Steady-State Power System Security Analysis with PowerWorld Simulator

S5: Available Transfer Capability

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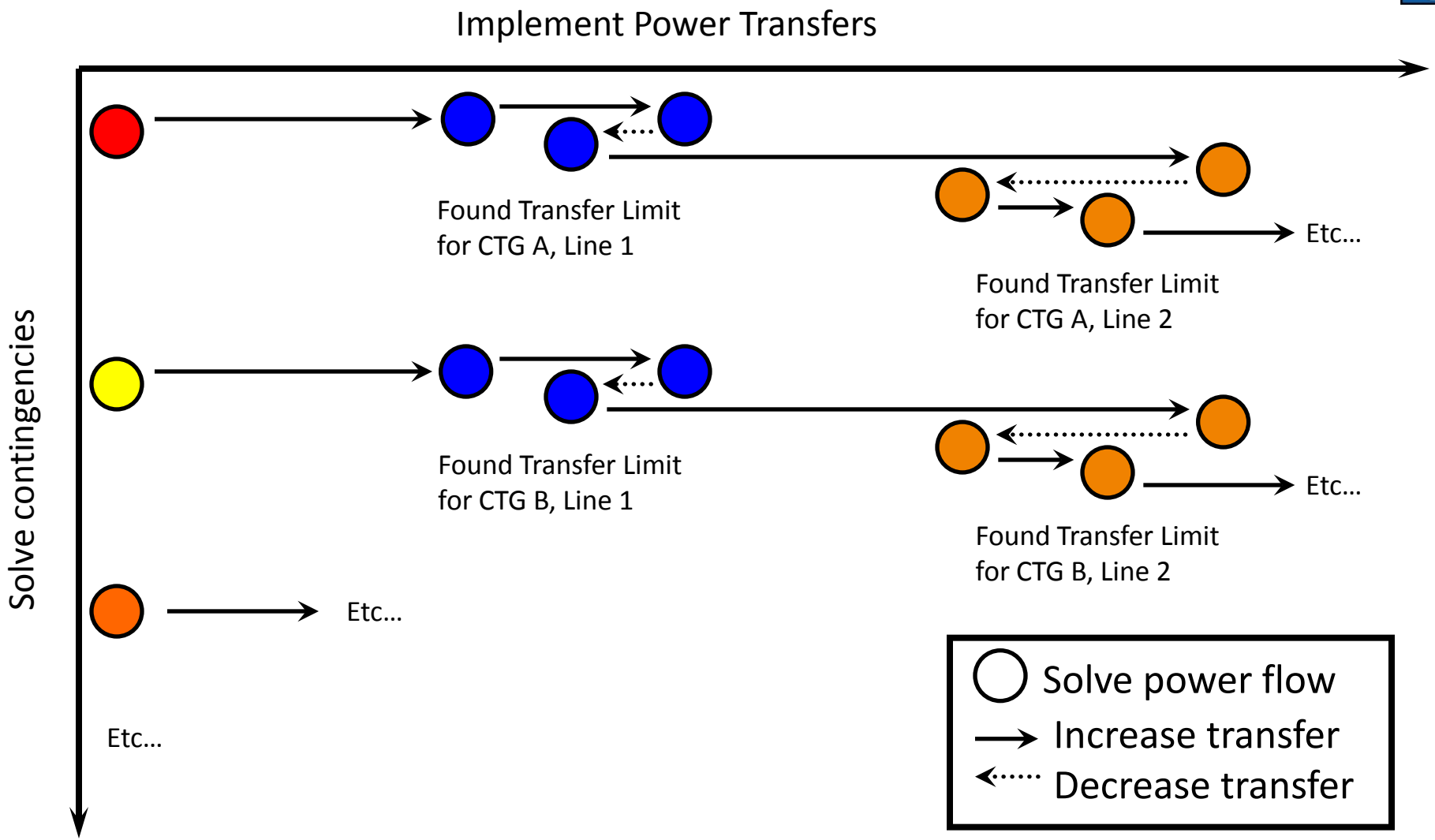
Available Transfer Capability

- Linear analysis method for solving the Available Transfer Capability (ATC)
- Utilizes the techniques for calculating linear sensitivities for PTDFs, LODFs and OTDFs
- Available with the ATC add-on for Simulator

Why Use Linear Techniques?

- Non-linear technique requires thousands of power flow solutions to examine even a relatively small number of monitored elements under a relatively small number of contingencies
  - Each contingency must be solved separately
  - Under each contingency, power transfer needs to be modeled for each monitored element separately
  - ATC for a limiting element/contingency pair is obtained when the monitored element is loaded to its specified limit
  - Iterative process required to determine the power transfer that loads each monitored element to its limit
  - Process is very time consuming
- Linear techniques only require a single power flow solution (must start with a solved power flow case) and provide accurate results in a fraction of the time even for a large number of monitored elements and contingencies

Why Use Linear Techniques?



Input for Available Transfer Capability (ATC)

- The input for ATC is
  - Power flow case
  - A list of contingencies
  - A buyer (sink) and seller (source) of power
- ATC will then determine how much power can be transferred between the buyer and seller
  - Will not allow overloads in the power system
  - Will not allow overloads after a contingency occurs either

What does ATC determine?

- The ATC tool looks at every possible combination of a Limiting Element and Limiting Contingency and determines the maximum transfer for each pair
  - The Limit Monitoring Settings defines the possible Limiting Elements
    - Choose your Limit Monitoring Settings carefully because fewer possible limiting elements results in a faster calculation
  - The contingencies defined in the Contingency Analysis tool determine the possible limiting contingencies
    - Again, fewer = faster calculation
- What does a Limitation of 100 MW mean?
  - After a transfer of 100 MW between the seller and buyer, the limiting element will be loaded to its limit during the limiting contingency

Calculate of linear ATC values for the Base Case

- For each monitored element M in the system determine a Transfer Limitation T

$$T_M = \begin{cases} \dfrac{Limit_M - MW_M}{PTDF_M} & ; \quad PTDF_M > 0 \\ \infty \text{ (infinite)} & ; \quad PTDF_M = 0 \\ \dfrac{-Limit_M - MW_M}{PTDF_M} & ; \quad PTDF_M < 0 \end{cases}$$

PTDF is positive, so look for Element overload in the positive direction

PTDF value is very small, which means that the transfer has a VERY SMALL impact on the limiting element.

Option for ignoring small PTDF values discussed soon

PTDF is negative, so look for Element overload in the negative direction

Calculate of linear ATC values for Contingencies

- Then, for each monitored element (M) during each contingency (C) determine another Transfer Limitation T

Calculation of OMW and OTDF was discussed in Linear Analysis Section

$$T_{M,C} = \begin{cases} \dfrac{Limit_M - OMW_{M,C}}{OTDF_{M,C}} & ; \quad OTDF_{M,C} > 0 \\ \infty \text{ (infinite)} & ; \quad OTDF_{M,C} = 0 \\ \dfrac{-Limit_M - OMW_{M,C}}{OTDF_{M,C}} & ; \quad OTDF_{M,C} < 0 \end{cases}$$

Same comments regarding the sign of the OTDF value as previous slide

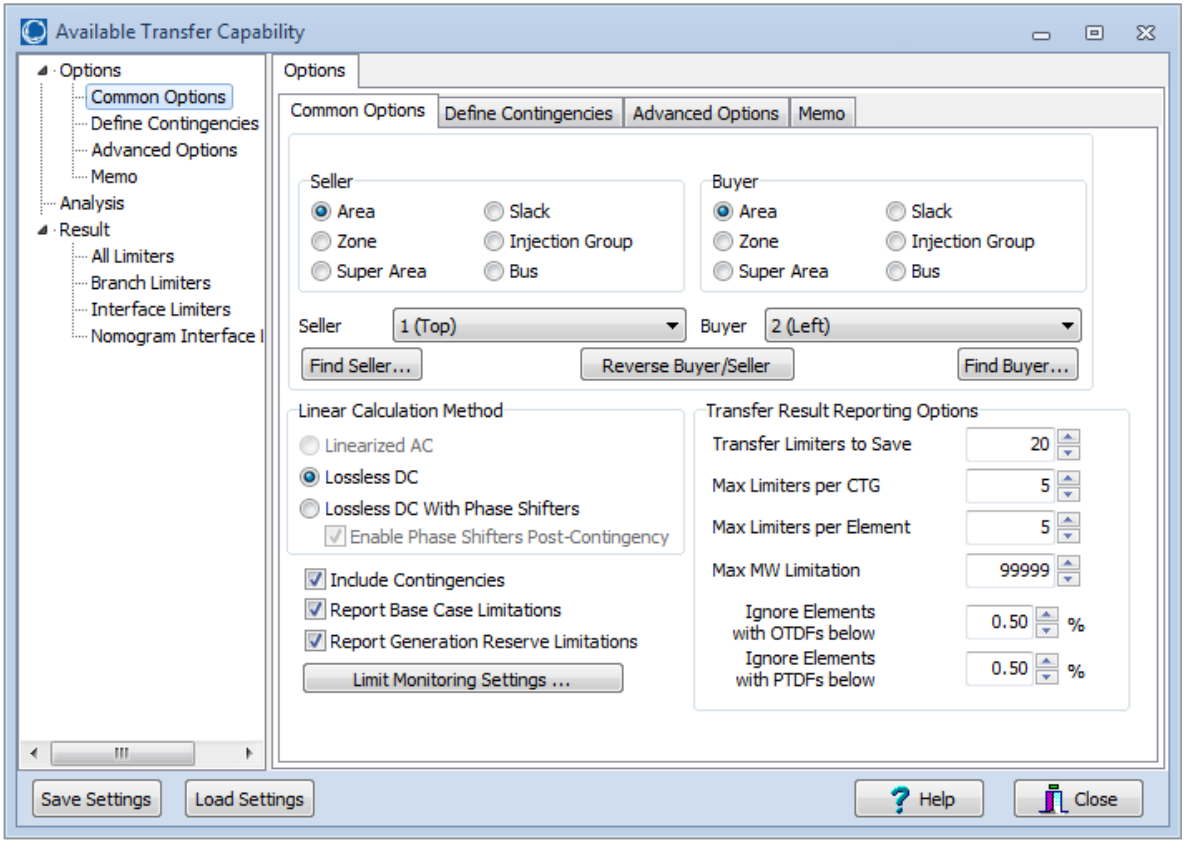
Output of Available Transfer Capability (ATC)

- A list of transfer limitations will be determined
- Each transfer limitation logs several important values
  - Transfer Limitation in MW
  - Limiting Element: the power system element, such as a transmission line, which causes the limitation
  - Limiting Contingency: the contingency during which the limitation is expected (could be none)
  - OTDF: the sensitivity of the limiting element to the transfer direction under the limiting Contingency (PTDF if base case)
  - OMW: the estimate of the limiting element flow after the limiting contingency occurs (but before transfer)
  - Limit: The MW limit (rating) of the limiting element

ATC Dialog

- To open choose **Add Ons → Available Transfer Capability (ATC)…**

Common Options



ATC Dialog: Common Options

- Seller and Buyer Type
  - Specifies the buses/loads/generators that make up the seller and buyer
- Linear Calculation Method
  - This is the calculation method used to determine PTDF and LODF values used in the linear ATC analysis.
- Include contingencies
  - Check to include contingencies in the calculation
  - Only contingency actions related to MW injection changes, branch outage/closures, and line rating changes will be used
    - This is because a linearized lossless DC model is used
  - POSTCHECK actions act as CHECK actions during linear methods and are checked at the zero transfer level
    - Option with Contingency Analysis settings can be set so that iterated contingency method will evaluate these after other actions have been "implemented". This will make the process slower but better reflects conditional actions.

ATC Dialog: Common Options

- Report Base Case Limitations
  - When checked, the ATC tool will report transfer limitations from the base case
- Report Generation Reserve Limitations
  - When checked, the ATC tool will report transfer limitations from generation reserve
- Limit Monitoring Settings
  - Click this button to open the Limit Monitoring Settings

ATC Dialog: Common Options

- Transfer Result Reporting Options
  - Transfer Limiters to Save = X
    - The lowest X limitations will be saved
  - The rest of the of the options all filter out limitations
    - Max Limiters per CTG = X
      - Only the X lowest limitations that have the same limiting contingency will be saved
      - Limitation's limiting element must also exist in the Y Limiters per Element for that limiting element
    - Max Limiters per Element = Y
      - Only the Y lowest limitations that have the same limiting element will be saved
      - Limitation's contingency must also exist in the X Limiters per CTG for that contingency
    - Max MW Limitation
      - Limitations higher than this will not be saved
      - If there are no limitations lower than this value, the lowest limitation will be reported.

ATC Dialog: Common Options

- Transfer Result Reporting Options
  - The rest of the options all filter out limitations
    - Ignore Elements with OTDFs/PTDFs below
      - Any Limitation that has an OTDF/PTDF below the specified value will not be saved. This means that the transfer has a very small impact on the limiting element, so it is reasonable to ignore the limitation.

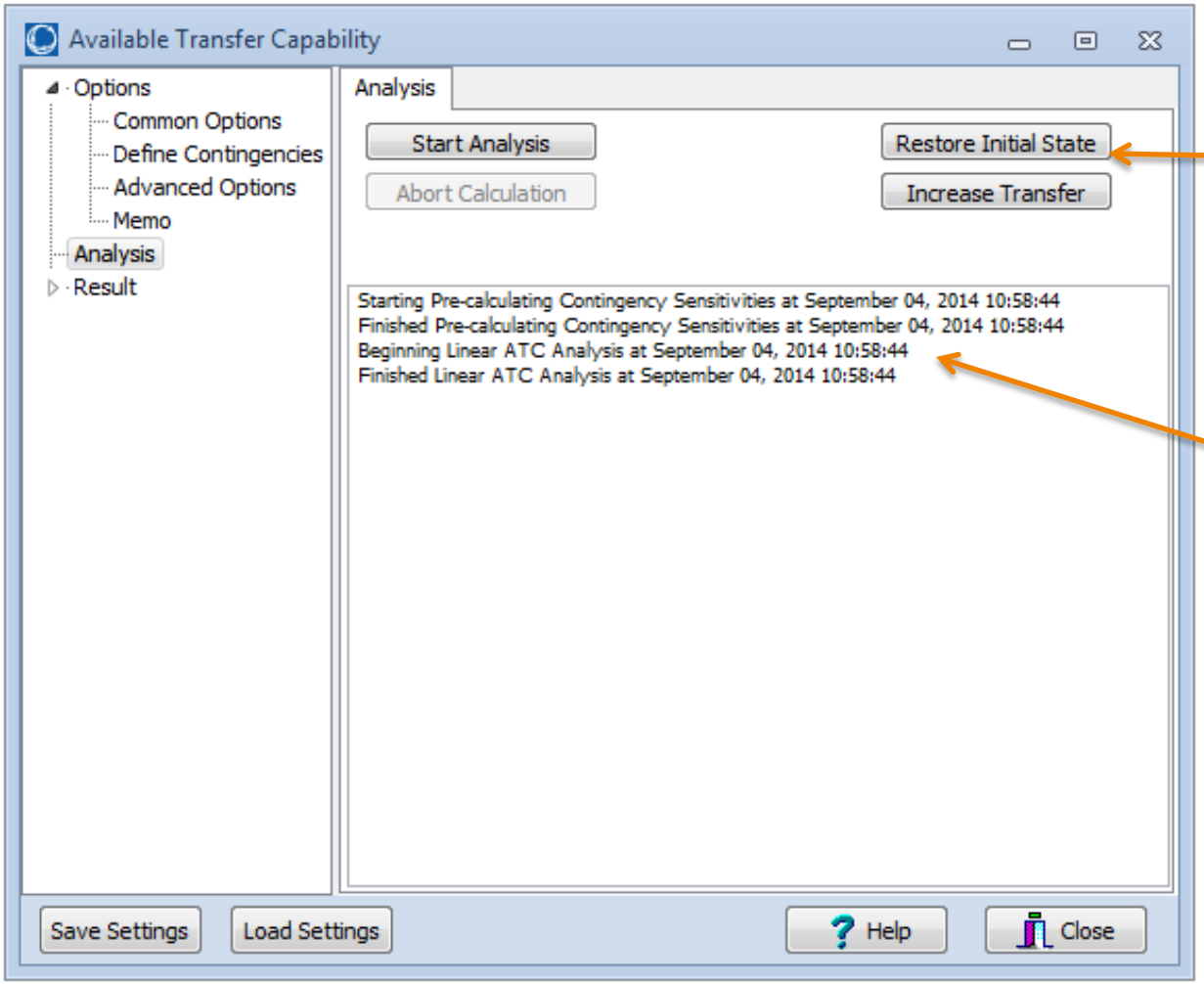
Sample 7-Bus System

- Open B7Flat.pwb
- Change to Run Mode and go to **Add Ons → ATC**
- Auto insert contingencies
  - Go to **Options → Define Contingencies** tab
  - Right-click on grid and choose **Insert Special → Auto Insert Contingencies**
  - Take all defaults and choose **Do Insert Contingencies**
- Set transfer direction
  - Go to **Options → Common Options** tab
  - Set **Seller** to Area 1
  - Set **Buyer** to Area 2

Sample 7-Bus System

- Option Settings
  - **Options → Common Options**
    - **Include Contingencies** checked
    - **Report Base Case Limitations** checked
    - **Report Generation Reserve Limitations** checked
    - **Transfer Limiters to Save** = 50
    - **Max Limiters per CTG** = 10
    - **Max Limiters per Element** = 10
    - **Max MW Limitation** = 99999
    - **Ignore Elements with OTDFs below** = 3%
    - **Ignore Elements with PTDFs below** = 3%
  - **Options → Advanced Options**
    - **ATC Solution Method** = Single Linear Step (SL)
    - **Model reactive power for linear methods by…** = Ignoring reactive power
    - **…Allow amp limits…** NOT checked
    - **Allow Generator MW Limit Enforcement in Single Linear Step** = NOT checked

ATC Dialog: Analysis Page



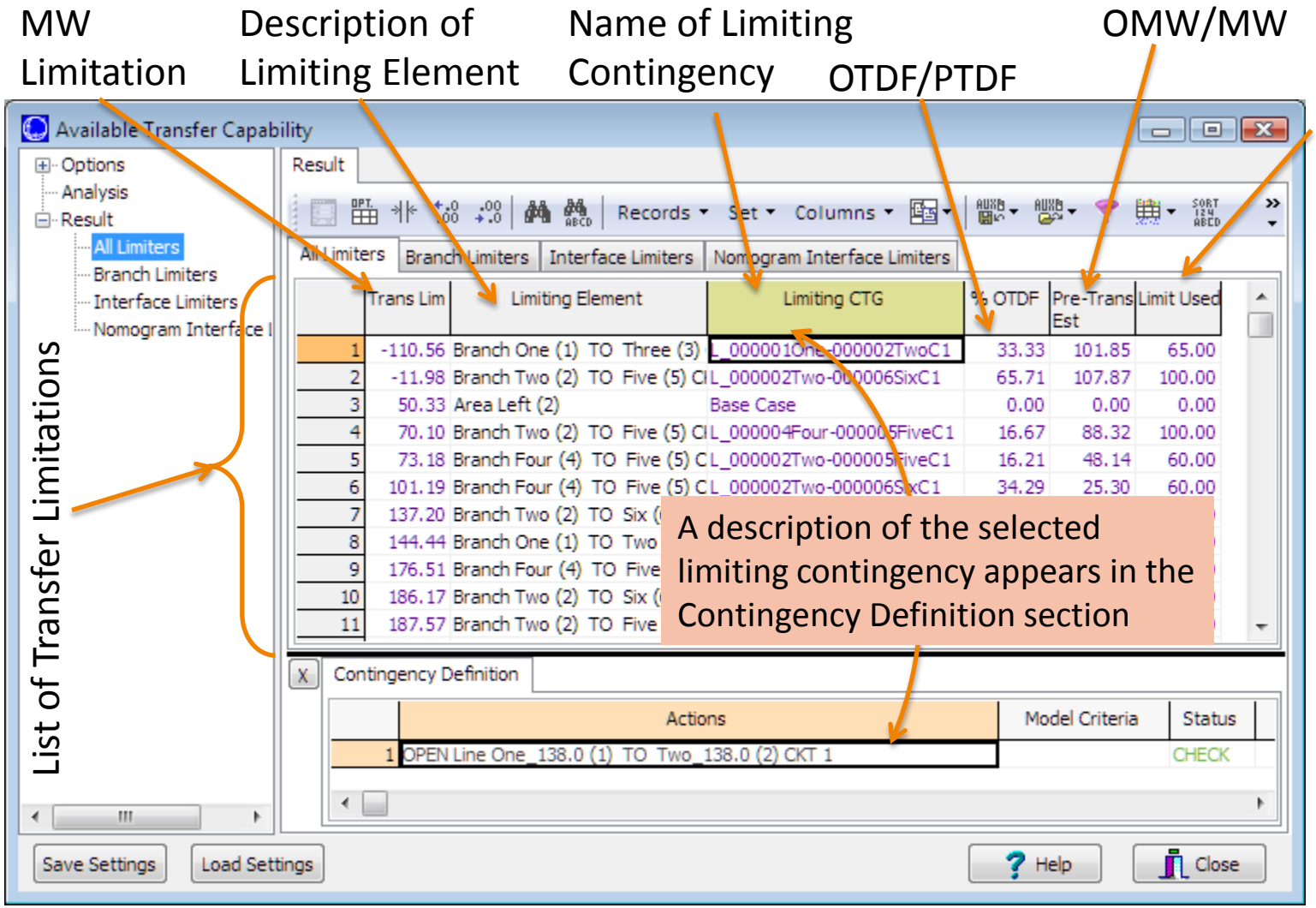
Buttons to Control the Analysis

Provides information about the overall ATC Solution Process

Analysis Page: Options and Buttons

- Start Analysis
- Abort Calculation
  - Will abort a calculation which is in progress
    - Simulator may have to complete some calculations prior to aborting
- Restore Initial State
  - Restore the system to the state when analysis started
- Increase Transfer
  - Click to increase the amount of the transfer by a user specified amount

ATC Dialog: Result Page: Default Columns



Note: **Limit Used** values may not be exactly equal to the MVA Limits of a branch.

If you change the **Use Amp Limits** or **Model Reactive Power** options, they may change.

Include the **MVA Limit Used** field to see the actual MVA limit.

Common Columns for Results

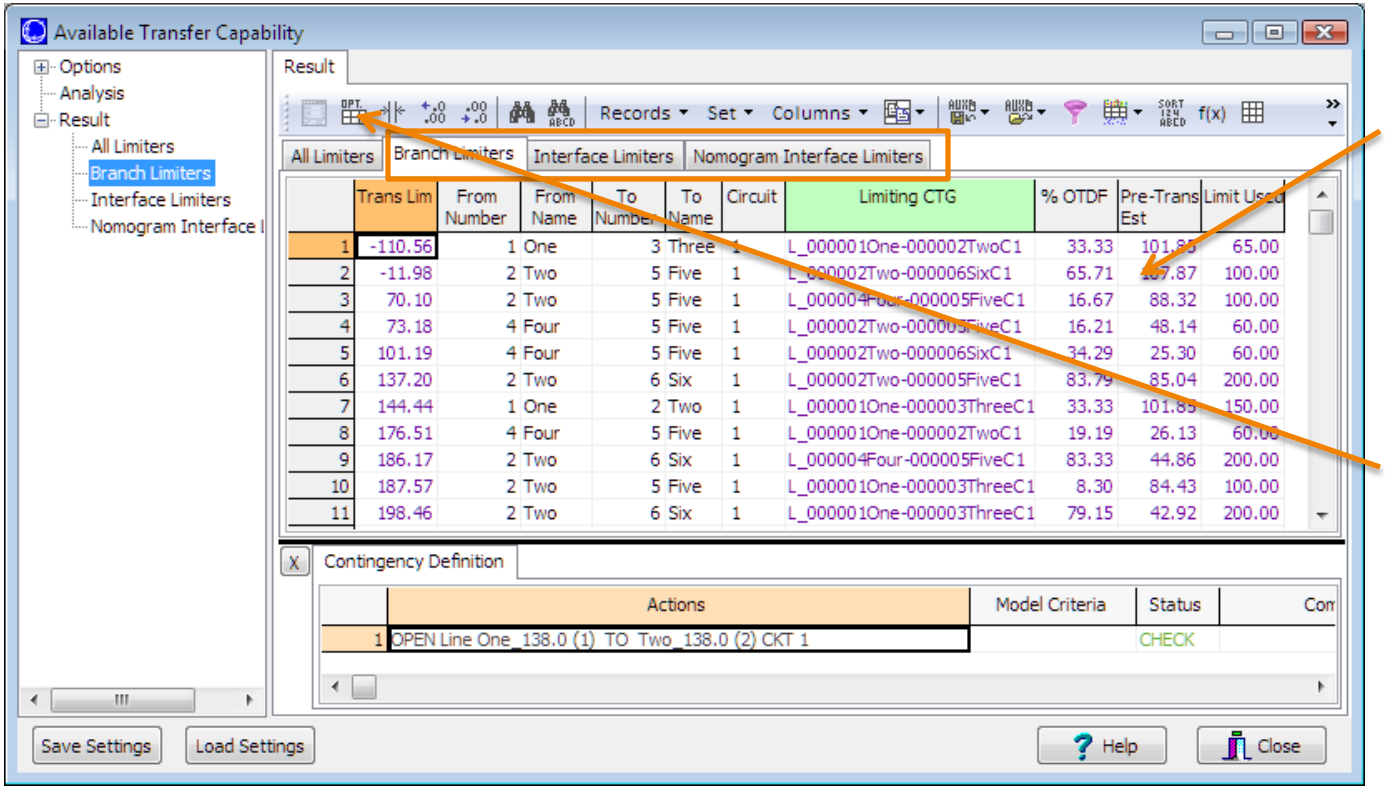
- Trans Lim
  - Transfer Limitation in MW
  - This is the ATC, or more appropriately ITC. This value reflects the amount of incremental transfer above what is already in the base case that can occur between the Seller and Buyer before the Limiting Element reaches its Limit under the Limiting CTG.
- Limiting Element
  - The power system element (normally a branch) that causes the limitation
  - This could be either the Buyer or Seller if choosing to Report Generation Reserve Limitations
- Limiting CTG
  - The contingency during which the limitation is expected
- % OTDF
  - The OTDF (or PTDF if base case) for the Limiting Element for this transfer direction

Common Columns for Results

- Limit Used
  - This is the value of the Limit being used by the ATC for the Limiting Element during the Limiting CTG
  - Reflects what is specified in Limit Monitoring Settings and options for modeling reactive power and amp limits
- Pre-Transfer Value Estimate
  - If a contingency is not included in the Limiter, this is equal to the Initial Value
  - When a contingency is included in the Limiter, this is the linear estimate of the post-contingency flow before any transfer occurs (outage MW)
- Initial Value
  - This is the flow on the Limiting Element in the Initial State (before any transfer or contingencies occur)

ATC Dialog: Showing only Branch Limiters

- Click on Branch Limiters to only show those limitations related to a branch limit
  - Can also do for interface limiters or nomogram interface limiters



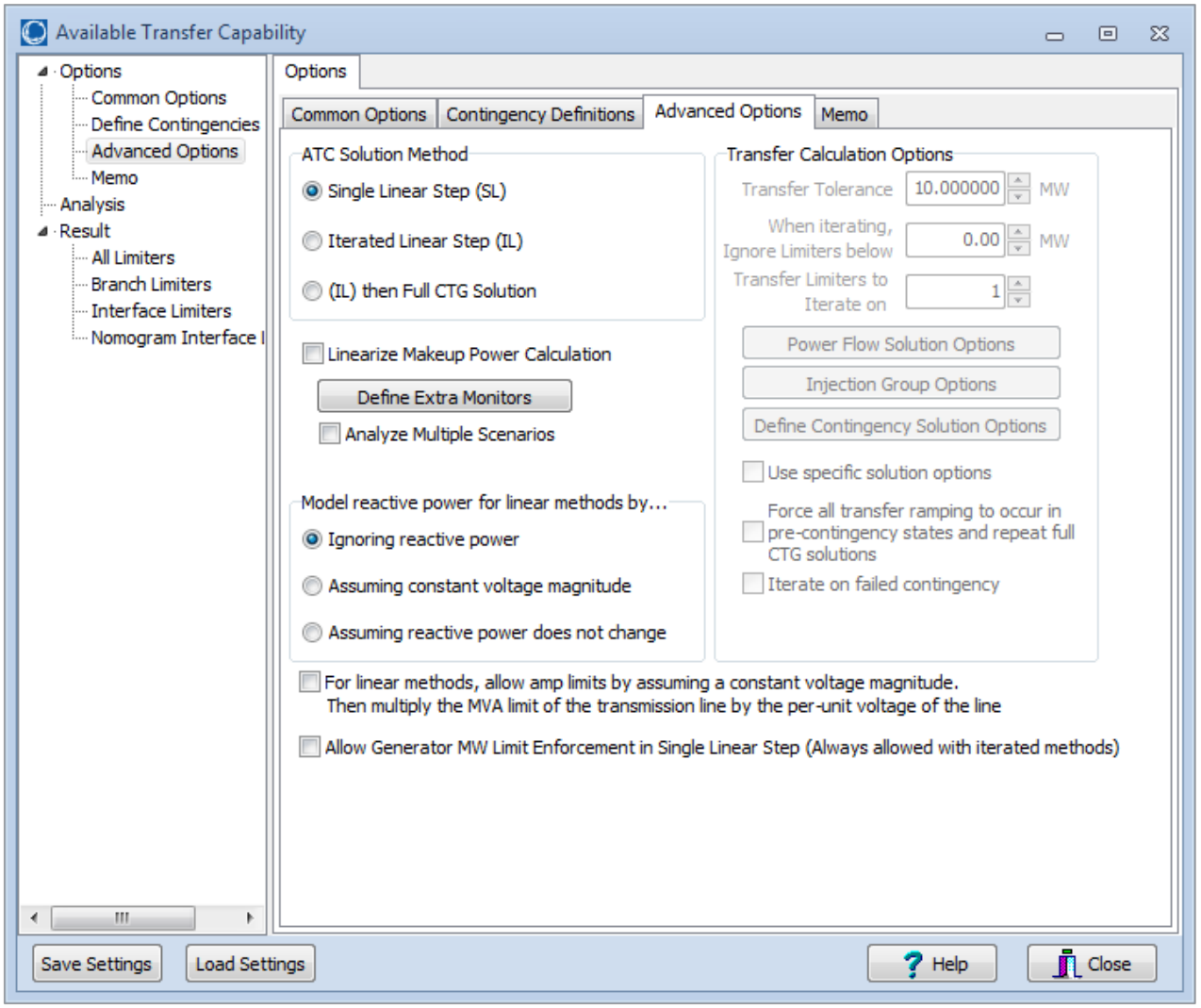
Right-click on this list display to bring up Display/Column options to add columns related to a branch or click on toolbar option

For instance, Area Names, Nominal voltages, etc.

Better/Faster Analysis

- Make good use of the **Ignore Elements with OTDFs/PTDFs** below options
  - Low PTDFs/OTDFs means that the limitation is really a problem with the system in general
  - Ask yourself if this should limit the transfer
- Limit the number of contingencies considered
  - Both faster and saves computer memory
- Limit the number of elements monitored
  - Both faster and saves computer memory
  - Can be done using the Limit Monitoring Settings

ATC Dialog Options: Advanced Options



ATC Advanced Options: Linear Method Options

- Linearize Makeup Power Calculation
  - Calculate the impact of makeup power on line flows at the beginning of each linear step and not for each contingency
  - Generator limits will not be enforced in the makeup power calculation
- Model reactive power for linear methods by…
  - Specify how you want to treat reactive power when using one of the linear methods
    - Ignore reactive power
    - Assume constant voltage magnitude
    - Assume reactive power does not change
- Allow Amp Limits
  - For linear methods, allow amp limits by assuming a constant voltage magnitude
    - This will multiply the MVA Limit by the per-unit operating voltage of the transmission line (can increase or decrease the Limit Used)
    - Treat Line Limits as Equivalent Amps option on the Limit Monitoring Settings dialog must also be checked

ATC Advanced Options: Linear Method Options

- Allow Generator MW Limit Enforcement in Single Linear Step
  - Always allowed when calculating linear steps as part of iterated methods
  - Other relevant options for Generator MW Limit enforcement must also be met
  - Only generators that are not already at limits will participate
    - Seller – generators must be below Max MW limit to participate
    - Buyer – generators must be above Min MW limit to participate

Determining Limit Used

- Limit Monitoring Settings
  - Determines the MVA Limit to start with
    - *MVA Limit = Defined MVA Limit * Monitor Percent*
- ATC is calculated at each end of a line
  - Most limiting value is reported as the ATC for a given line
  - Limits are calculated at each end of a line to determine the most limiting ATC
- Allow amp limits

Determining Limit Used

- Model reactive power for linear methods
  - Ignore reactive power

    Limit Used = MVA Limit
    - With Allow amp limits

      *Limit Used = MVA Limit * V*

      where *V* is the bus voltage at the end of the line from which the limit is taken
  - Assume constant voltage magnitude
    - Intersection of operating circle and limiting circle used to assign adjusted limits to lines
    - Operating circle defines a circle of valid MW and Mvar values for a transmission line as a transfer takes place across the system
    - Limiting circle has a radius equal to the MVA limit of the line

Determining Limit Used

- Model reactive power for linear methods
  - Assume reactive power does not change

$$Limit\ Used = \sqrt{(MVA\ Limit)^2 - (Mvar)^2}$$

    - With Allow amp limits

$$Limit\ Used = \sqrt{(MVA\ Limit*V)^2 - (Mvar)^2}$$

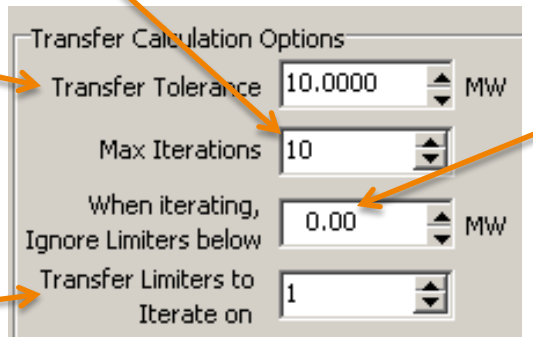
where *V* is the bus voltage at the end of the line from which the limit is taken

ATC Advanced Options: ATC Solution Methods

- Single Linear Step
  - Complete Linearization of the problem using PTDF, LODF and OTDF calculations
  - Very fast solution
- Iterated Linear Step
  - Iterates between a Single Linear Step calculation and ramping out the transfer until the linear step calculations result in a transfer of zero (within a tolerance)
  - Only available for buyer/seller types of Area, Super Area or Injection Group
- (IL) then Full CTG
  - Performs the Iterated Linear Step, then actually implements the full contingency and moves the post-contingency state around until the limiting element reaches its limit exactly.
    - Optionally can force the transfer ramping to occur pre-contingency
  - Only available for buyer/seller types of Area, Super Area or Injection Group

ATC Advanced Options: Iterated Solution Methods

- Perform the following for Both Iterated Methods
  1. Perform Single Linear Step ATC calculation
  2. Stepsize = Minimum Transfer Limitation found which is greater than the Minimum Value to Iterate On
     (Note: save this initial step size for use by Full AC)
  3. If [abs(Stepsize) > Tolerance] and [Iteration < Max Itr] then
     Ramp transfer out by Stepsize
     Resolve Power Flow
     Go back to step 1
     Else Continue
  4. Take the first Specified Number of Transfer Limitations and Iterate on them Individually (see next slide for description of individual iteration)



How Simulator Iterates on Individual Transfer Limitations

- Internally changes limit monitoring to only monitor the Limiting Element (line or interface only, other limitation will stop the process)
- Internally change to only process a single contingency (or the base case if appropriate)

1. Perform Single Linear Step ATC calculation (this should only return a single transfer limitation because we are only monitoring a single line under a single contingency)
2. Stepsize = Transfer Limitation Found
3. If [abs(Stepsize) > Tolerance] and [Iteration < Max Itr] then
   a. Ramp transfer by Stepsize and Resolve Power Flow
   b. Go back to step 1
4. Else Continue
5. If doing *(IL) then Full CTG* (ramping in post-contingency states) then
   a. Implement the Contingency Power Flow Solution
   b. Internally change to process no contingencies
   c. Perform steps 1 through 3 until tolerance met or max iterations reached

How Simulator Iterates on Individual Transfer Limitations

6. If doing *(IL) then Full CTG* (ramping in pre-contingency states) then
   a. Store the system state following the iterated process on the single monitored line and contingency
   b. Implement the Contingency Power Flow Solution
      i. If contingency power flow converges then continue with 6c
      ii. Else if option to iterate on failed contingency is true then iterate on failed contingency
      iii. Else Stop
   c. Perform Single Linear Step ATC calculation on the individual limiter (single monitored line without contingency)
   d. Stepsize = Transfer Limitation Found
   e. If [abs(Stepsize) > Tolerance] and [Iteration < Max Itr] then
      i. Restore system state stored in 6a
      ii. Ramp transfer by Stepsize and resolve power flow
      iii. Go back to step 6b
   f. Else Stop

ATC Advanced Options: Transfer Calculation Options

- Transfer Tolerance
  - When using iterative methods, this tolerance is used to determine when the ATC method has converged
- Max Iterations
  - Maximum iterations for the iterated techniques
    - If this occurs, you will see a transfer limited labeled oscillating
- When Iterating Ignore Limits Below
  - Set this to iterate only on the limitations that are larger than a specified value
- Transfer Limiters to Iterate on
  - Number of transfer limiters to iterate on the IL or (IL) then Full CTG solution methods.

ATC Advanced Options: Transfer Calculation Options

- Power Flow Solution Options
- Injection Group Options
  - When using injection groups for the Seller and Buyer, island-based AGC is used. These are the same options that are set for Island-Based AGC when dispatching using an injection group.
- Define/Modify Contingency Solution Options
- Use specific solution options for contingencies
  - Check to use solution options defined by pressing **Define Contingency Solution Options**
  - Uncheck to use solution options defined by pressing **Power Flow Solution Options**

ATC Advanced Options: Transfer Calculation Options

- Options for minimum per-unit voltage for constant power and constant current loads set to 0 internally for base case and contingency solutions
- Force all transfer ramping to occur in pre-contingency states and repeat full CTG solutions
  - Determines if the ramping occurs before or after applying the contingency
  - Can make a difference for contingencies that contain conditional actions
- Iterate on failed contingency
  - Only available with option to force ramping to occur pre-contingency
  - Additional process to determine more precisely at what transfer level a contingency fails to solve

What does the Trans Lim Mean for the ATC Solution Methods?

- Single Linear Step (SL)
  - Only one Linear ATC step is performed
  - The Transfer Limitation values are those found during this step
- Iterated Linear Step (IL)
  - The Linear ATC method is iterated during this method
  - The Transfer Limitation values for the limits that are iterated on individually are those found during the final step performed plus the accumulated amount the transfer has been ramped during the iterations
  - The Transfer Limitation values for limits not iterated on individually are the values found from the initial iterated step when all limiters are iterated on

What does the Trans Lim Mean for the ATC Solution Methods?

- Iterated Linear Step (IL) then Full CTG
  - The Transfer Limitation values for limiters that are iterated on individually equal the accumulated amount the transfer was ramped as of the last successful solution
  - The Transfer Limitation values for limiters that are not iterated on individually are the values found from the initial iterated step when all limiters are iterated on

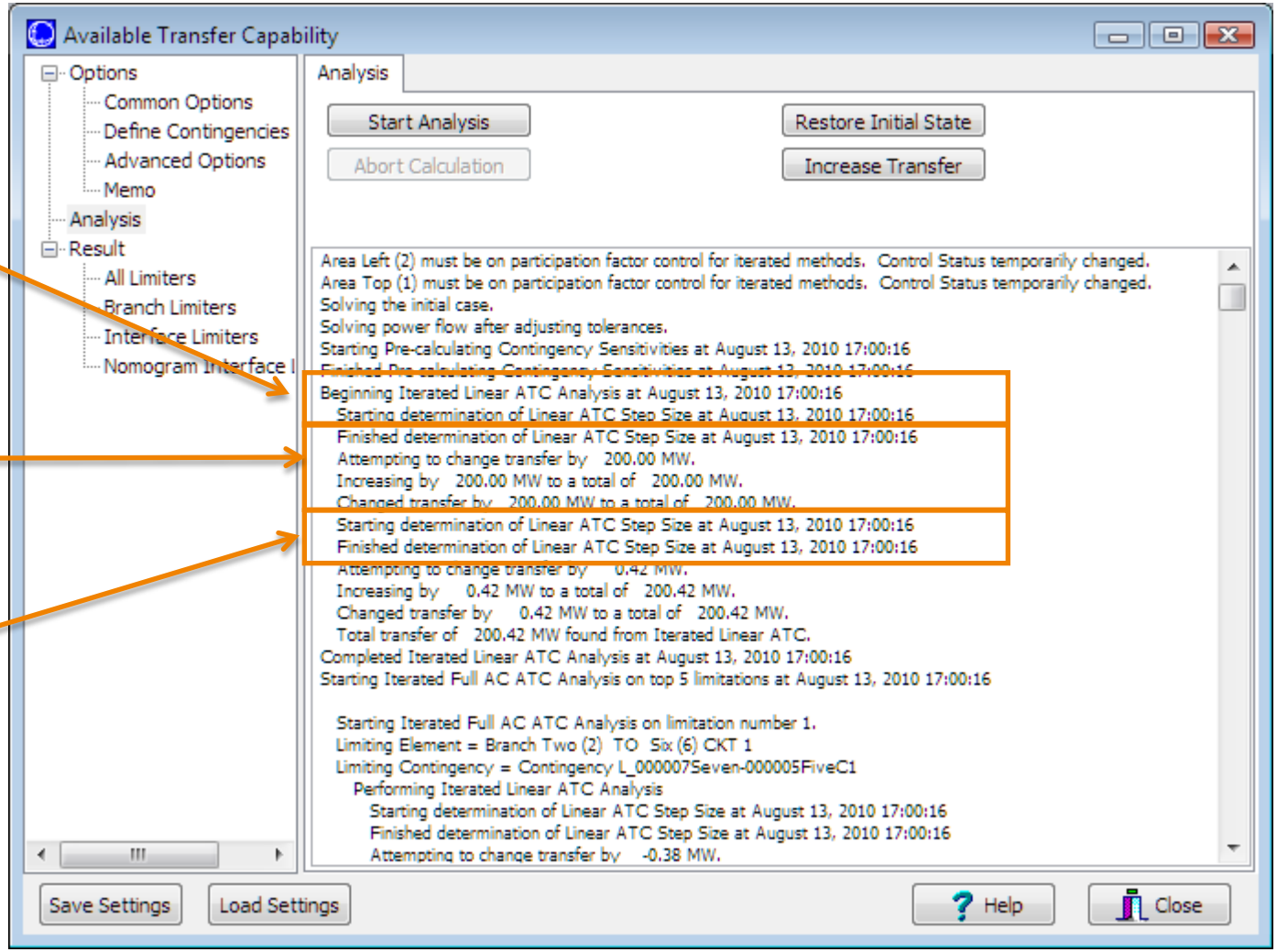
Example Iterated Linear ATC

Determines Linear ATC at Initial State

Actually implements the 200 MW transfer

Determines Linear ATC at new transfer level

etc.

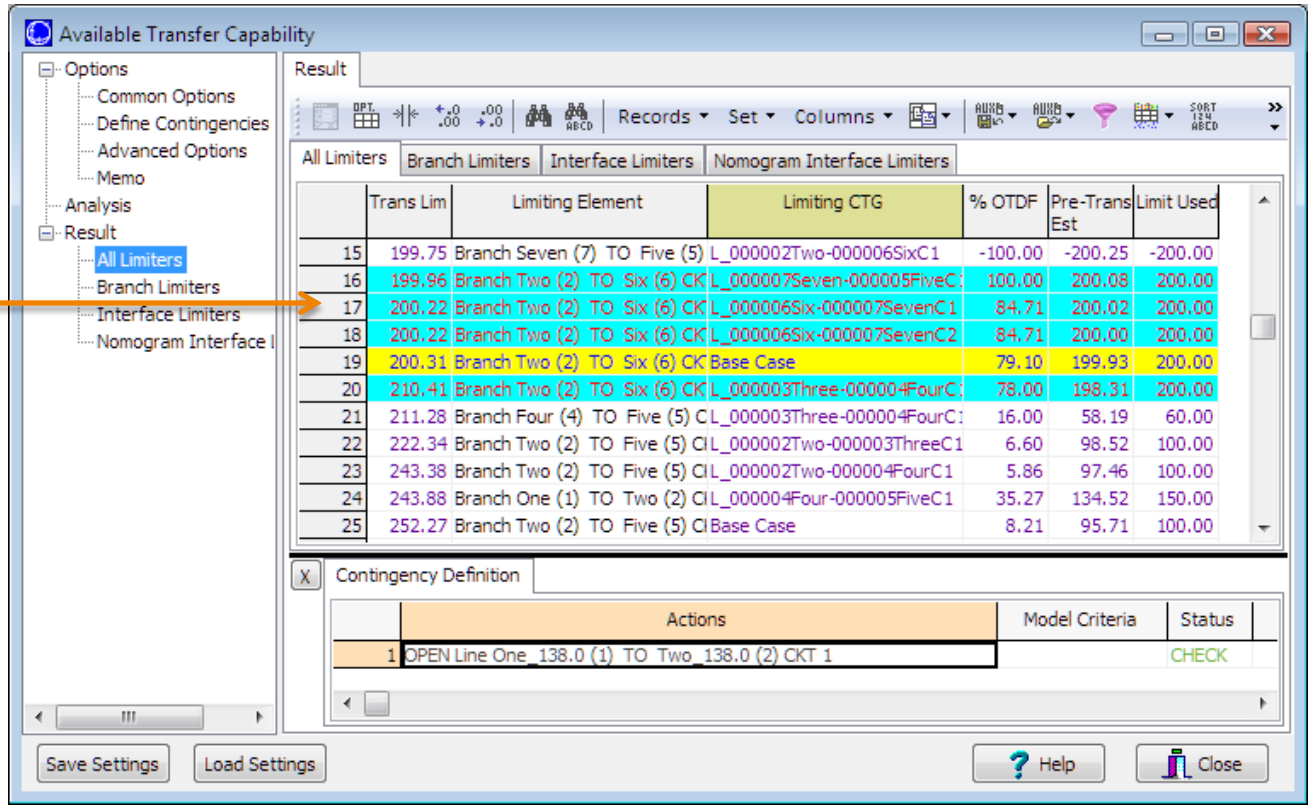


Example Iterated Linear ATC Results

Limitations that were iterated are highlighted in yellow or cyan

Yellow – iterated on but linear estimate of contingency

Cyan – contingency actually implemented



When Iterating Ignore Limits Below was set to 200 MW, thus as it was iterating out, it ignored limits below this

Special notes regarding Iterated Techniques

- Pre-Transfer Value Estimate
  - For Iterated Linear, this is value at the last Iteration Step
- % OTDF
  - For Iterated Techniques, this the value at the last Iteration Step

Special notes regarding Iterated Techniques

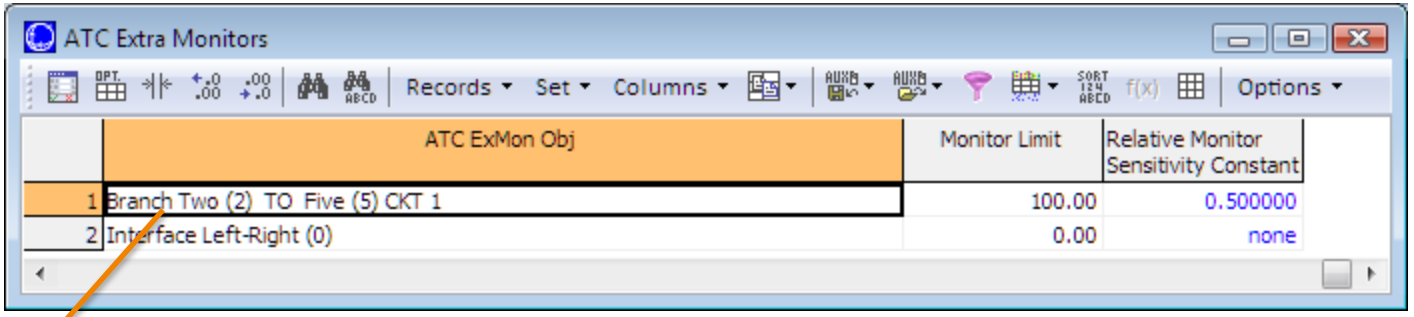
- Special Transfer Limitations
  - Special keywords appearing in either the **Limiting Element** or **Iteratively Found** fields and colors indicate if power flow solution failed and where in the process that it failed
  - Give indication if a power flow failure is due to ramping the transfer
    - POWERFLOW_DIVERGENCE (fuchsia), RAMP_FAIL_IN_FULL (fuchsia), RAMP_FAIL_IN_FULL_AFTER_CTG (gray)
  - Give indication if a power flow failure is due to solving a contingency
    - CTG_FAIL_IN_FULL (orange), CTG_FAIL_ITERATED (red), CTG_FAIL_IN_BASE (purple)
  - Give indication if the solution fails because an Abort contingency action was implemented
    - CTG_ABORTED_LINEAR (orange), CTG_ABORTED_AFTER_LINEAR (orange), CTG_ABORTED_IN_FULL (orange), CTG_ABORTED_ITERATED (red)
  - Gives indication if the transfer step is oscillating
    - OSCILLATING (lime green)

ATC Advanced Options: ATC Extra Monitors

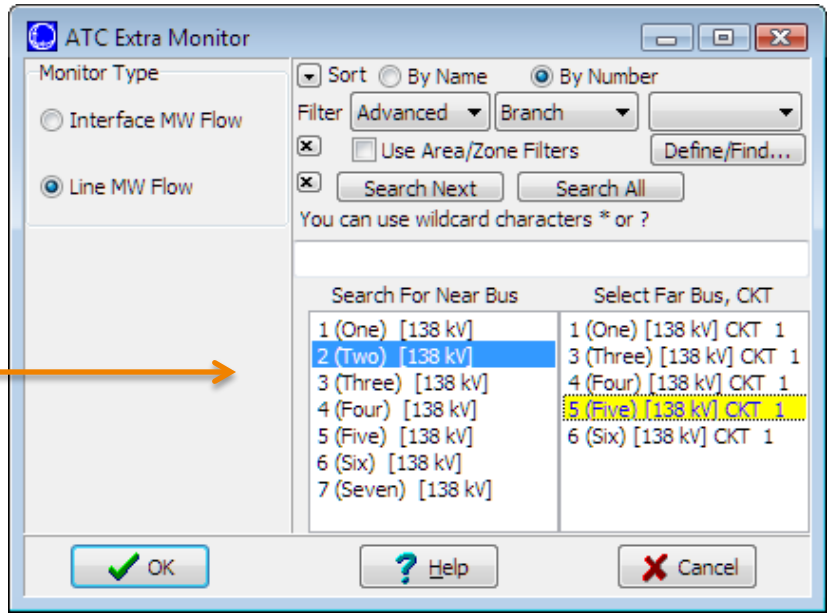
- What is an Extra Monitor?
  - An Extra Monitor consists of only two pieces of information
    - An interface or branch (the extra monitor)
    - Relative Monitor Sensitivity Constant
  - The ATC tool calculates numbers representing the maximum MW transfer between the Seller and Buyer
  - When you define an Extra Monitor, Simulator will estimate the flow on this branch or interface at the Transfer Limitation calculated
    - Provides you with an estimate of what a particular branch or interface flow will be at the transfer limit

ATC Advanced Options: Defining ATC Extra Monitors

- Click **Define Extra Monitors** to open the list of Extra Monitors



Right-click and choose Insert to open a dialog to define the extra monitor element



ATC Advanced Options: Relative Monitor Sensitivity Constant

- Provides an additional method of filtering out transfer limitations
- If this constant is larger than zero, then only Transfer Limitations whose OTDF (PTDF if base case) and Limit Used meet the following constraint will be included in the Result

$$\frac{OTDF_{M,C}}{LimitUsed_{M}} * \frac{Rating_{ExtraMon}}{PTDF_{ExtraMon}} \geq \left(\begin{array}{l} \text{Relative Monitor} \\ \text{Sensitivity Constant} \end{array} \right)$$

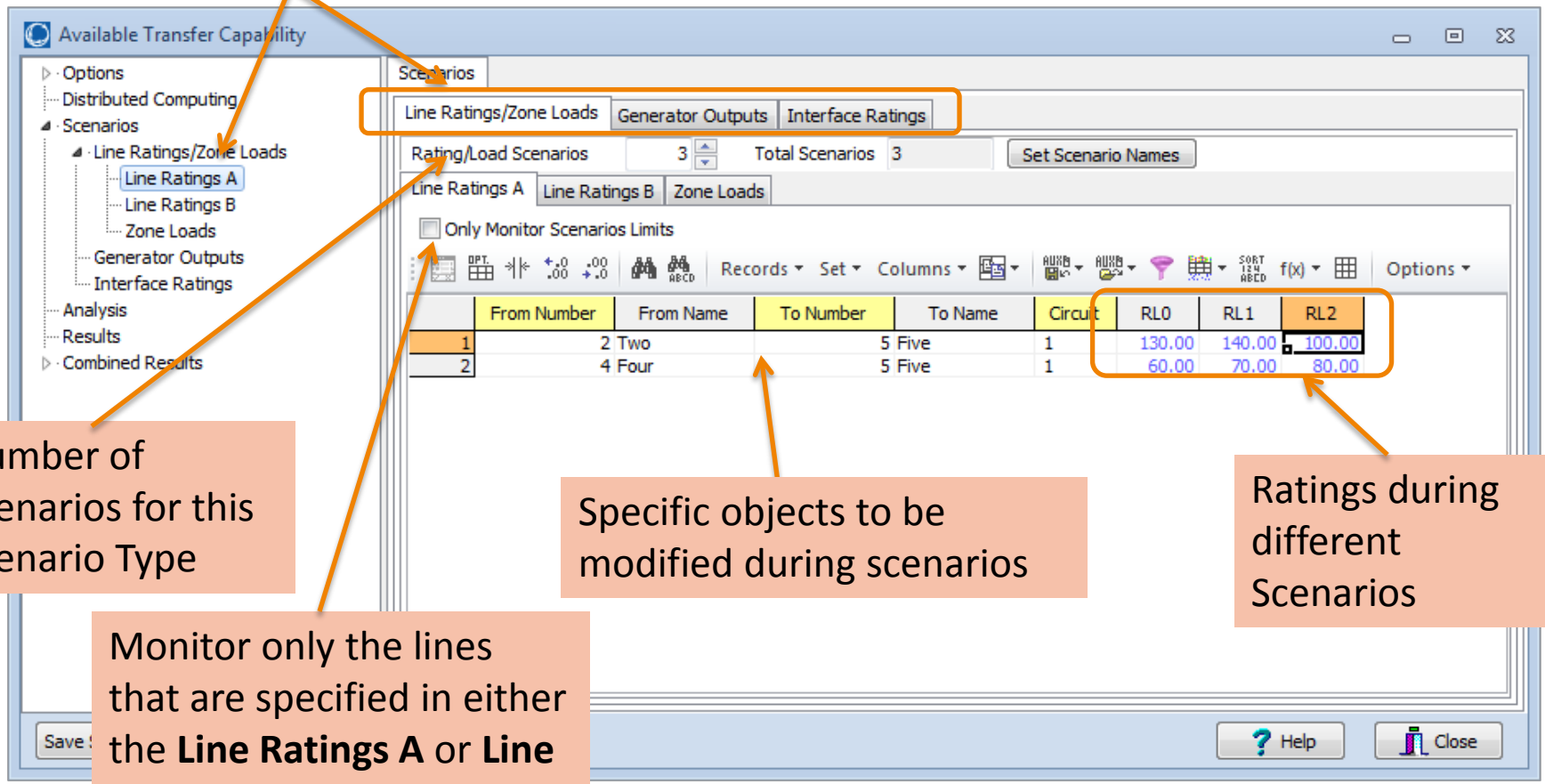
- This provides a measure of how much the limiting element is affected by the transfer RELATIVE to its MW limit

ATC Advanced Options: Multiple Scenarios

- Analyze Multiple Scenarios
  - Check to calculate ATC values for several scenarios
    - Adds a new page called Scenarios to the form
    - The Result page is replaced with Results page

Analyze Multiple Scenarios ATC

Pages for different Scenario Types



Number of Scenarios for this Scenario Type

Monitor only the lines that are specified in either the **Line Ratings A** or **Line Ratings B** lists

Specific objects to be modified during scenarios

Ratings during different Scenarios

Line Ratings/Zone Loads

- These Scenarios would be based on atmospheric temperatures
- Line Ratings scenarios can change the “A” and/or “B” Rating of the line
- Zone Loads
  - The AGC method (none, area/super area, or island-based) in place in the base case will be used to make any necessary generation adjustments due to the load changes

Generator Outputs

- Create these generator output scenarios to show different generation profiles
  - The AGC method (none, area/super area, or island-based) in place in the base case will be used to make any necessary generation adjustments due to the generator changes

Interface Ratings

- These scenarios can be used to change the Interface “A” Ratings
  - Could be used to specify different interface flow scenarios if using the OPF to enforce interface flows as an equality

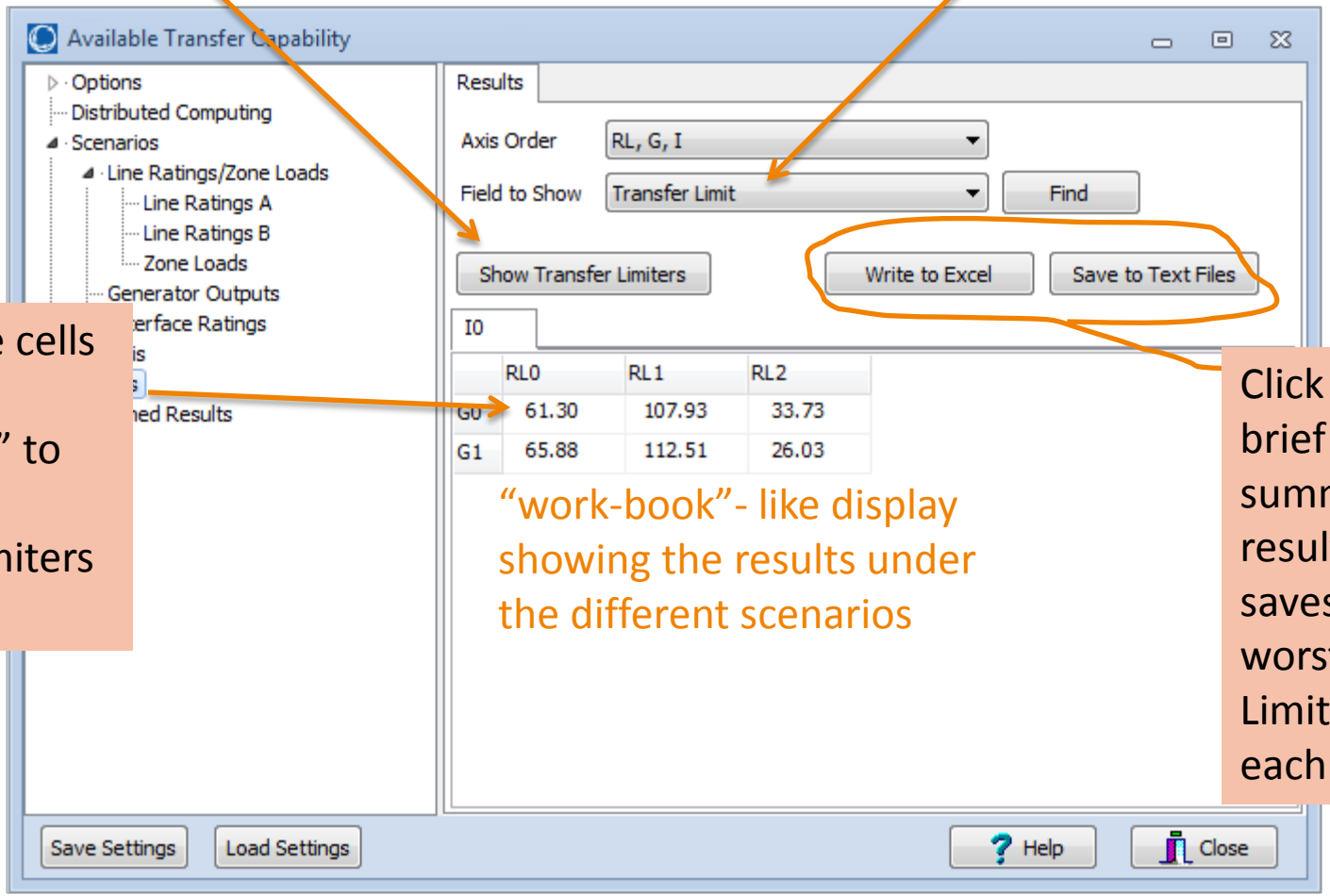
How are Scenarios Analyzed?

- Simulator performs ATC analysis on ALL possible combinations of scenarios
  - 10 sets of Line Ratings/Zone Loads
  - 8 sets of generation profiles
  - 3 interface constraints
  - → Means there are 10*8*3 = 240 Scenarios
- Obviously More Scenarios = Longer Solution Time

Results for Multiple Scenario Analysis

Opens the Transfer Limiters Display

Value to show in the summary table

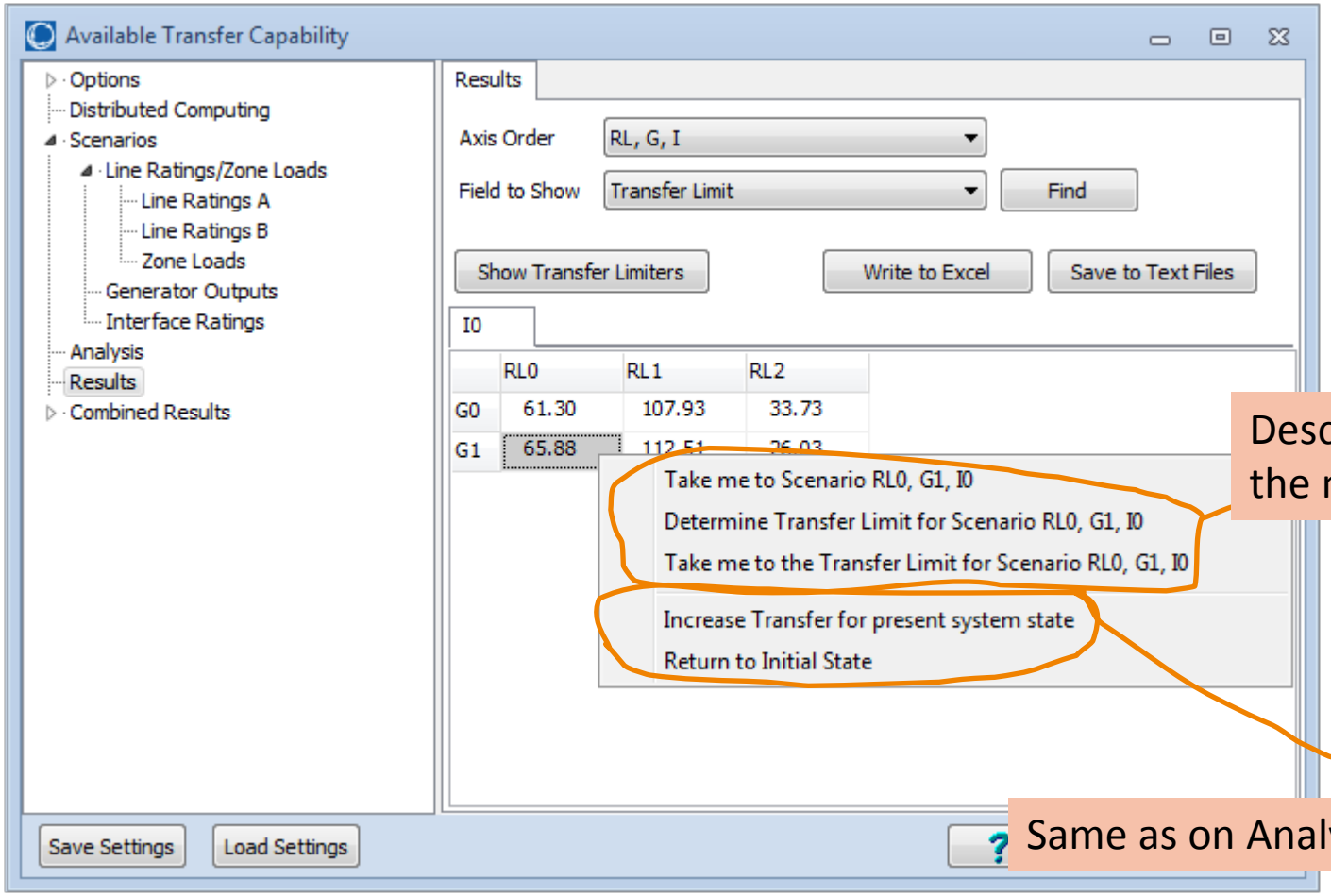


Click on the cells of the "workbook" to update the Transfer Limiters Display

"work-book"- like display showing the results under the different scenarios

Click to save brief summaries of results (only saves the worst Limitation for each Scenario)

Local Menu on Multiple Scenario Analysis



Scenario Specified Local Menu Items

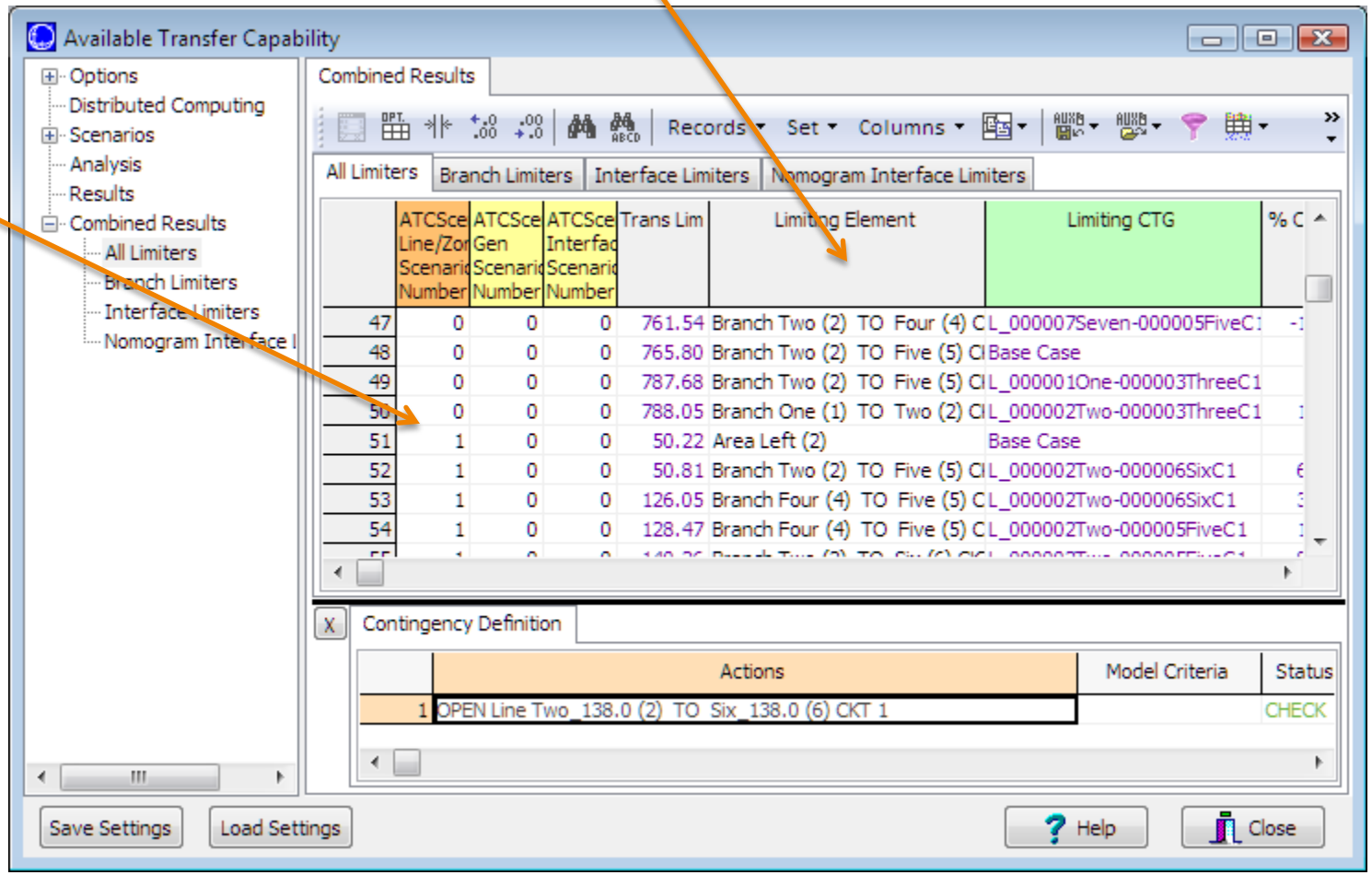
- Take Me To Scenario
  - Changes power system state to reflect the Scenario with no additional transfer
- Determine Transfer Limit for Scenario
  - Determines the ATC, but Initial State is restored when analysis is done (if appropriate)
- Take me to the Transfer Limit for Scenario
  - Determines the ATC and moves the power system state to this transfer limit

Multiple Scenario Analysis Combined Results

Identifies individual limiters belonging to each scenario

Scenarios identified by combination of integer identifiers for each scenario type

Assists greatly in accessing the multiple scenario results through auxiliary files and SimAuto



Special Fields Provide Access to SUBDATA

- ATCScenario object with <SUBDATA TransferLimiter>
  - Instead of creating new object type, extra key fields are added to existing TransferLimiter object type
    - ATCLineZoneChanges, ATCGenChanges, ATCInterfaceChanges
  - When fields are present, records are associated with the ATC scenario identified by the extra key fields
  - When fields are not present, records are associated with the standard single set of ATC results