Modeling of RAS and Relays in Power Flow Contingency Analysis

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Transient Stability RAS Models

- Transient Stability RAS modeling is something special
  - This needs to be better defined
  - May result in user-defined model
  - May result in creation of specific models for specific RAS schemes
    - New Line Relay model (FACRI_SC)
    - New Shunt model (FACRI_SS)
  - PowerWorld and other software vendors are looking for guidance here
- Modeling of these features in the power flow simulations is another consideration

Power Flow Contingency Analysis Relay and RAS Models

- Relay Modeling
  - There are many possibilities for this
  - Best choice may be to just let software vendors make modifications to software
    - Automatically support the querying of transient relay models to determine if they may impact the steady-state power flow solutions
    - Will present this concept later in presentation
- RAS Modeling
  - Remainder of this presentation will show the existing abilities to model steady-state RAS schemes in PowerWorld Simulator

PowerWorld RAS Modeling

- This has a very long history in PowerWorld Simulator dating to 2000
- The contingency analysis tool has been designed from its beginning in about 2000 to include RAS modeling
  - Work done with BPA in 2000-2004 timeframe
  - Follow-on work at BPA to ensure concepts were inherited in ATC and PVQV tools (2004-2006)
  - Also work with ISO – NE and TVA throughout 2006 – 2012
  - Continued work with BPA recently as well
- This presentation is a recap of features going back to 2000 and an introduction of some new ones added recently

Features Related to Modeling Contingency Analysis RAS (1/3)

- Advanced filtering (created in 2000)
- Conditional contingency actions (2001)
  - Model Criteria (Model Conditions and Model Filters)
  - CHECK and POSTCHECK actions
- Lookup tables or expressions in Contingencies (2002)
  - Model Expressions
- Contingency actions grouped together (2003)
  - Contingency Blocks
  - Contingency Global Actions
- Storing which actions were triggered
  - What Actually Occurred (2003)
  - Specifying origin of action – Blocks, Global Actions (2011)
- Generation Drop Modeling
  - Injection Group Contingency Actions (2002)
  - Injection Group Generator Scale in Merit Order(2004)

Features Related to Modeling Contingency Analysis RAS (2/3)

- Limit Monitoring by Exception (2007)
- Generation Drop Modeling Revisit
  - Injection Group Generator Open in Merit Order (2009)
  - Accounting for overlapping gen drop (2012)
  - Contingency Action - Evaluate Model Expression in Reference State (2012)
- Full Topology Models (on next page)
- Contingency Analysis Custom Monitoring
  - Ability to monitor anything during a contingency (2011)
- Conditional Actions based on Status Only (2012)
  - TOPOLOGYCHECK actions
- Global RAS Modeling (2012)
  - Use Global Contingency action with new Model Condition Feature: *Evaluate in Reference State*

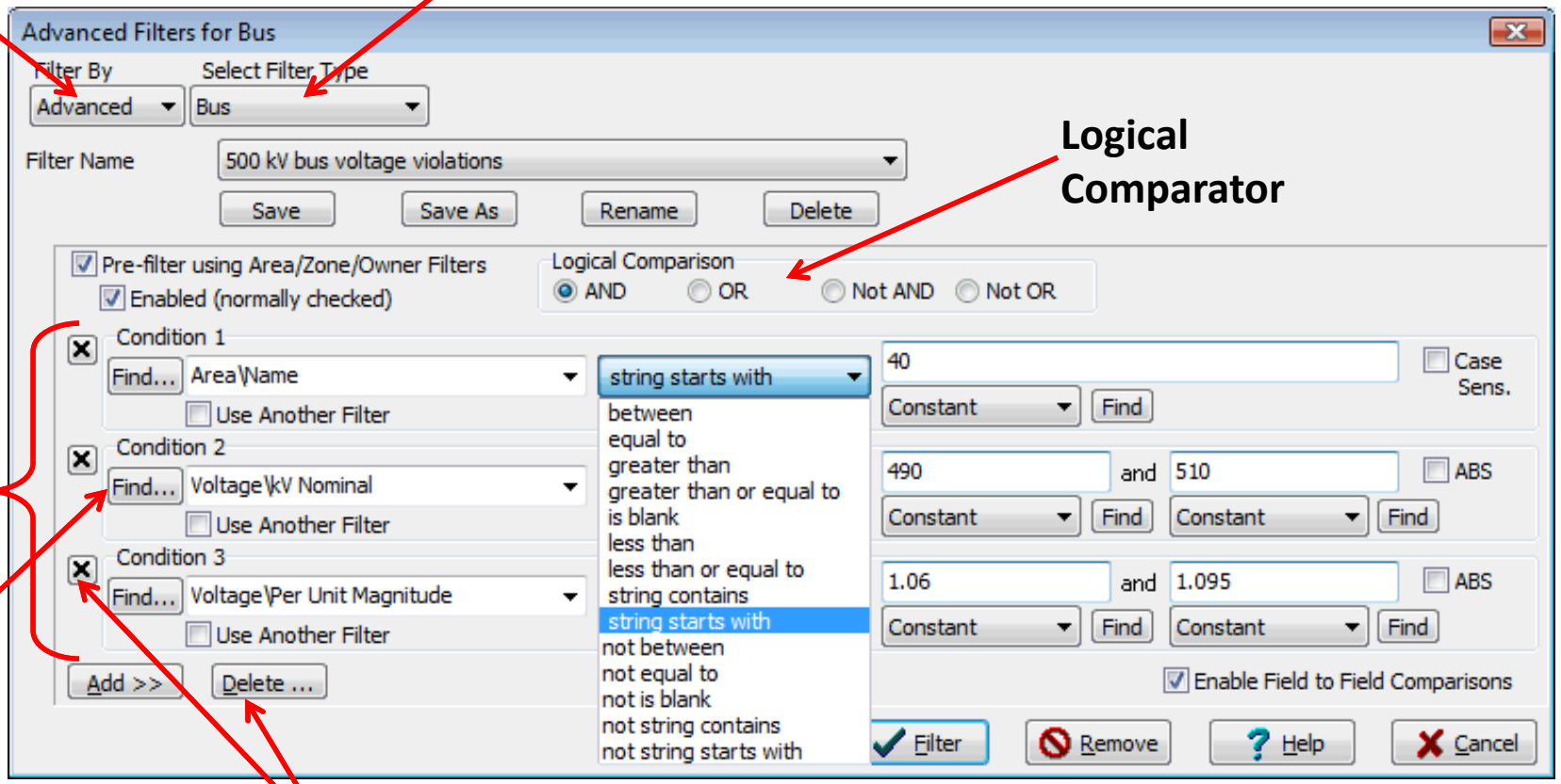
Features Related to Modeling Contingency Analysis RAS (3/3)

- Using Full Topology Models (node-breaker models) (2007)
  - Integrated Topology Processing (Incremental Topology Processing) (2007)
  - Limit Monitoring restriction to Superbus (2008)
  - Open with Breakers contingency actions (2009)
  - Close with Breakers contingency actions (2011)
  - Derived Status and Derived Online (2011)
  - Refinements (2012)

Advanced Filtering (2000)
First Step for Conditional RAS

- Advanced Filtering is an integral part of Simulator's GUI for all our tools
  - Built directly on top of our case information displays (tables)
  - Any field that you can see in a table can be filtered
  - Table data displays, monitoring, oneline formatting, really everything
- Filtering is completely generic and available for all objects in Simulator
  - Compare field to a constant (Flow > 500)
  - Compare field to another field (Flow > Limit)
  - Build any logical combinations of conditions and other filters
    - Be careful for circular references when using filters inside filters
  - No maximum on conditions
  - Compare across objects (Branches could be filtered based on whether the voltage was low at either end)

Advanced Filter Dialog



Filter By will be discussed shortly (Advanced or Device)

Type of object being filtered

Logical Comparator

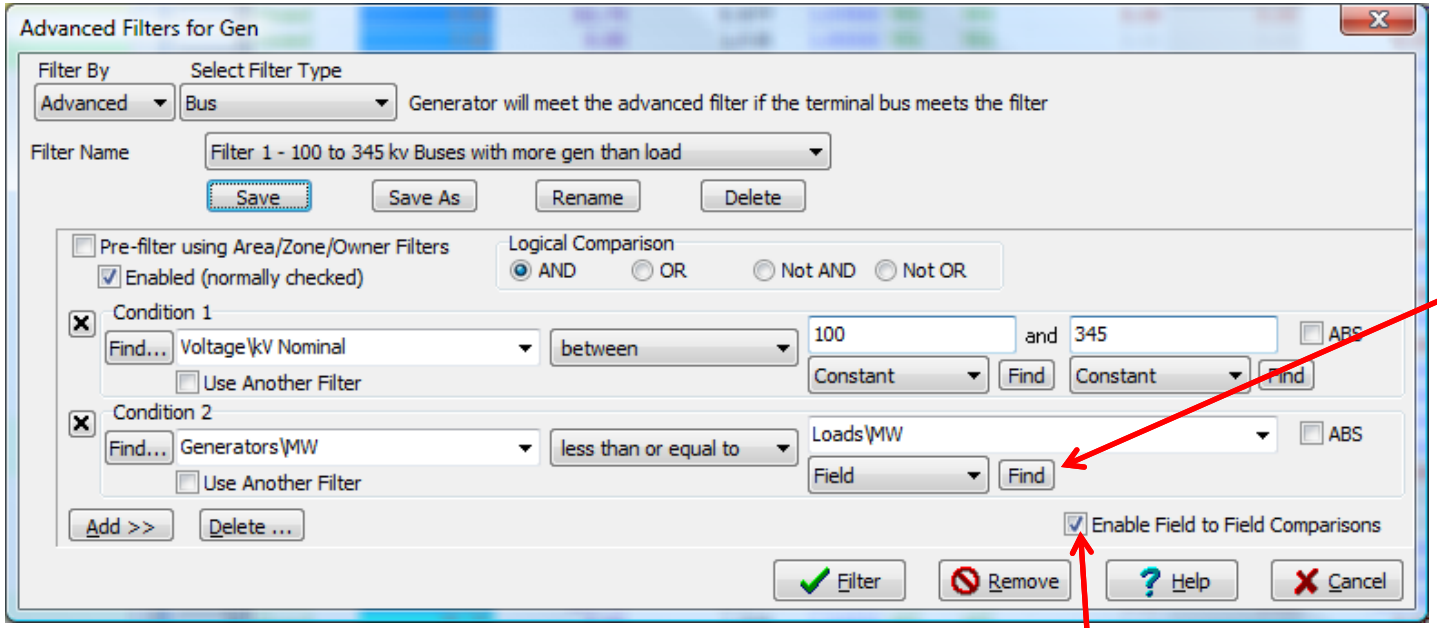
Conditions

Use the Find… buttons

Click to delete a condition

Field-To-Field Comparisons

- Users have the option to include Field-To-Field comparisons



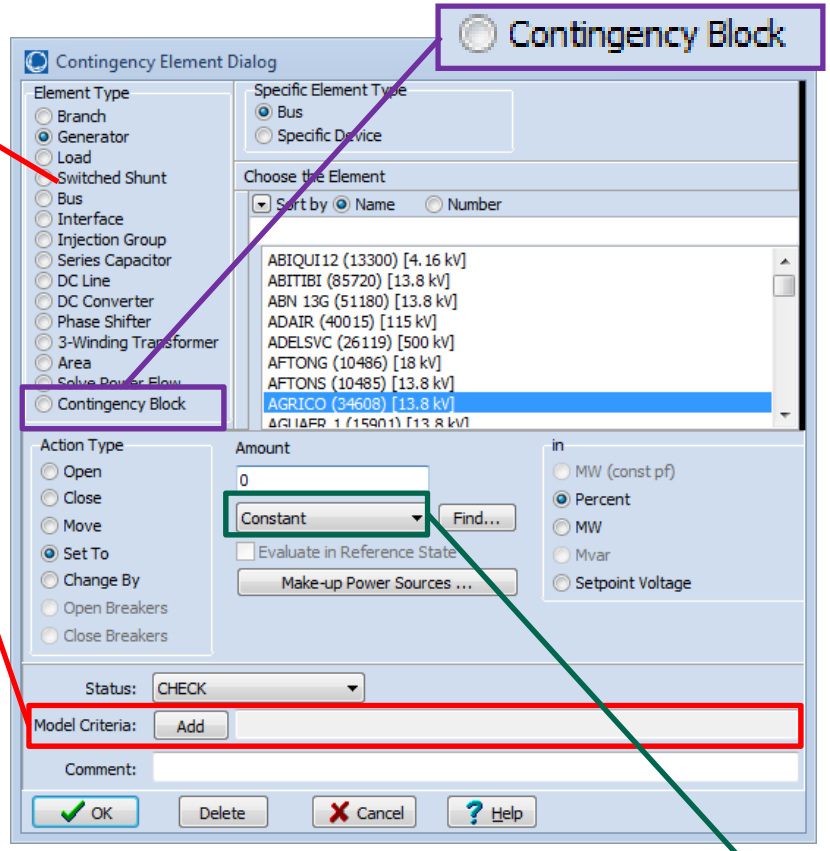
Click the Find Button to choose another field to compare to instead of a constant value.

Check the box for Enable Field to Field Comparisons

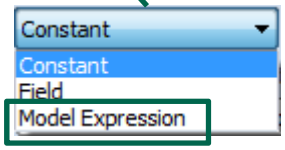
Conditional Contingency Actions (2001)

- Many choices of various contingency actions are available
- Model Criteria specifies a Boolean condition under which the action should be applied
  - Model Conditions
  - Model Filters
  - When a contingency is applied, these actions only occur if the Model Criteria is true

We'll discuss shortly



We'll discuss shortly

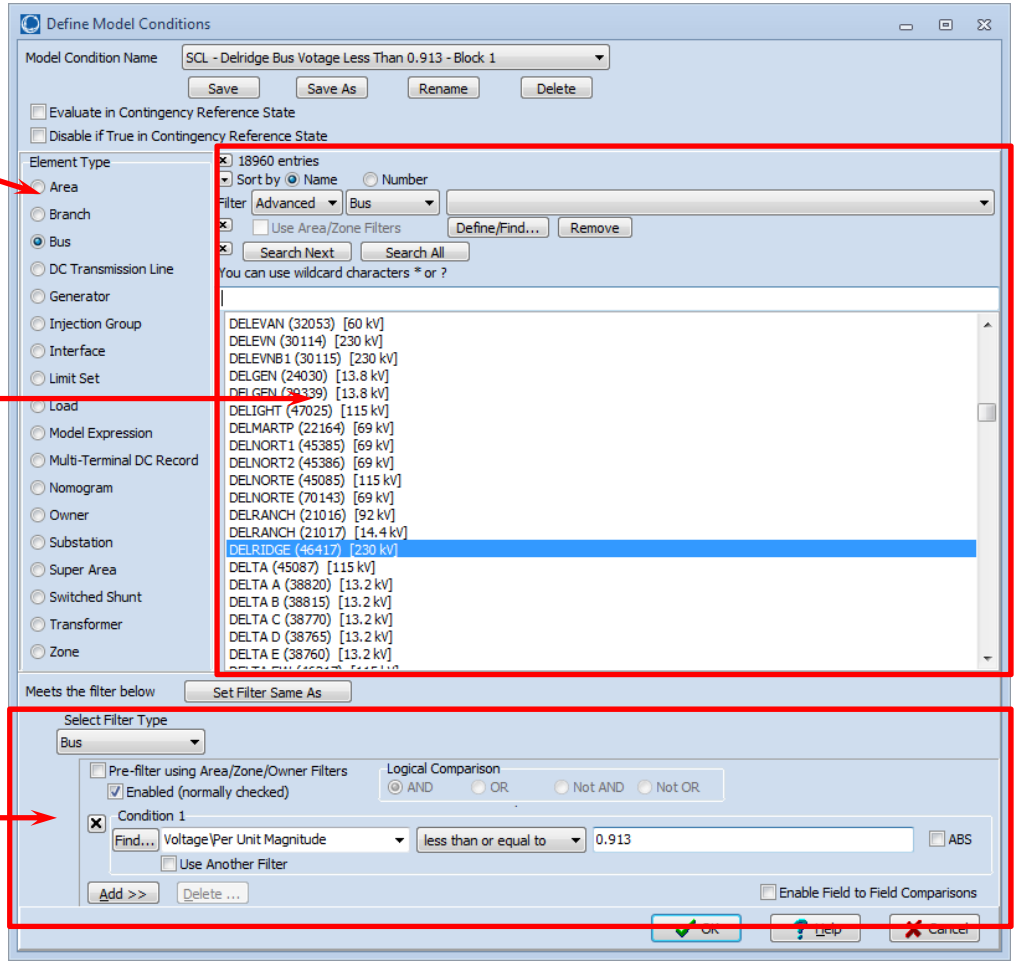


Model Conditions and Model Filters

- Model Condition (couples two things)
  - Particular object
  - An Advanced Filter definition
  - Model Condition is met if the advanced filter to the particular object is TRUE
  - TRUE Model Condition means action is applied
- Model Filter
  - A Boolean expression of other Model Conditions and Model Filters
  - TRUE Model Filter means action is applied

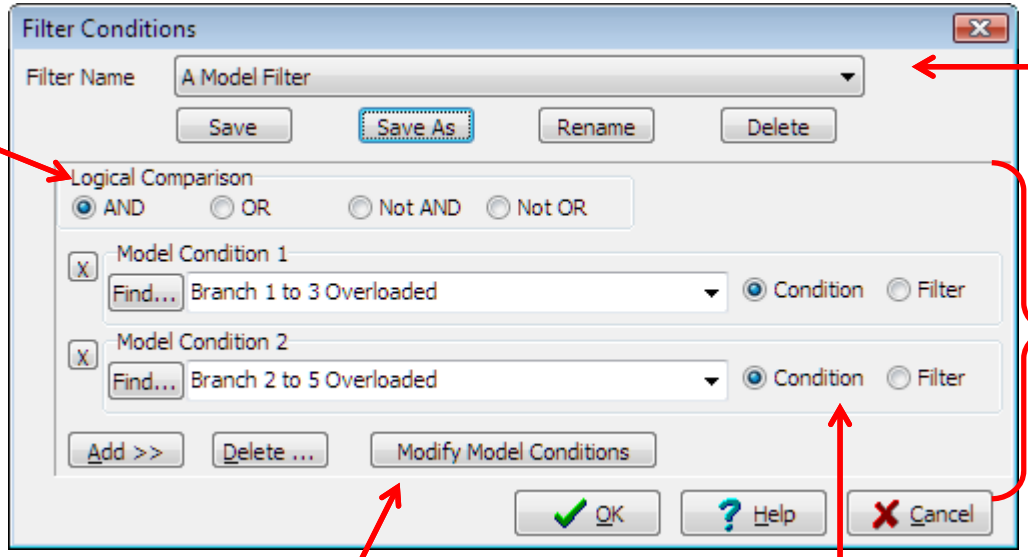
Conditional Contingency Actions Model Conditions (2001)

- Choose Object Type
- Choose Object
- Build Advanced Filter Definition



Conditional Contingency Actions Model Filters (2001)

- Just piece together a list of Model Conditions or Filters and a logical comparison



Logical comparison for the Model Conditions

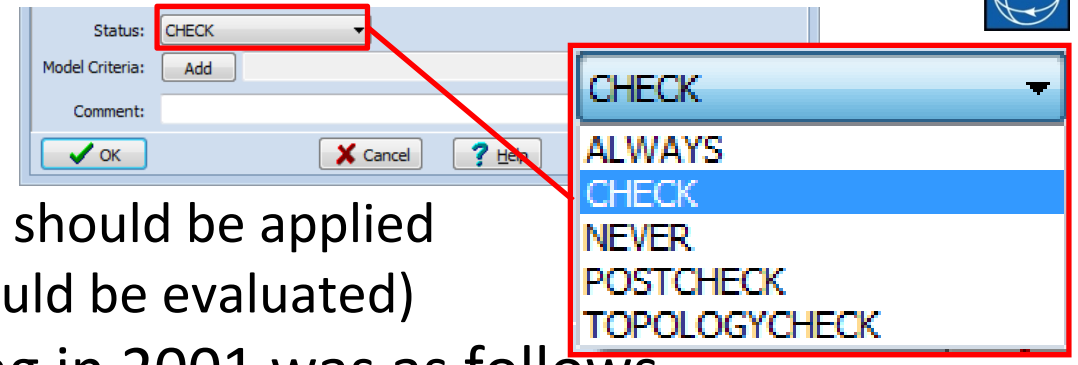
Give the Model Filter a name and save

Similar to the Advanced Filter Dialog

Click to Modify Model Conditions

Model Filters may contain Model Conditions or other Model Filters

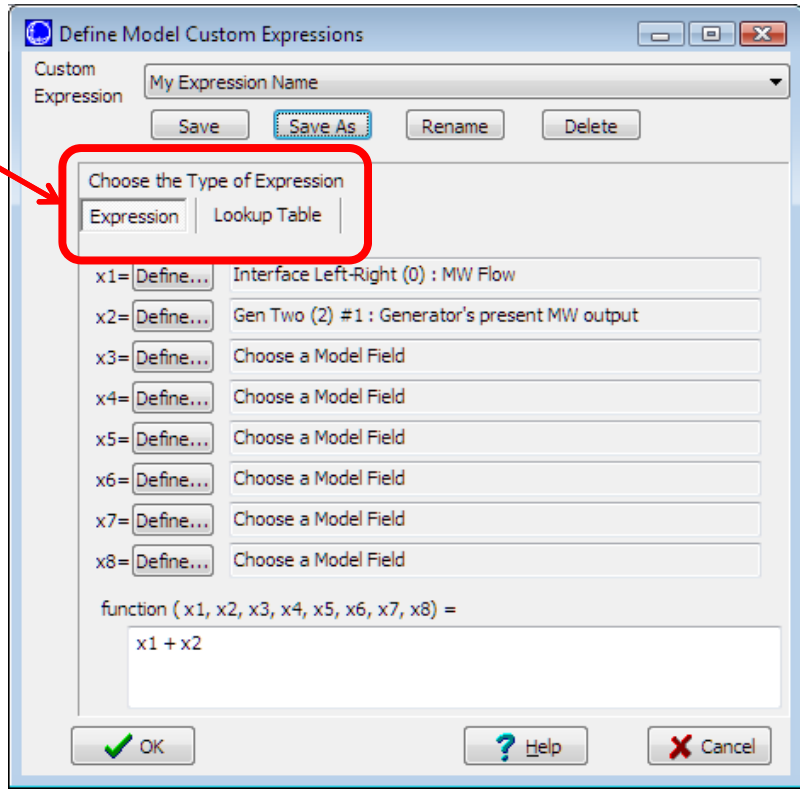
Conditional Contingency Actions: Action Status (2001)



- Action Status
  - Specifies when action should be applied
  - (i.e. when criteria should be evaluated)
- Contingency Processing in 2001 was as follows
  1. Apply *ALWAYS* actions and true *CHECK* actions
     - (Note: *CHECK* actions are evaluated in reference state)
  2. Update topology (branch, bus status)
  3. Solve power flow
  4. Apply true *POSTCHECK* actions
  5. Repeat steps 2-4 until no more *POSTCHECK* actions become true
- We will discuss *TOPOLOGYCHECK* shortly

Contingency Model Expressions

- Types
  - Expressions: mathematical expressions involving one or more model fields
    - Model Field can be any field of any object in the model
  - Lookup Tables: return a value based on the values of one or two model fields
- May be used inside
  - Some kinds of contingency elements
    - Set Gen MW to Model Expression
    - See earlier slide
  - Advanced Filters
  - Model Conditions
- Examples
  - Gen Drop Equal to a Lookup Table
  - Gen Drop Equal to 40% of Interface Flow

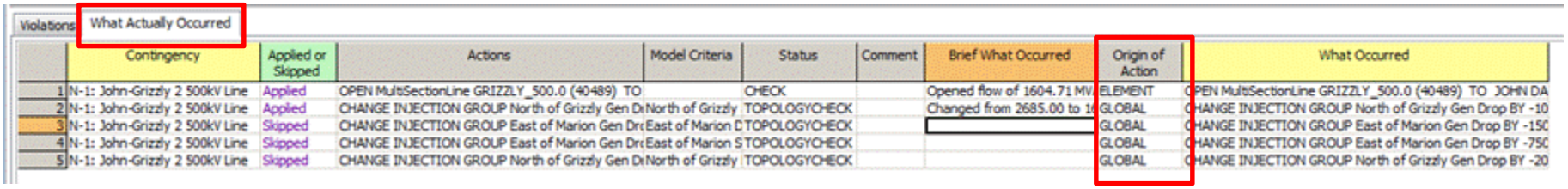


Contingency actions grouped together (2002)

- Contingency Blocks
  - Provide a grouping of contingency actions
  - A contingency definition can then refer to the contingency block
    - Multiple contingencies might do the same set of actions
    - Frankly, the need for this became much less with enhanced contingency definitions of Injection Group, Interface actions, etc.
- Contingency Global Actions
  - Define a list of contingency actions that are inherited by ALL contingency definitions
  - Only makes sense if these are all conditional
  - Allows you to setup definitions such as a branch that monitors a line flow and trips the line if it's too high
    - Useful for modeling relays and RAS

What Actually Occurred? (2003)

- Consequence of Conditional Actions
  - Need a mechanism to report what action were Applied and which were Skipped
    - Implemented in 2003
    - Improvements to GUI in 2008
  - Need a mechanism to report the "origin" of the contingency action that is applied or skipped (2011)
    - ELEMENT
    - BLOCK
    - GLOBAL
    - Future… RELAY model?
  - List of "What Actually Occurred" is part of the results of a contingency (similar to how violations are part of the results)



Violations | What Actually Occurred

	Contingency	Applied or Skipped	Actions	Model Criteria	Status	Comment	Brief What Occurred	Origin of Action	What Occurred
1	N-1: John-Grizzly 2 500kV Line	Applied	OPEN MultiSectionLine GRIZZLY_500.0 (40489) TO		CHECK		Opened flow of 1604.71 MV	ELEMENT	OPEN MultiSectionLine GRIZZLY_500.0 (40489) TO JOHN DA
2	N-1: John-Grizzly 2 500kV Line	Applied	CHANGE INJECTION GROUP North of Grizzly Gen Dr	North of Grizzly	TOPOLOGYCHECK		Changed from 2685.00 to 1	GLOBAL	CHANGE INJECTION GROUP North of Grizzly Gen Drop BY -10
3	N-1: John-Grizzly 2 500kV Line	Skipped	CHANGE INJECTION GROUP East of Marion Gen Dr	East of Marion D	TOPOLOGYCHECK			GLOBAL	CHANGE INJECTION GROUP East of Marion Gen Drop BY -150
4	N-1: John-Grizzly 2 500kV Line	Skipped	CHANGE INJECTION GROUP East of Marion Gen Dr	East of Marion S	TOPOLOGYCHECK			GLOBAL	CHANGE INJECTION GROUP East of Marion Gen Drop BY -750
5	N-1: John-Grizzly 2 500kV Line	Skipped	CHANGE INJECTION GROUP North of Grizzly Gen Dr	North of Grizzly	TOPOLOGYCHECK			GLOBAL	CHANGE INJECTION GROUP North of Grizzly Gen Drop BY -20

Straightforward Future Addition

- Conceptually a Relay Model in power flow contingency analysis would act similar to
  - Contingency action that opens a device (or devices)
  - **Status** = *POSTCHECK*
  - **Model Criteria =** Model Condition based on
    - Violating Bus Voltage Limit
    - Over Line Current
    - Apparent Impedance looking down line is inside Impedance Region (distance relay)
- Potential addition to power flow contingency analysis
  - Force software to directly use *transient stability* relay models in *power flow* contingency analysis
  - Note: do NOT force extra definition of actions

Future: Transient Relay Models in the Power Flow Contingency

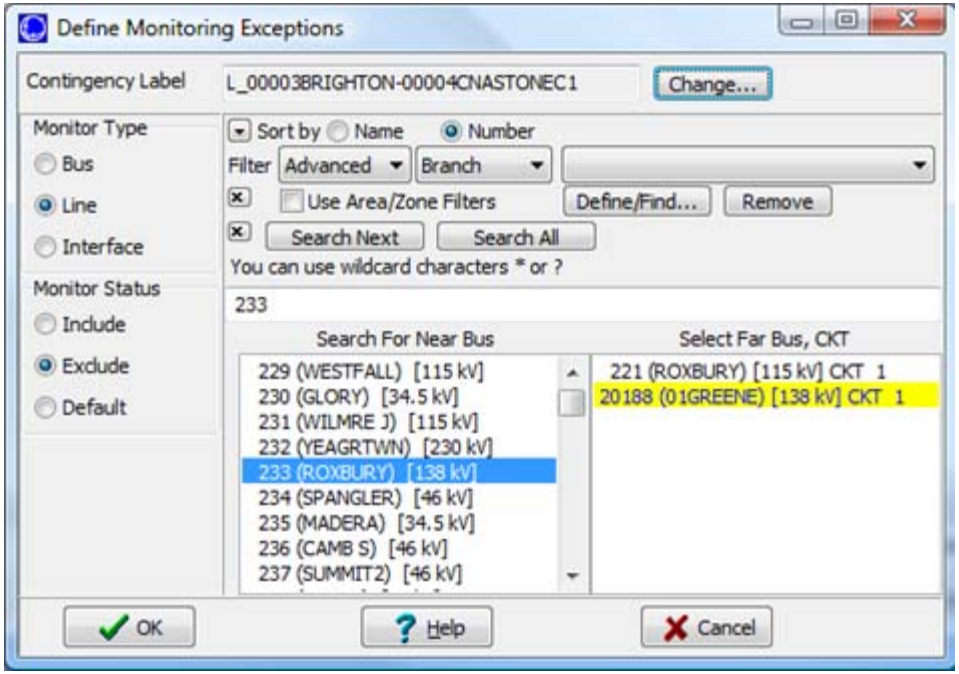
- Internally Simulator would automatically evaluate steady-state implications of the stability relay models at the same time that existing *POSTCHECK* actions are evaluated
  - Assume in power flow contingency that post-contingency states exists forever
    - Timing data in relay models would be ignored as state exists forever
    - Over-current relays would just look at the minimum current threshold from transient model
    - Voltage based relays would look at largest minimum voltage and smallest maximum voltage
    - Distance/Impedance relays would evaluate highest zone for model
  - What Actually Occurred results would indicate if any of these actions are initiated
  - User Requirements for this feature
    - Define your stability relay models
    - Check a box to enable this new feature
- Potential auto-reporting options
  - Automatically report as a contingency violation if any relay models actual operate

Contingency Limit Monitoring by Exception (2007)

- Create exceptions to Limit Monitoring settings for specific contingencies and monitored elements
- Not recommended
  - Basically means "I know there is RAS but I don't want to model it, and don't tell me about these violations"

Example: Ignore a particular line during a particular contingency

We know it can be alleviated (instead of explicit RAS modeling)

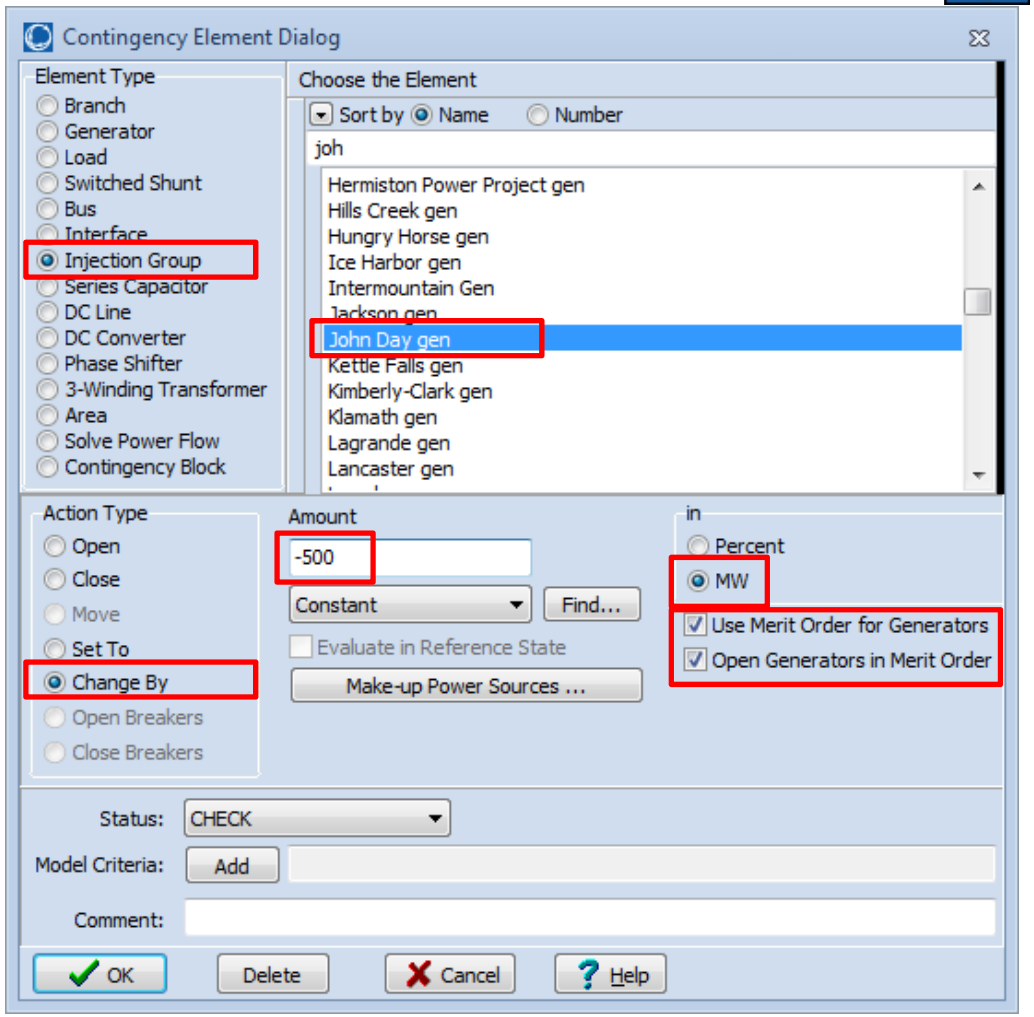


Modeling Generation Dropping → A common RAS scheme

- Contingency Blocks (2002)
  - Initially added to allow grouping of generator outages or scaling
  - Can be used for anything else though
- Injection Group Contingency Actions (2002)
  - Gave ability to OPEN all generation in an injection group
  - Gave ability to SET or CHANGE MW output (done by scaling generation)
- Injection Group Generator Scale in Merit Order(2004)
  - Scale in Merit Order allowed you to scale up (or down) generation one at a time to max (or min) limits until total MW change achieved
- Generator Open in Merit Order (2009)
  - Allows you to specify an amount of gen to reduce by opening generators
  - Opens generation until all gens would exceed the specified amount
- Accounting for overlapping gen drop (2012)
  - Possible for multiple RAS to operate simultaneously
  - Multiple RAS may ask to open the same generation
  - Accounting for overlap means that if multiple schemes are operating then subsequent ones will count drops from earlier schemes in their MW totals
- Contingency Action - Evaluate Model Expression in Reference State (2012)
  - Needed so you can properly arm the amount of generation drop

Example of Injection Group Contingency Action

- Assume Injection Group named John Day gen is defined
- Change the total John Day generation by -500 MW by opening generator in merit order



Contingency Analysis: Overlapping Gen Drop (2012)

- Accounting for Overlapping Generation when using merit-order generation dropping
  - Drop 500 MW from Injection Group #1
  - Drop 400 MW from Injection Group #2
  - Order matters: Group #1 will drop 500 MW, but when going to drop Group #2, if there is overlap and 200 MW of generation in Group #2 was already dropped due to Group #1 dropping, then only an additional 200 MW will be dropped.
  - You won't always get 900 MW of dropping (example above would only drop 700 MW)

- Note: default behavior is to take into account this overlap. This may be turned off in the Basic Contingency Modeling options

RAS models before 2012

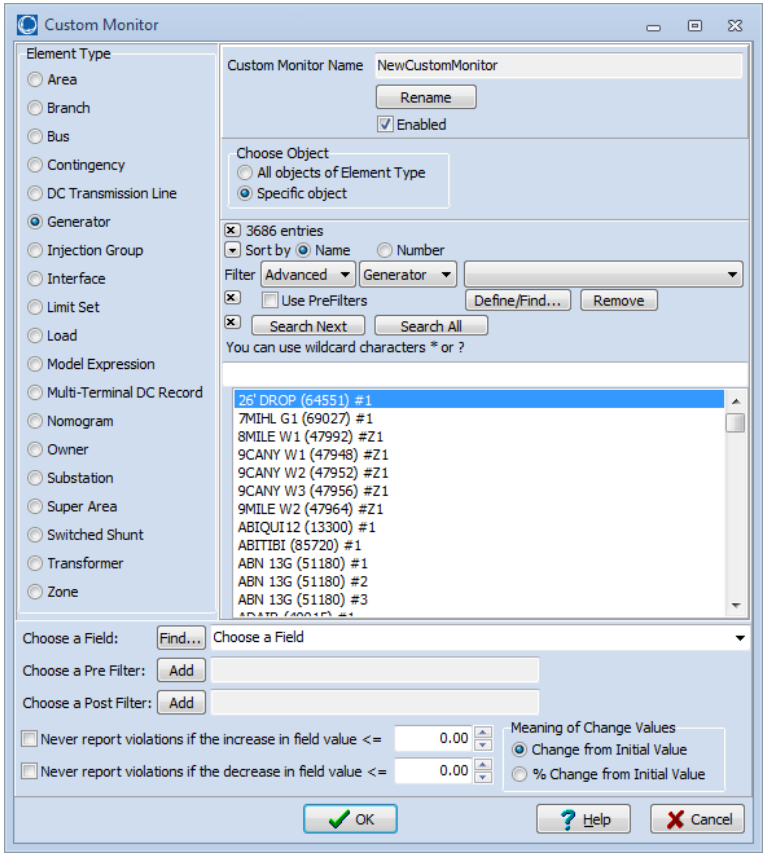
- Typically the RAS model is modeled explicitly with the line outage contingency that triggers the RAS to occur
  - Just automatically apply the gen drop for instance for a particular line outage
  - Possible make a Contingency Block that performs this and refer to Contingency Block from outages that use this RAS
- Limitations of this
  - If line is out in the reference state you must modify your contingency definitions
    - Otherwise the RAS is initiated in contingency though no change
    - Data maintenance issue
  - Will not capture the cascading outage that trigger RAS when
    - Line A overloads → Trip Line A → causes Line B to trip which triggers RAS associated with Line B
    - Basically, unless you have all these RAS and relays enabled in your contingency run, the Simulation will NOT show cascade of Southwest Blackout

Evaluate Model in Reference State (2012)

- Needed to arm the amount of generation drop based on *Reference State* only
  - Important if there are *POSTCHECK* actions
  - Possible that other *POSTCHECK* actions have occurred and you're iterating back on subsequent *POSTCHECK* actions with a new system state.
- Example:
  - Amount of generation drop is based on a two-dimensional nomogram which is a function of two interface flows
  - The "arming level" is handle based on the reference state, not what the MW flow happens to be at a particular point in contingency analysis process
    - Use Model Expression Lookup Table (Simulator supports 1D and 2D lookups tables)
    - For amount to drop, point to Model Expression
    - Check box for **Evaluate Model in Reference State**

Custom Contingency Monitoring (2011)

- Ability to monitor anything during a contingency (2011)
  - Specify an object type
  - Choose either
    - All objects of that type
    - Choose a specific object
  - Choose Field to Monitor
  - Pre Filter
    - Advanced Filter applied to object in Reference State
  - Post Filter
    - Advanced Filter applied to object in post-contingency state
  - Options to never report violation if value doesn't change by threshold



Conditional Actions based on Status Only (2012)

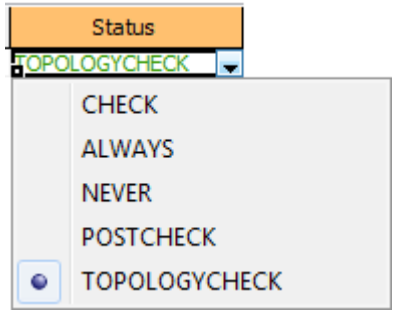
- Users of Simulator had a persistent problem in some contingency runs when using RAS
  - RAS is configured to open 2,000 MW of generation when Line X trips
  - Before 2012, this was achieved by configuring a *POSTCHECK* action that looks at the branch status and trips generation if the branch is out of service
  - Works most of the time, but...
  - What if the outage of Line X results in an unsolvable steady state power flow solution?
    - Basically means that the RAS scheme is actually preventing a voltage collapse from occurring
    - This means that the *POSTCHECK* action is never evaluated because the power flow solution failed.
- Solution: *TOPOLOGYCHECK* actions

Contingency Analysis: TOPOLOGYCHECK (2012)

- ***TOPOLOGYCHECK*** Contingency Element Status.
- Contingency Processing now goes as follows
  1. Apply *ALWAYS* actions and true *CHECK* actions
  2. Update topology (branch, bus status)

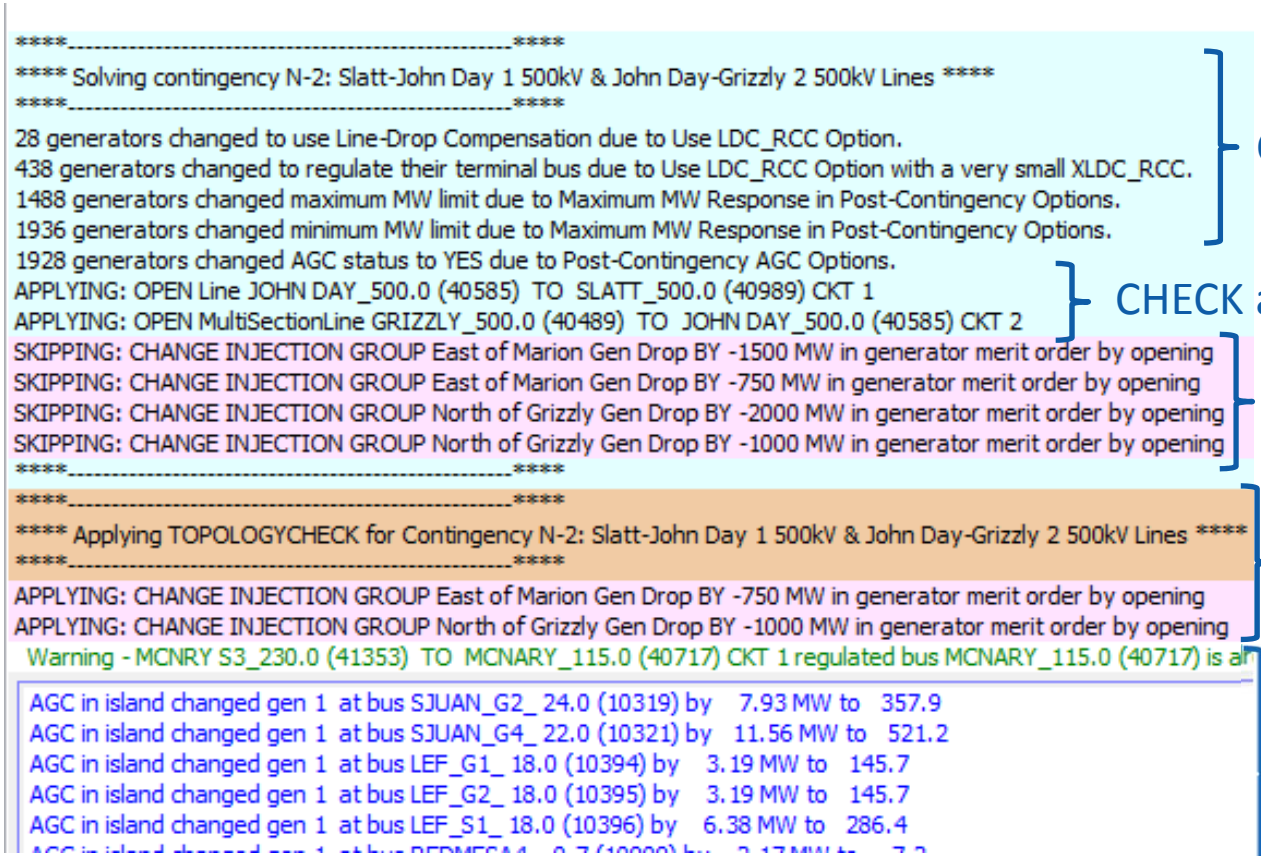
NEW 3. Apply true *TOPOLOGYCHECK* actions

  4. Solve power flow
  5. Apply true *POSTCHECK* actions and true *TOPOLOGYCHECK* actions
  6. If any *POSTCHECK* or *TOPOLOGYCHECK* actions are done then repeat steps 2-5



- Note: TOPOLOGYCHECK should only be used with Model Conditions related to bus/branch statuses

TOPOLOGYCHECK Status Message Log

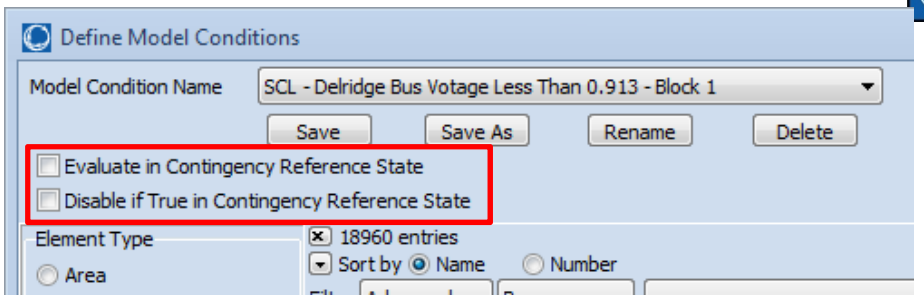


Light blue indicates contingency element

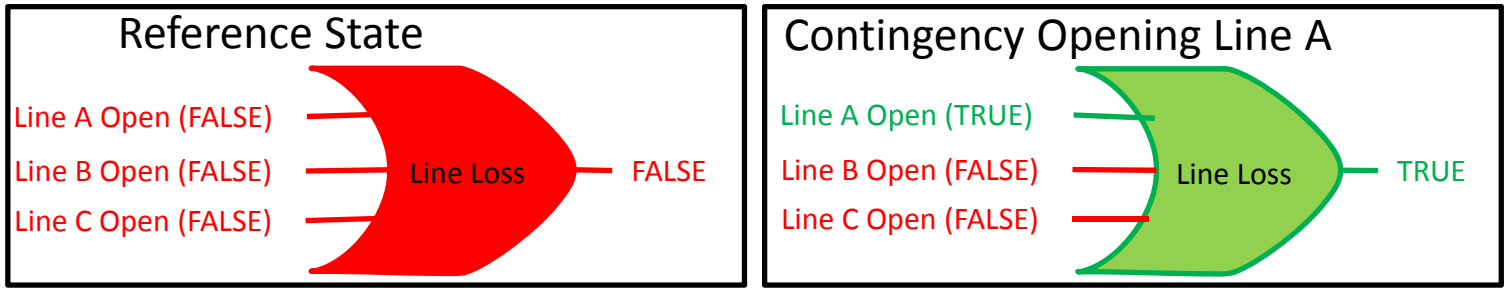
Pink indicates Global Action

Global RAS Modeling (2012): Reference State Evaluations

- Model Condition Option
  - Evaluate in Contingency Reference State
  - Disable if True in Contingency Reference State



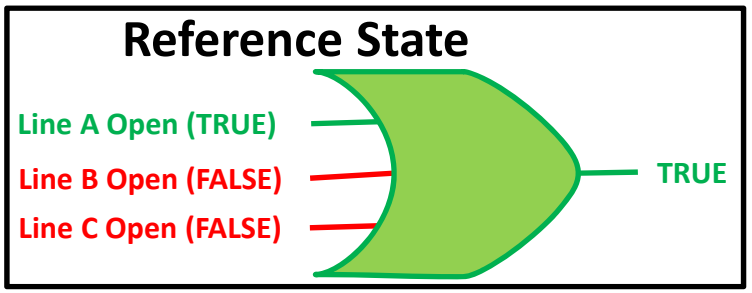
    - Example: Model Filter that takes the OR of three Model Conditions that test whether particular lines are Open
      - As soon as one of the lines is opened by a contingency, the model filter will evaluate to TRUE and you'll trigger appropriate actions.



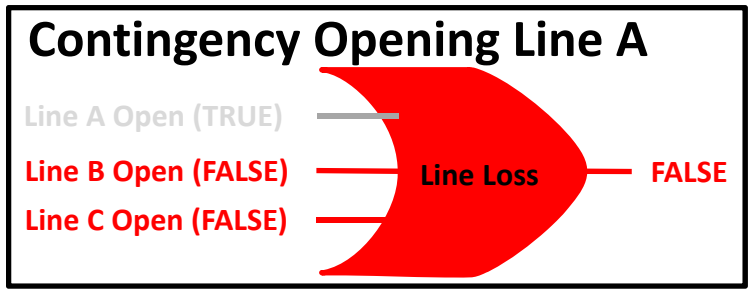
      - Works great as long as all three lines are CLOSED in the Reference State

Contingency Analysis: Disable if TRUE in Reference State

- What if Line A is OPEN in the Reference State?
  - This logic will end up returning TRUE for *EVERY* contingency



- Disable if TRUE in Reference State Option means
  - The Model Condition is completely ignored!
  - It's like the Model Condition doesn't even exist.
  - The result of this will depend on the type of logic the model condition is fed into



Contingency Analysis: Disable if TRUE in Reference State

- Reminder
  - Global Contingency Actions are a list of contingency elements that are included as part of every contingency solution
- Implication:
  - Specify an action as part of the Global Contingency Actions using the *Disable if TRUE in Reference State* choice
  - This allows you to model a global RAS in the power flow contingency action
    - Define one record in Global Contingency Action and you don't need to manage which contingencies use it
    - Also allows potential for cascading RAS under any contingency

Using Full Topology Models (node-breaker models)

- Highlights Related to Contingency Analysis
  - Integrated Topology Processing (2007)
    - Contingency Analysis Incremental Topology Processing
  - Limit Monitoring restriction to Superbus (2008)
  - Open with Breakers contingency actions (2009)
  - Close with Breakers contingency actions (2011)
  - Derived Status and Derived Online (2011)
    - Improvements for special situations in 2012

History of Software Development

- History of the *Contingency Analysis Tool*
  - Initial development in early PowerWorld Simulator versions before 1999
  - Work with BPA to make conditional actions and many advanced features (2000 – 2004)
  - Work with ISO – New England to implement features for full-topology models (2006 – 2008)
  - Work with ISO-NE and TVA on Full-Topology Model (2008 – 2012)
  - Work with BPA to permit more generic modeling of RAS (2011 – 2012)
    - Global RAS so don't need to embed RAS in particular contingencies
    - Allows use in full-topology models
    - Consistent modeling for all users inside BPA
- History of other tools in Simulator are very similar
  - A handful of customers drive the *incremental* development in lots of small projects
  - Almost all of Simulator's tools have been made in this manner
    - ATC, PVQV, OPF, SCOPF, OPF Reserves, Scheduled Actions, SimAuto, Integrated Topology Processing, Transient Stability, Sensitivity tools, Connection tools, etc…
    - Only exception we can think of is GIC (nobody even did this previously)

Software Development Process

- More than 100 small incremental tasks done over more than 13 years with several clients
  - As small as a 0.5 person-days, no bigger than 2 person-months
- Project Timing
  - Most tasks are spelled out with 3 – 5 days of software development time and a deliverable within 2 weeks
    - Expectation is that user will test the new features *immediately* and within a few days we're certain it functions as desired
    - Feedback with the PowerWorld developer and actual end-user is frequent (weekly, if not daily at times)
  - Even large project get broken up into small tasks so progress can be measured and user is constantly engaged in providing feedback
- Why do it this way?
  - Software developer doesn't understand what the user needs
  - Often the user isn't certain either
  - Small tasks ensure everyone learns quickly what works and what doesn't → constant short engagements builds trust
  - Nice thing about software is manufacturing process is free (compile, move file to web server, email notice)