Power System Economics and Market Modeling

M5: Security-Constrained Optimal Power Flow

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First – More OPF Topics

- A few more OPF Topics will be covered first
  - Interfaces with Contingent elements
    - How interfaces with Line Open/Close elements are handled
  - Area Transactions as OPF Controls
  - DC Power Flow modeling for the OPF
    - Modeling of Losses in a DC power flow. Is this possible?
      - Both dispatch sensitivities
      - Reduction of generation requirement
    - Modeling of VAR flows. Is this possible?
      - Using the "power circle" and assuming unity voltages

Interfaces with Contingent Elements

- Interfaces can have contingent elements
  - Line OPEN and Line CLOSE elements
- You must specify how you would like to treat these special interfaces
  - Choose the **Options** ribbon tab → **Simulator Options**
  - Go to **Power Flow Solution Page** (default)
  - Go to **General Tab**
  - Monitor/Enforce Contingent Interface Elements
    - Never
      - will never calculate the post-contingent flows on the interface
    - Power Flow/OPF, but not CA/SCOPF
      - in the powerflow and OPF we will show the "post-contingent" flow
    - All Applications including CA/SCOPF
      - In the SCOPF and CA we will also show the "post-contingent" flow

Area Transactions as OPF Controls: Why would you do this?

- Situation #1: If the following situation is met
  - One Area/Superarea is on OPF control
  - A second Area/Superarea does not have cost information and is on Participation Factor Control
  - The second area interacts with the first area, and you have a general "cost curve" for how much the first area purchases/sells power from the second area
  - You can then create a MW transaction between the two areas and specify a "cost curve" which applies to the second area
  - The OPF can then be configured to essentially dispatch the second area as though it's a giant generator available to buy or sell power from
    - The cost curve specified will be used to dispatch the transaction
    - The second area will spread power out using particpation factors.

Area Transactions as OPF Controls: Why would you do this?

- Situation #2: If the following situation is met
  - One Area/Superarea is on OPF control
  - A second Area/Superarea is also on OPF Control
  - You want the two areas to be able to freely transfer power between one another, however you want to limit the maximum amount of transfer between the two
    - You might also want to place a “premium” on the transfer so that the two areas will buy/sell only if the price difference is large than some threshold
  - If you wanted two areas to transfer power between one another without any limits, then you would just create a Super Area with both in it.

Area Transactions as OPF Controls

- You may define area-to-area MW transactions that can be dispatched by the OPF
- Choose **Model Explorer → Aggregations → MW Transactions**
- Go to **List of Transactions** Tab
- Right-Click and Choose **Insert**
  - You must give the transaction a Minimum/Maximum transfer amount
  - Allow OPF to determine the price
    - If both areas are on OPF, then it will just figure out the appropriate amount of transfer and price (within the range specified)
  - Or may enter a Cost Curve for the transaction
    - If one area is on OPF, and the other is on Part. Factor, then this the area on OPF will "dispatch" the area on Part. Factor as though it's a big "generator"

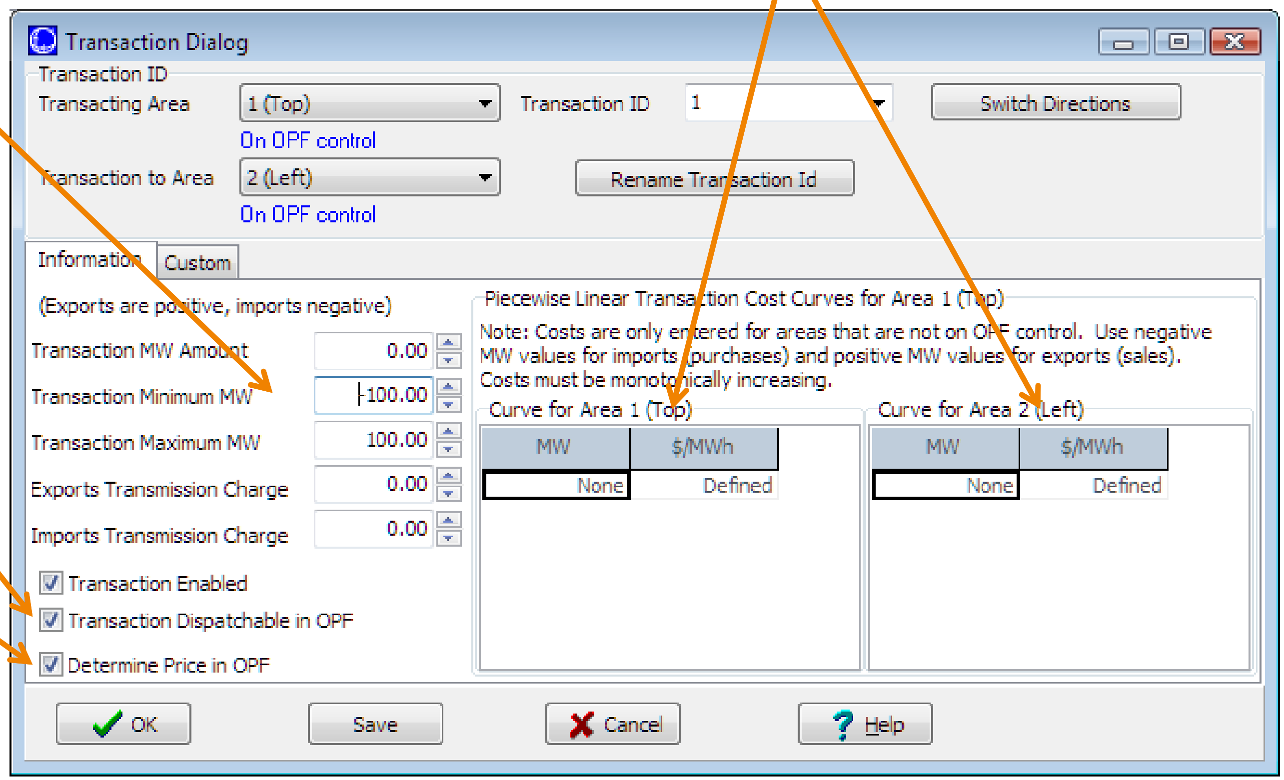
Area Transactions as OPF Controls

Specify a Min/Max Range for transfer

Check to allow dispatch

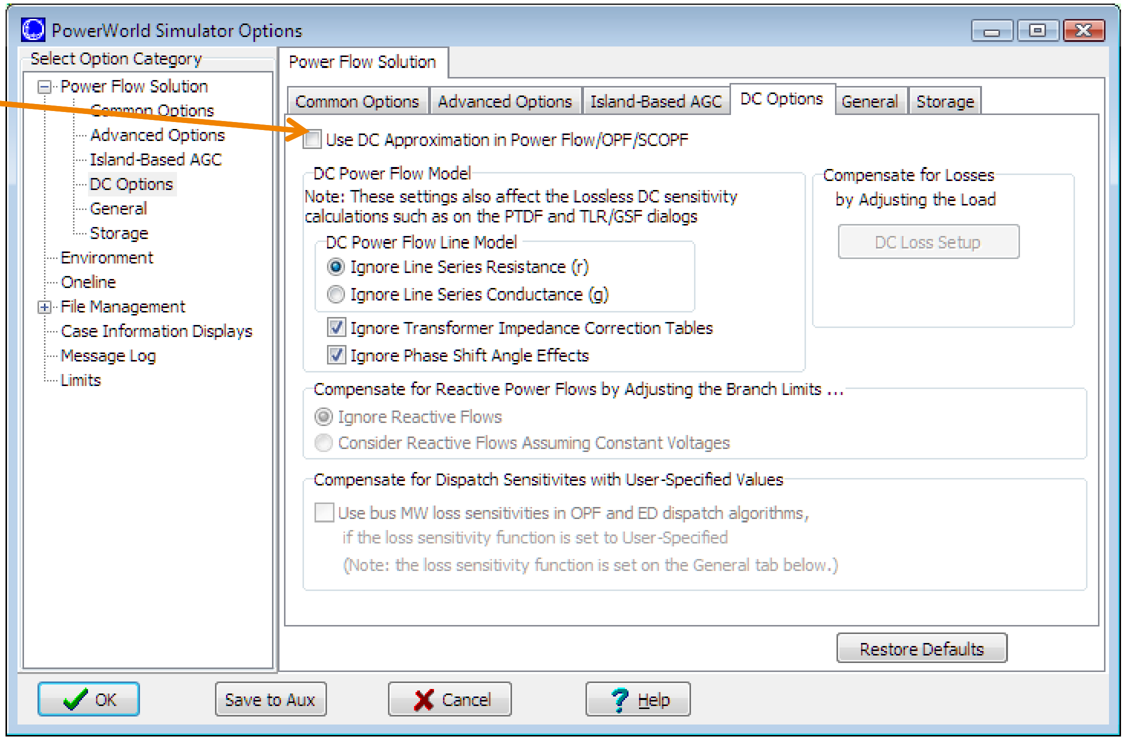
Check to have OPF determine price (cost curves will not be used then)

Specify an Export Cost Curve and Import Cost Curve



Simulator Options: Power Flow Solution Page

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



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

Simulator Options: Power Flow Solution Page

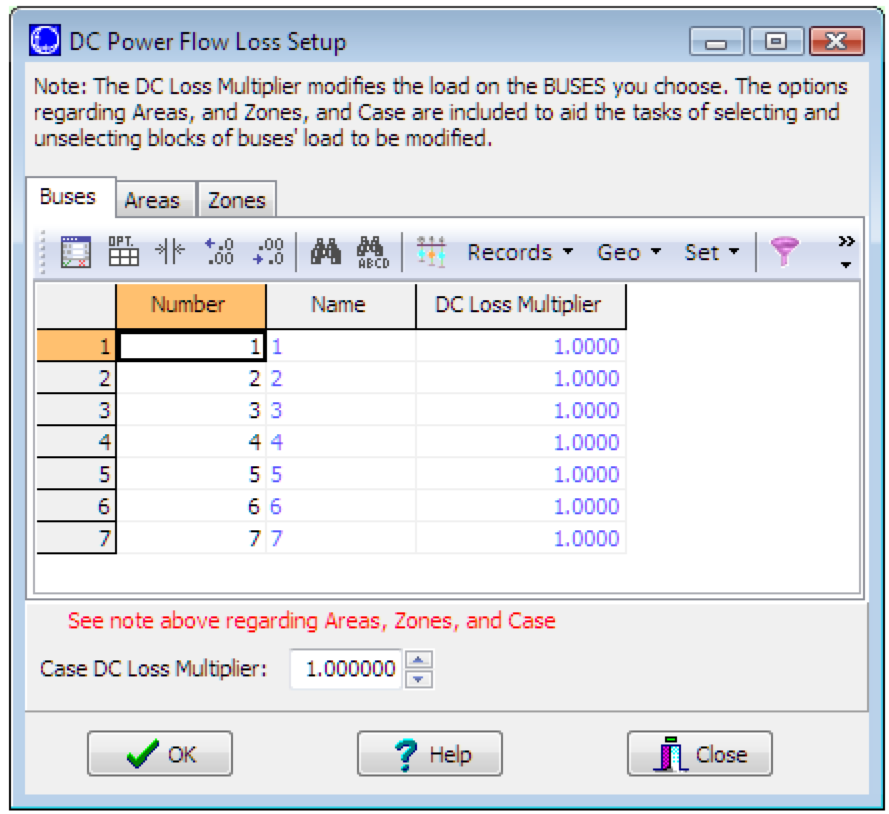
- DC Options Tab
  - Compensate for Losses by Adjusting Loads
    - Specify a load multiplier at each bus. When solving the DC power, Simulator will artificially increase loads by this multiplier
  - Compensate for Reactive Power Flows by Adjusting the Branch Limits
  - Compensate for Dispatch Sensitivities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

Compensate for Mvar Flows by Adjusting the Branch Limits

- Normally a DC power flow simply ignores all Mvar flows
- Consider Reactive Flows Assuming Constant Voltages
  - This will modify Simulator so that it approximates Vars flows using a “power circle”
  - If you’re familiar with impedance relay settings, this is similar to those
  - It’s an option to approximate Var flow, but no markets use this right now.

DC Power Flow Loss Setup: Compensate for Losses with Loads

- Click compensate for Losses by Adjusting Loads
- Specify a multiplier at each bus
  - In the DC Power Flow (and thus the OPF/SCOPF), Simulator will artificially increase loads at these buses



Compensate for Dispatch Sensitivities with User-Spec. Values

- Go to the **Tools** ribbon tab → **Sensitivities** → **Loss Sensitivities** and calculate your loss sensitivities
  - Then change the **Loss Function Type** to *User-Specified*
- Now if you choose this check box, the DC power flow will apply a "penalty factor" to each generator according to its loss sensitivity.
  - This approximates how losses would affect the dispatch
  - Some markets do make use of such an approximation.

SCOPF Overview

- Secure power system operation requires that there be no unmanageable base case or contingent violations
- Complete optimization requires considering the base case and contingencies
- Solution of this problem is known as Security Constrained OPF (SCOPF)
- Most of time is spent in contingency analysis
- We will also cover some new features of the OPF which are also helpful in the SCOPF

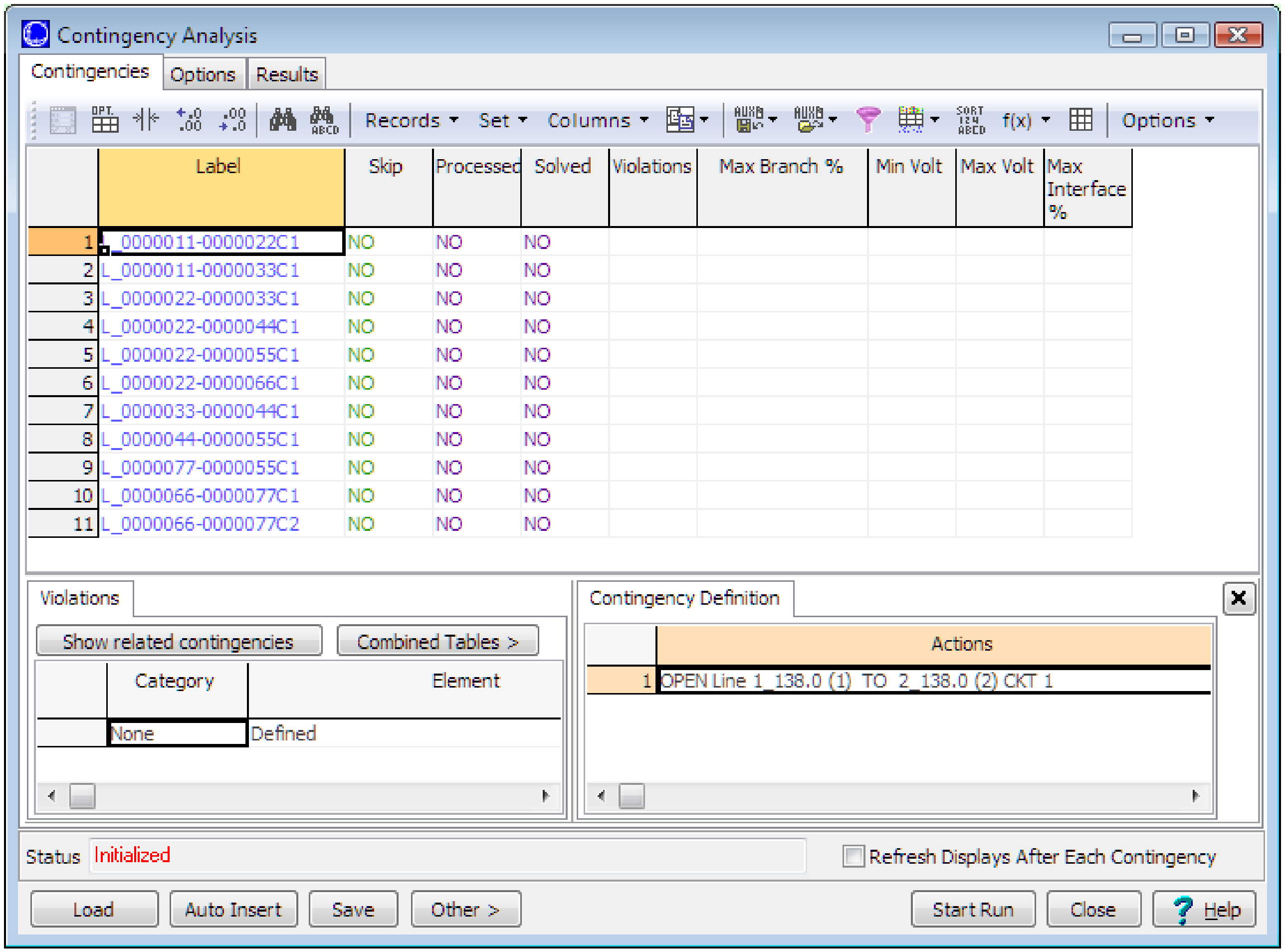
Contingency Analysis Overview

- Analysis of power system topology resulting from any statistically likely contingency
- Simulator is equipped with tools for analyzing contingencies in an automatic fashion
- Contingencies can be single or multiple element outage

Contingency Analysis

- Contingencies Include:
  - Switching of Lines and Transformers
  - Loss or Recovery of Generating Units
  - Shifting of Load
  - Loss or Recovery of Switched Shunts
- Contingency Analysis tools can be accessed from the **Tools** ribbon tab → **Contingency Analysis**, or from the button on the SCOPF Form

Contingency Analysis Dialog



The contingency analysis dialog is used to view the contingency analysis process and to edit the contingency set.

SCOPF Solution Process

- SCOPF has three major steps
  - initialization to setup the SCOPF LP tableau and control structures
  - contingency analysis, storing control sensitivities associated with each contingent violation
  - SCOPF iterations, with each iteration enforcing the newest most severe contingent violation
- Open SCOPF dialog from **Add Ons** ribbon tab → **SCOPF**
  - The three steps are solved automatically from the button **Run Full Security Constrained OPF**.

SCOPF Solution Process, cont'd

- SCOPF terminates when all of the contingent violations have been processed
- After each violation is processed, all of the unprocessed violations are updated
  - this step is crucial since often resolving the most severe violation resolves numerous other violations
  - example: a single line might be violating in a number of contingencies; fixing the worst contingency fixes the others as well

SCOPF Solution Process, cont'd

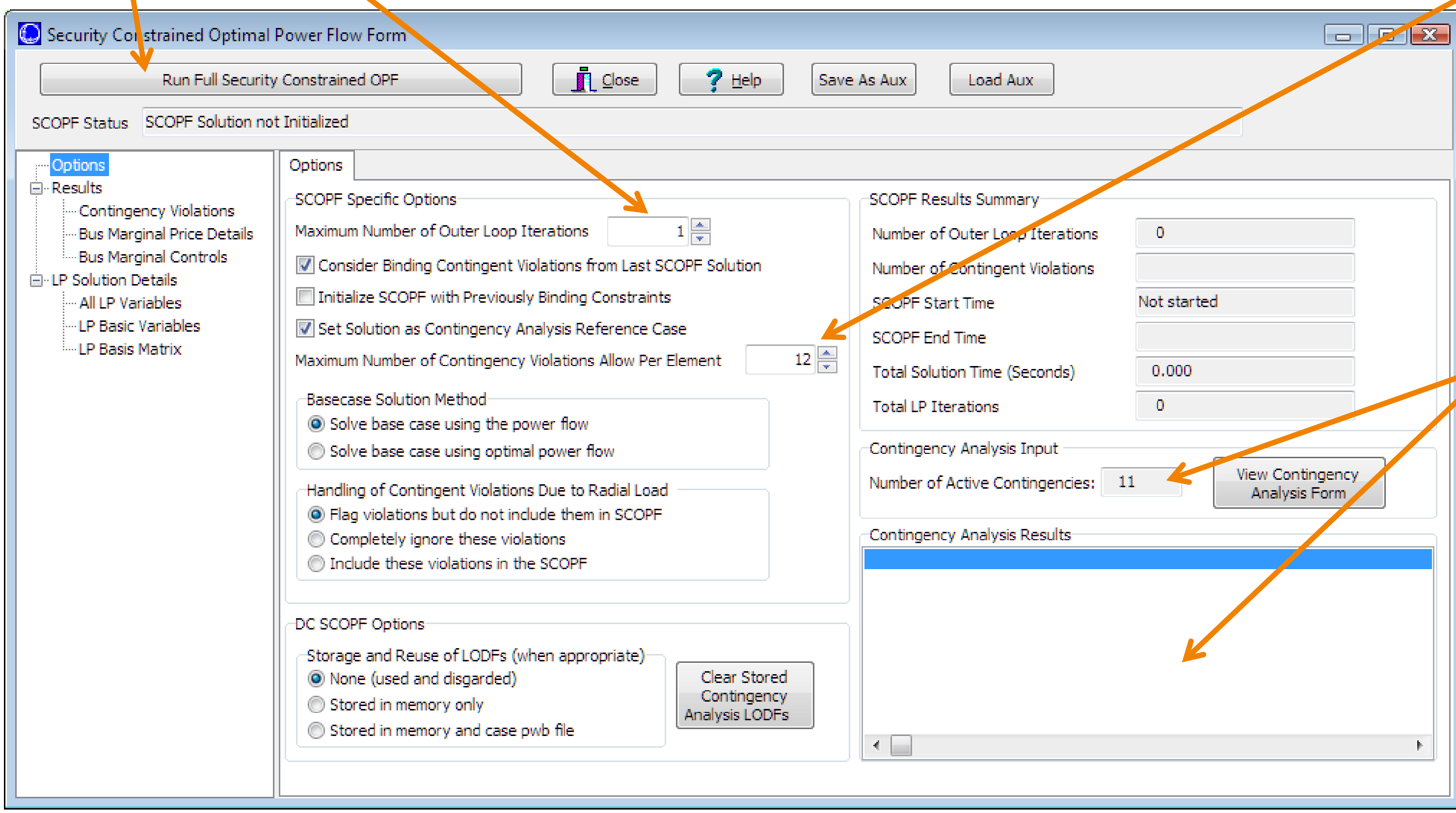
- Adjusting controls to relieve some violations may result in new violations that did not previously occur.
- Checking for new violations requires a new contingency solution
  - SCOPF performs this function by iterating the entire process around an Outer Loop
  - Care must be taken since the corrected violations will not be binding in the next Outer Loop Iteration and hence will be excluded from the LP tableau

SCOPF Form: Options

Click to solve an integrated SCOPF

Set maximum number of Outer Loop Iterations

Limiting violations per element can speed up processing



These fields are updated as contingency analysis solves

SCOPF Form: Options

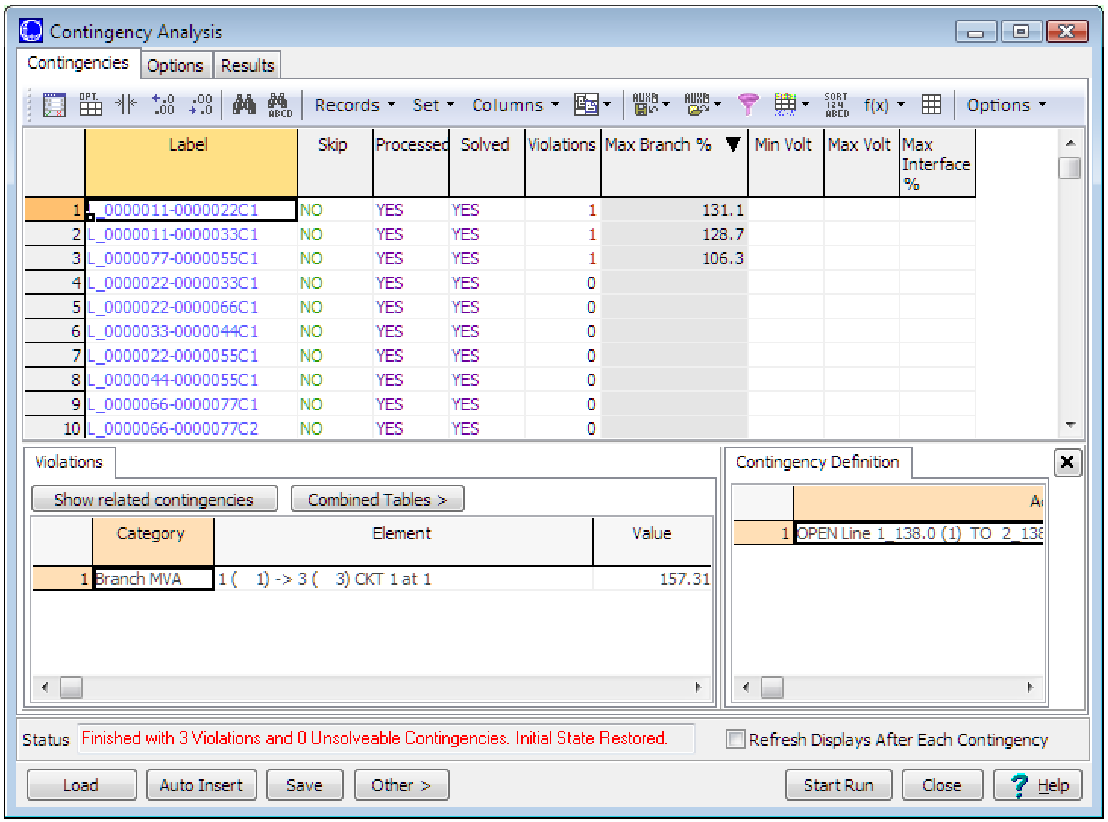
- Consider Binding Contingent Violations from Last SCOPF Solution
  - Can prevent the SCOPF from hunting between having a constraint binding in one solution, and resolving with it not binding in a later solution because it was previously remedied
  - Leave checked, unless major changes are made to the system since the previous solution
- Initialize SCOPF with Previously Binding Constraints
  - Forces the SCOPF to start with the same LP tableau from the previous solution
  - Helps solution speed when the changes to the system are small
  - Simulator automatically applies this option between multiple outer loops. This option allows the user to solve multiple outer loops by repeatedly solving the SCOPF manually, with outer loop counter = 1.

SCOPF Example: 7-bus Case

- Open case B7SCOPF
- Open **Contingency Analysis** from the **Tools** ribbon tab
- **Auto Insert** all single transmission line or transformer outages (11 total contingencies)

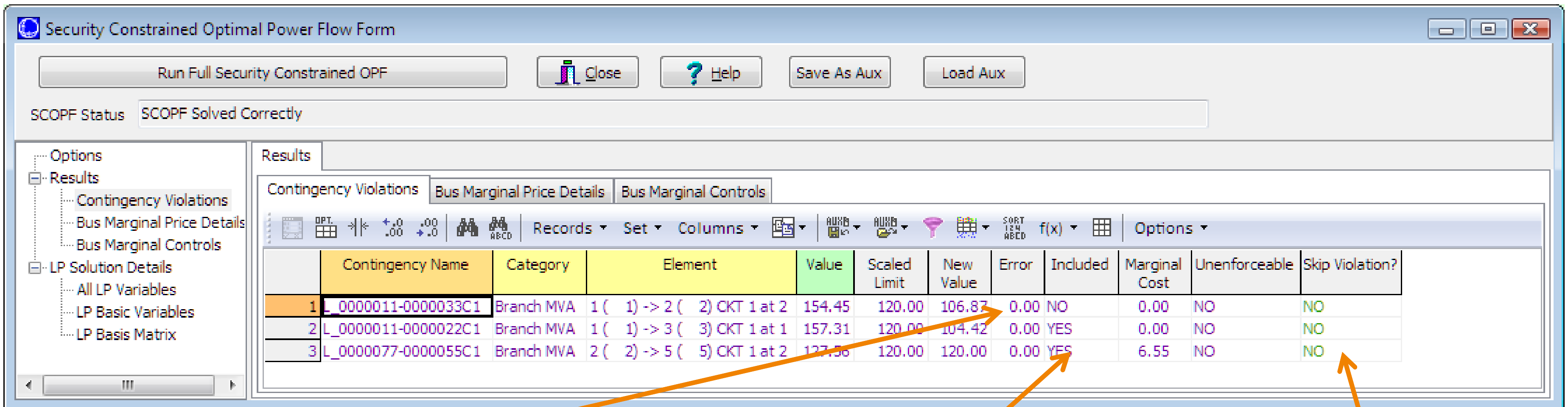
SCOPF Example: 7-bus Case

- Contingency Analysis on the Base Case reveals three violations



SCOPF Violations

The CTG Violations page lists the results from contingency analysis, which violations were included in SCOPF solution, and the final error for each violation



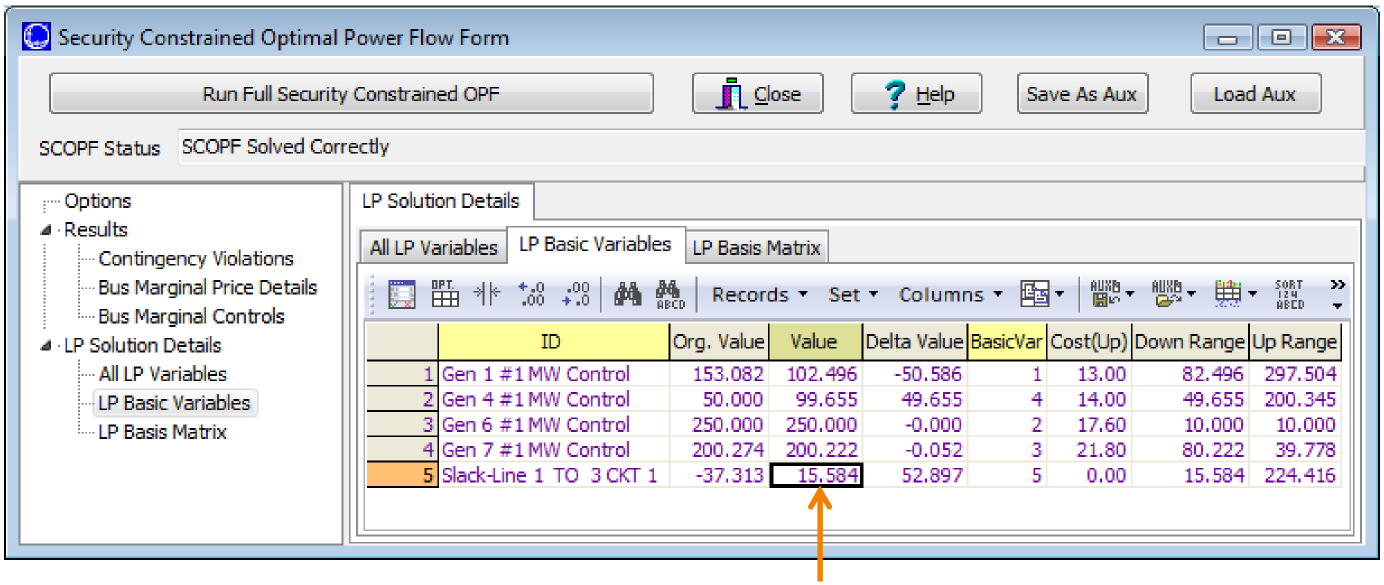
Negative errors indicate the violations have been corrected

Tells which violations were used to adjust controls

May be toggled when doing a manual SCOPF solution

SCOPF Solution Details

- LP Basic Variables provide insight to control adjustments and unenforceable constraints



If a constraint is unenforceable, the Value field associated with its slack variable would be negative.

SCOPF Results

- Note case hourly cost has increased from \$16,011 to \$16,048
- Relieving the contingency violations required increased dispatch of more costly generation

How to handle interfaces with contingent elements in the SCOPF

- Interfaces can have contingent elements
  - Line OPEN and Line CLOSE elements
- Because the SCOPF is already modeling contingencies, you must specify now you would like to treat these special interfaces
  - Choose the **Options** ribbon tab → **Simulator Options**
  - Go to **Power Flow Solution** Page
  - Go to **General** Tab
  - Monitor/Enforce Contingent Interface Elements
    - Never- will never calculate the post-contingent flows on the interface
    - Power Flow/OPF, but not CA/SCOPF
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      - In the SCOPF and CA we will also show the “post-contingent” flow