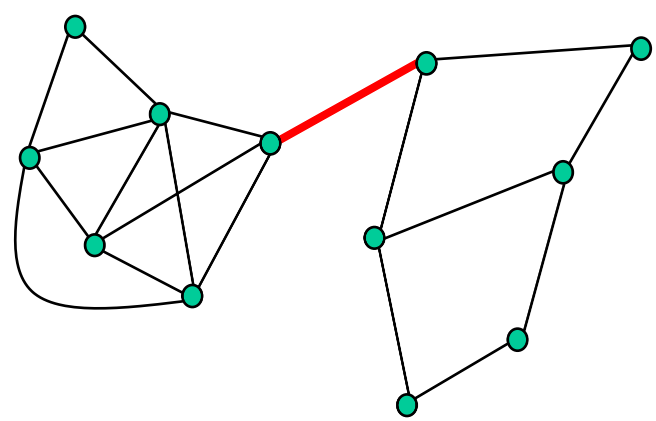
Result: Labels every Bus

Facility Analysis



Result: Returns a list of branches

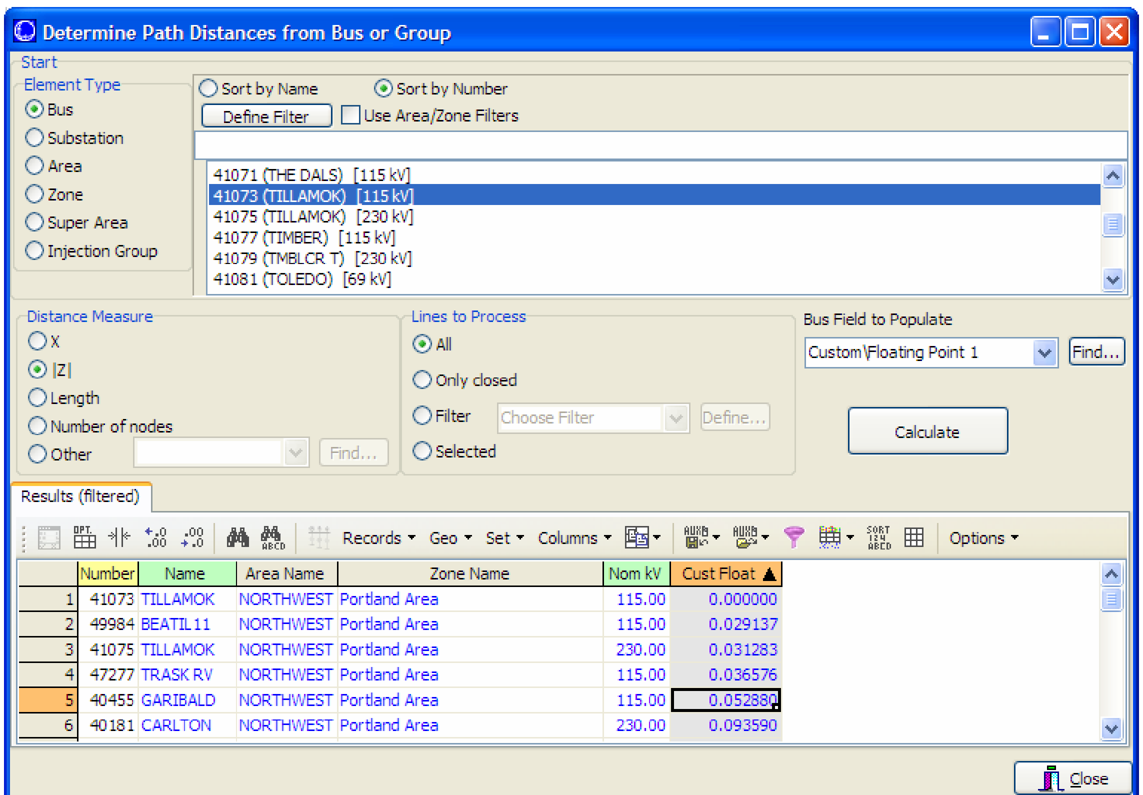
Branches that Create Islands



Result: Returns a list of branches

Determine Path Distances From Bus or Group

- This tool allows you to choose a single bus or a group of buses, and then determine the distance from that to all the other buses in the group



Determine Path Distances From Bus or Group Dialog

- Start Group
  - All buses inside this group will be marked with a distance of zero
- Distance Measure
  - Each branch in the network will be treated as having a distance equal to the choice made here
- Lines to Process
  - Specify a filter to limit the branches that can be traversed during this process
- Bus Field to Populate
  - After clicking **Calculate**, the shortest total distance to the Start Group will be calculated for *EVERY* bus in the system.
  - Result of calculation is pasted into this Bus Field and this bus Field is automatically added to the case information display at the bottom

SCRIPT: DeterminePathDistance([start], BranchDistMeas, BranchFilter, BusField);

Determine Shortest Path From Bus or Group

- Start Group, End Group
  - Specify a start and end group to determine distances between
- Distance Measure
  - Each branch in the network will be treated as having a distance equal to the choice made here
- Lines to Process
  - Specify a filter to limit the branches that can be traversed during this process
- Click calculate to determine the shortest series of branches that goes from the Start Group to the End Group.

SCRIPT: DetermineShortestPath([start], [end], BranchDistanceMeasure, BranchFilter, Filename);

Facility Analysis

- This dialog allows you to choose two sets of buses on the Select the Buses
  - Buses with *Which System?* = EXTERNAL
  - Buses with *Selected?* = YES
- When you then switch to the Facility Analysis Tab, you can click **Find Minimum Cut** to find the minimum number of branches to remove to separate the two sets of buses
- The results will be shown in a list of branches at the bottom of the dialog

Branches that Create Islands

- Find a list of branches that if removed will split the network into two islands.
- Click **Determine Branches** button to execute.
- Lines to Process
  - Specify a filter to limit the branches that will be checked for creating islands
- Middle part of dialog will list the branches that if opened will create an island
- When you choose a branch from the middle list, the bottom portion of the dialog will list the buses that become islanded as a result of the selected branches outage