Distributed Flexible AC Transmission System (D-FACTS)

Jamie Weber

weber@powerworld.com, 217-384-6330 ext. 13

Slide Preparation: Kate Rogers Davis

kate@powerworld.com, 217-384-6330, Ext 14

PowerWorld Corporation

2001 South First Street
Champaign, Illinois 61820
+1 (217) 384.6330

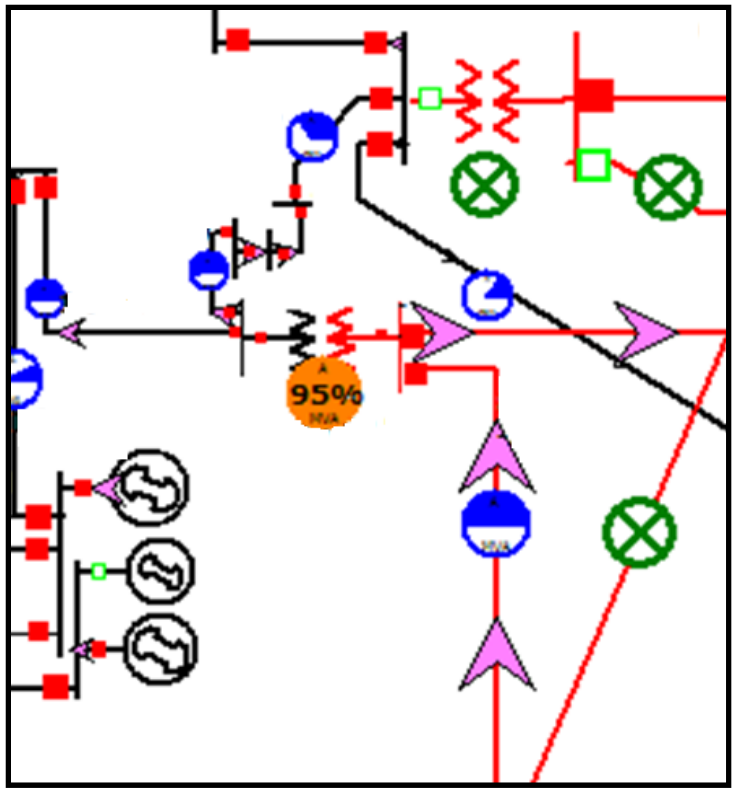
support@powerworld.com
http://www.powerworld.com

Outline

- Background
  - Power flow control
  - FACTS vs. D-FACTS
- PowerWorld D-FACTS Modeling
  - Stand alone operation
  - Line impedance sensitivities
  - Contingency analysis
- Continuing Work

Power Flow Control

- Power flow is not directly controllable - to change the way power flows in the system, we need to be able to change line impedance, voltage magnitude, or angle differences
- Benefits
  - Relieve overloaded lines
  - Reduce transmission losses
  - Maintain acceptable voltages
  - Improve stability
  - Full utilization of existing system
- Limitations
  - Cost
  - Size and installation



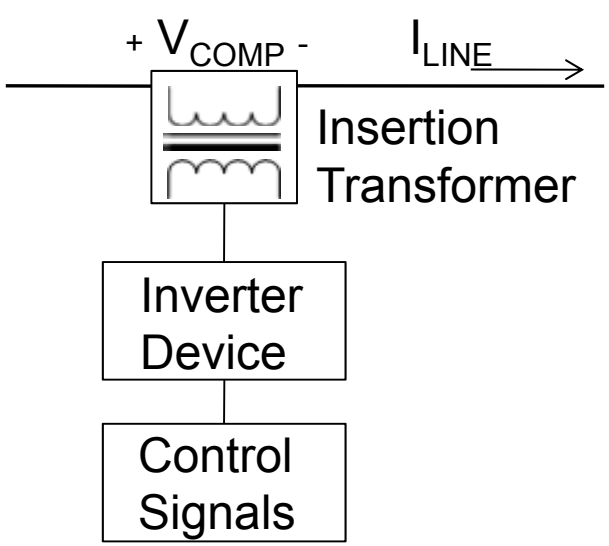
Flexible AC Transmission Systems (FACTS) – IEEE Definitions

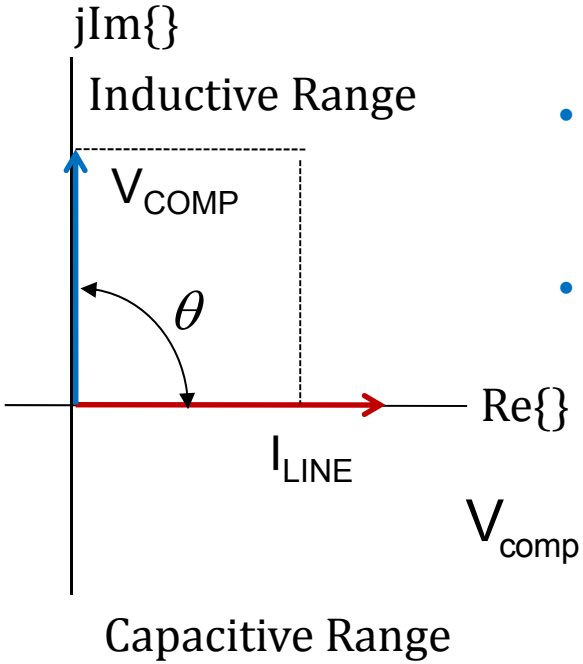
- Flexibility
  - ability to accommodate changes in the system or operating conditions without violating stability margins
- Flexible AC Transmission System
  - incorporates power electronics and other static controllers to enhance controllability and increase transfer capability
- FACTS Controller
  - provides control of one or more AC transmission system parameter

FACTS Working Group, "Proposed Terms and Definitions for Flexible AC Transmission System (FACTS)", *IEEE Transactions on Power Delivery*, Vol. 12, Issue 4, October 1997.

Active Impedance Injection

- The Synchronous Voltage Source (SVS)





- In practice, V_{COMP} is 90 degrees out of phase with the line current)
- Otherwise you must have a power source!

$$V_{comp} = I_{Line} Z$$
$$= -jI_{Line} X_c \text{ or } jI_{Line} X_L$$

- Injects an AC voltage, V_{COMP}
- Controls V_{COMP} with respect to I_{LINE}
- Changes effective line impedance
- Many FACTS devices use this concept

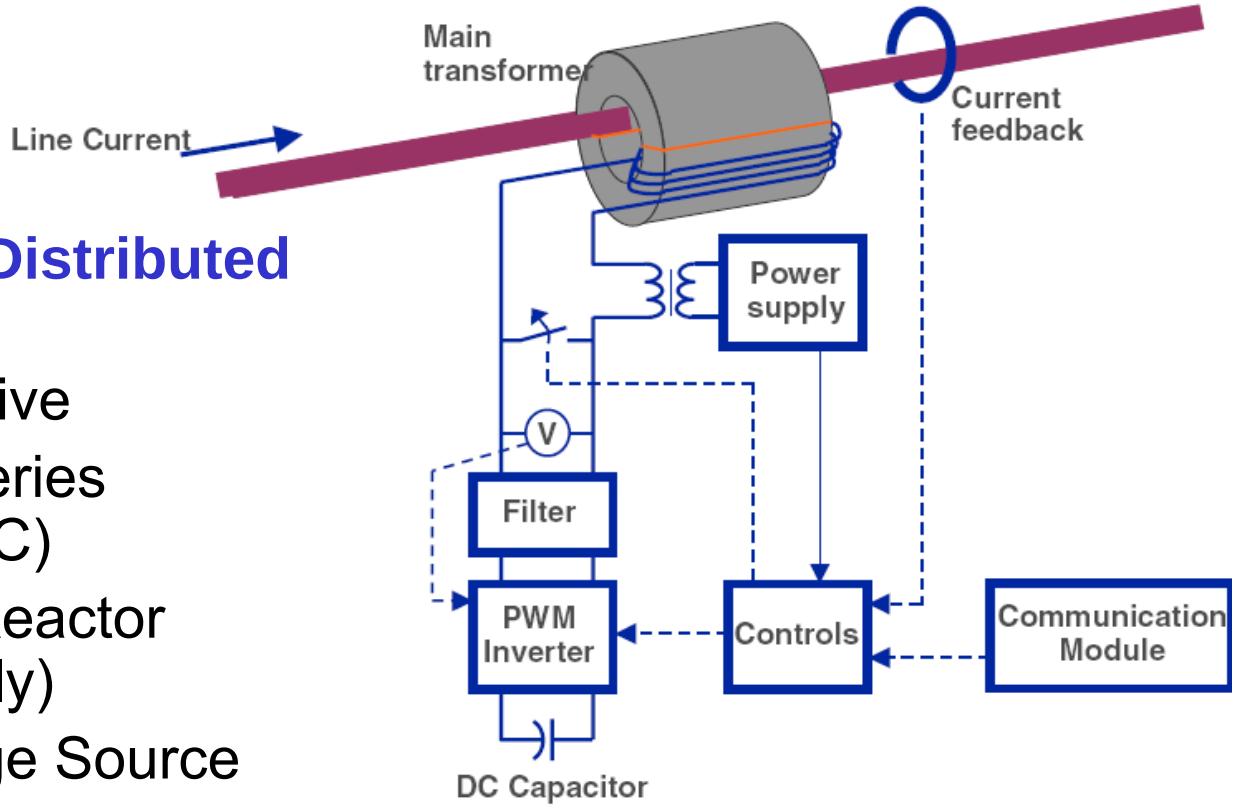
FACTS Technologies

- Static Var Compensator (SVC)
  - Thyristor-controlled capacitors and reactors
  - Stability and voltage control
- Thyristor-Controlled Series Capacitors (TCSC) or Thyristor-Switched Series Capacitors (TSSC)
  - Thyristor-controlled capacitors and reactors
  - Capacitive or inductive compensation
- Static Synchronous Series Compensator (SSSC)
  - Uses a SVS
  - Capacitive or inductive compensation

FACTS Technologies

- Static Synchronous Compensator (STATCOM) or Static Synchronous Compensator (SSC)
  - Uses a SVS
  - Analogous to synchronous condensers
- Unified Power Flow Controller (UPFC)
  - Combination of STATCOM and SSSC
  - Control voltage and real and reactive power flows
- Variable Frequency Transformer (VFT)
  - Transfer power between asynchronous grids
  - First installation in Quebec, 2004
- And more…

D-FACTS Devices



Recently-Introduced Distributed FACTS Devices

- Capacitive or inductive
- Distributed Static Series Compensator (DSSC)
- Distributed Series Reactor (DSR) (inductive only)
- Synchronous Voltage Source
- Attach directly to lines
- Small and modular

D. Divan, "Improving power line utilization and performance with D-FACTS devices," *IEEE PES General Meeting*, June 2005.

How can D-FACTS Improve Operations

- Exploit the fact that not all locations have equal impact
- Determine the best locations for the applications of interest
- Then, determine D-FACTS settings to achieve the desired purpose
- Potential applications for D-FACTS include
  - reducing flow through overloaded lines
  - minimizing losses
  - minimizing cost

D-FACTS Technology

- Smart Wire Grid is currently building and deploying DSRs
- An ARPA-E project with Smart Wire Grid is in progress to implement D-FACTS devices in software and analyze their benefits to power systems

PowerWorld D-FACTS Support

- PowerWorld recently added implementation of the stand-alone functionality of D-FACTS devices, where the value of series reactive impedance X on the line is set as a function of the line current.
- This mode of operation for series-connected D-FACTS devices is described in [1] and [2].

[1] H. Johal and D. Divan, “Design considerations for series-connected distributed FACTS converters,” *IEEE Transactions on Industry Applications*, vol. 43, no. 6, pp. 1609-1618, Nov./Dec. 2007.

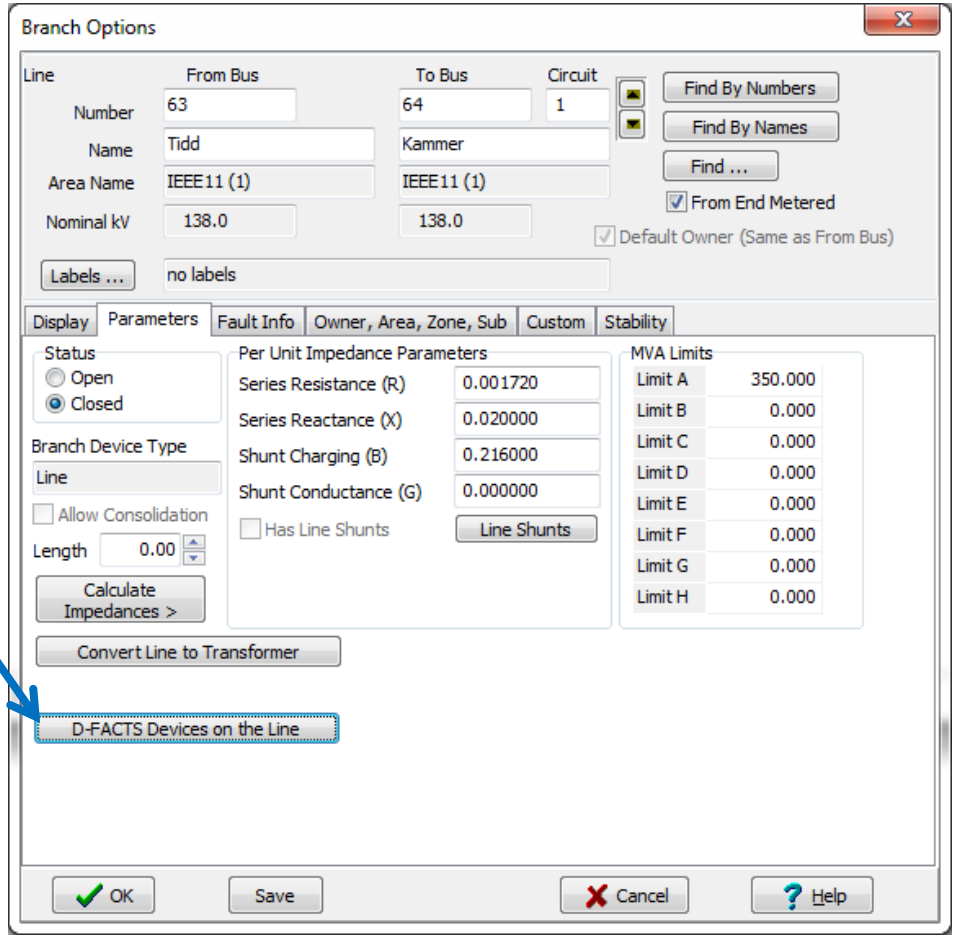
[2] H. Johal and D. Divan, “Current limiting conductors: A distributed approach for increasing T&D system capacity and enhancing reliability,” in *2005/2006 IEEE PES Transmission and Distribution Conference and Exhibition*, pp.1127-1133, May 2006.

D-FACTS Model Inputs

- For each line with D-FACTS devices, the user enters the number of modules and the reactive impedance per module
- The user also specifies values of line current magnitude I_0 and I_{lim}
  - Below I_0, the D-FACTS devices are inactive
  - Above I_{lim}, the cumulative impedance injection of the D-FACTS devices on the line is at its maximum value

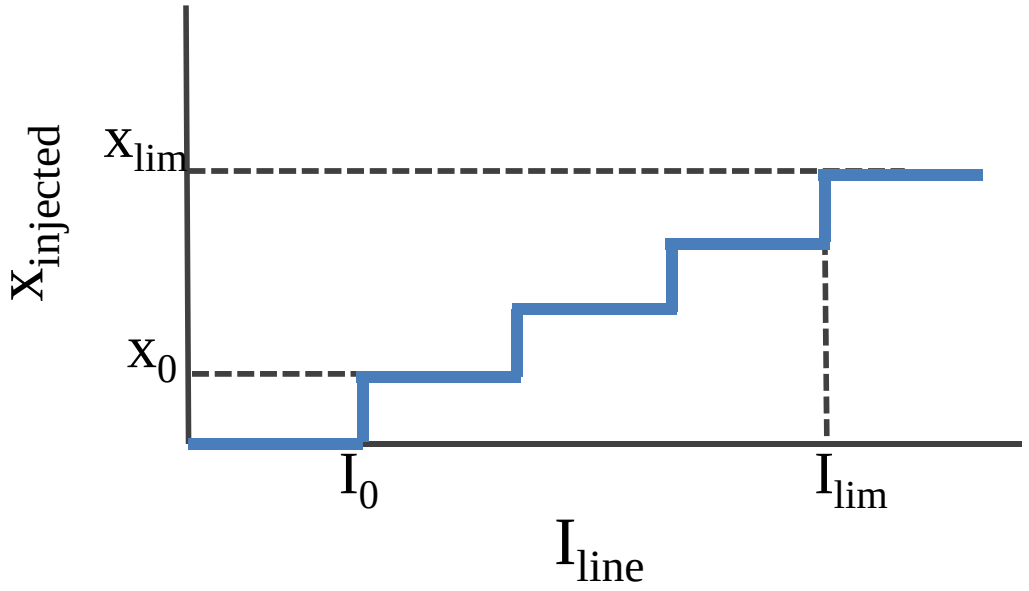
Inserting D-FACTS

- On the transmission line dialog, click on “D-FACTS Devices on the Line” to see the D-FACTS settings

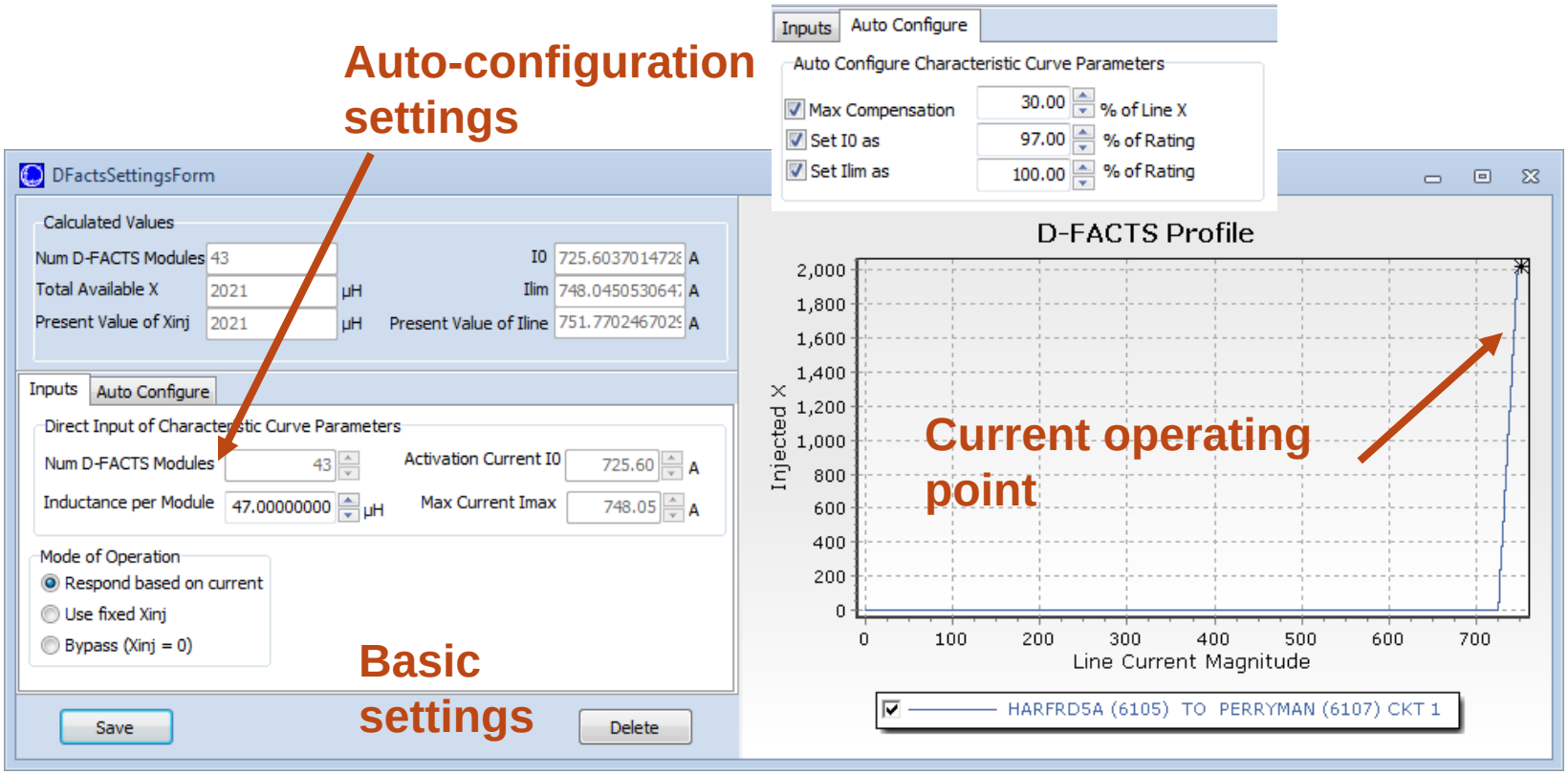


D-FACTS Operational Profile

- A piecewise linear function of the form shown below is created and used internally based on the entered information

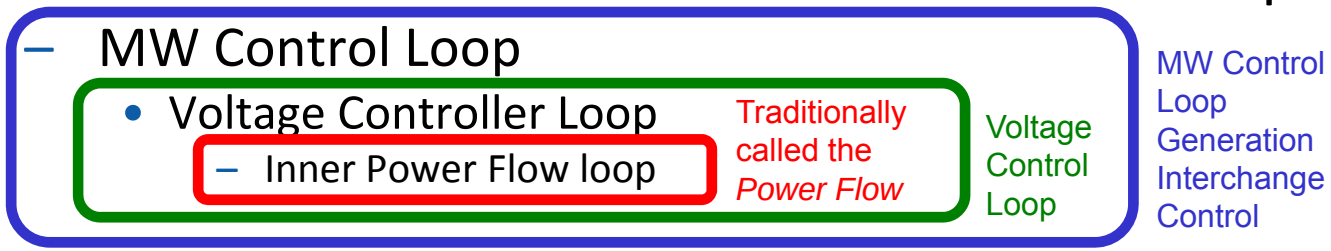


D-FACTS Dialog



Power Flow Support

- Simulation Solution Process: Three Nested Loops

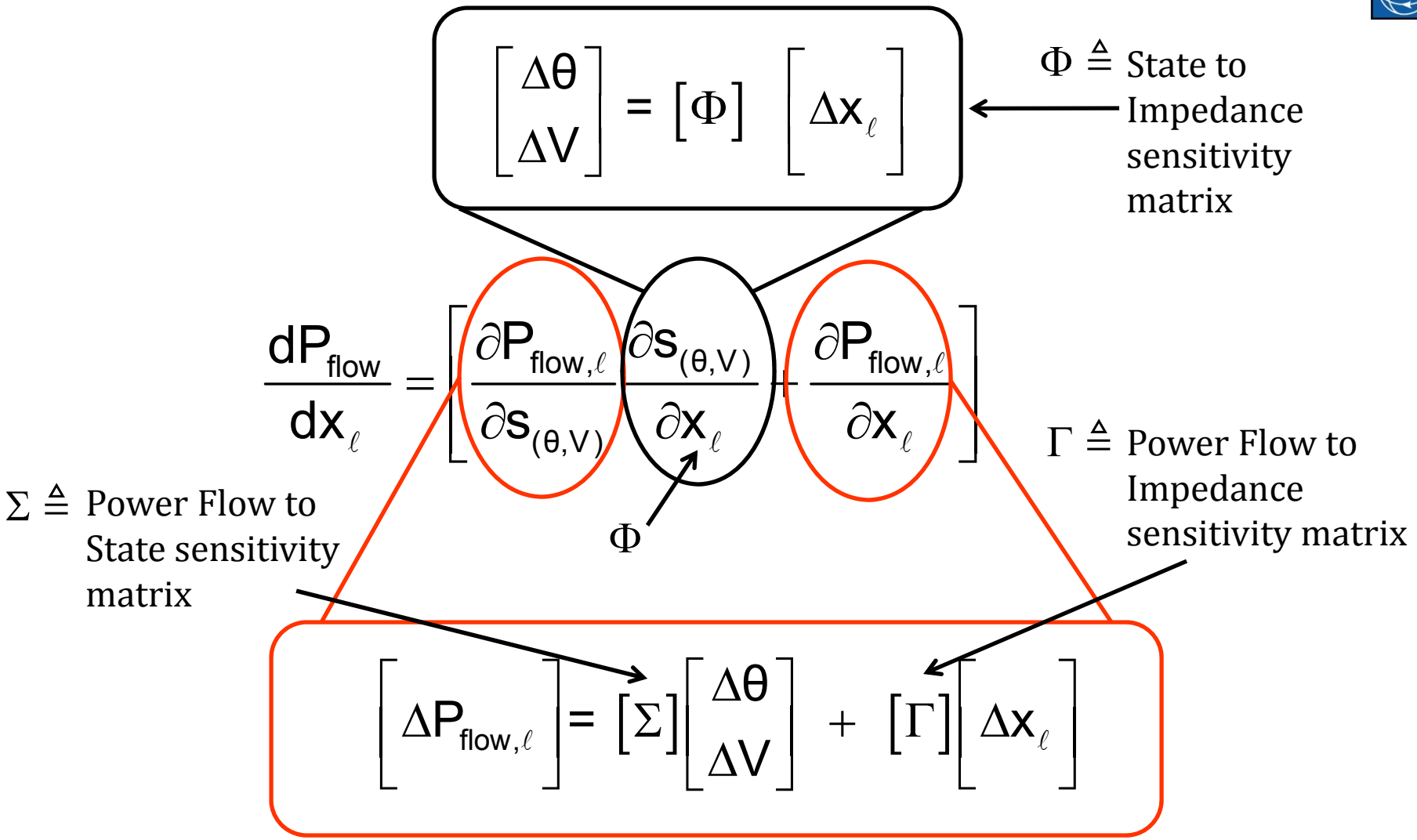


- PowerWorld Simulator implements the control of D-FACTS devices in the voltage control loop of the power flow solution.
- That is, after the inner power flow loop is solved to determine the state variables, the line current is calculated, and the D-FACTS values are adjusted according to their predefined piecewise linear lookup functions, if necessary.
- If the D-FACTS values are changed, an additional power flow inner loop is solved.

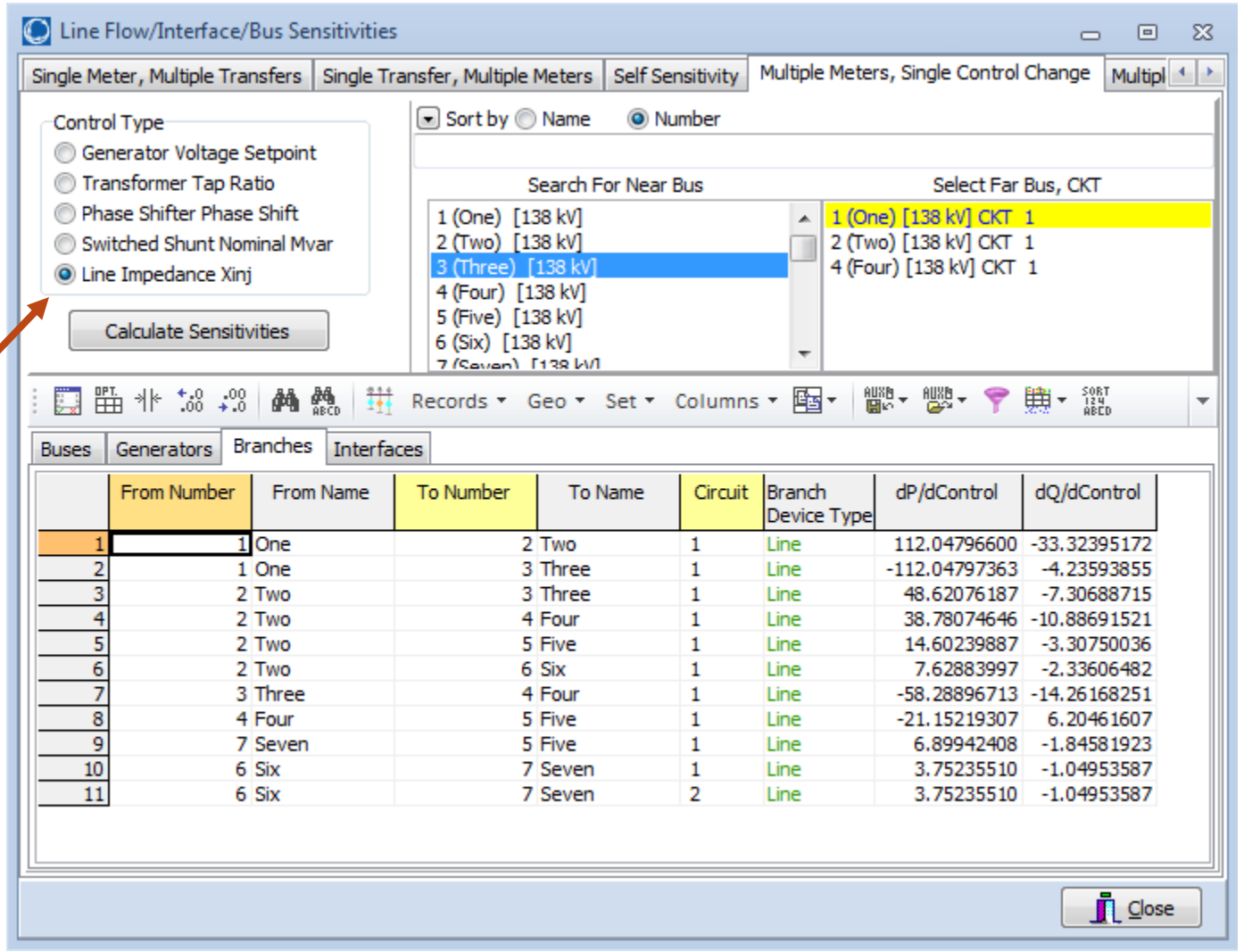
Line Impedance Sensitivities

- How does a change in line impedance affect the rest of the system?
- What can be controlled by changing line impedances?
- What D-FACTS settings will provide this control?

Line Impedance Sensitivities



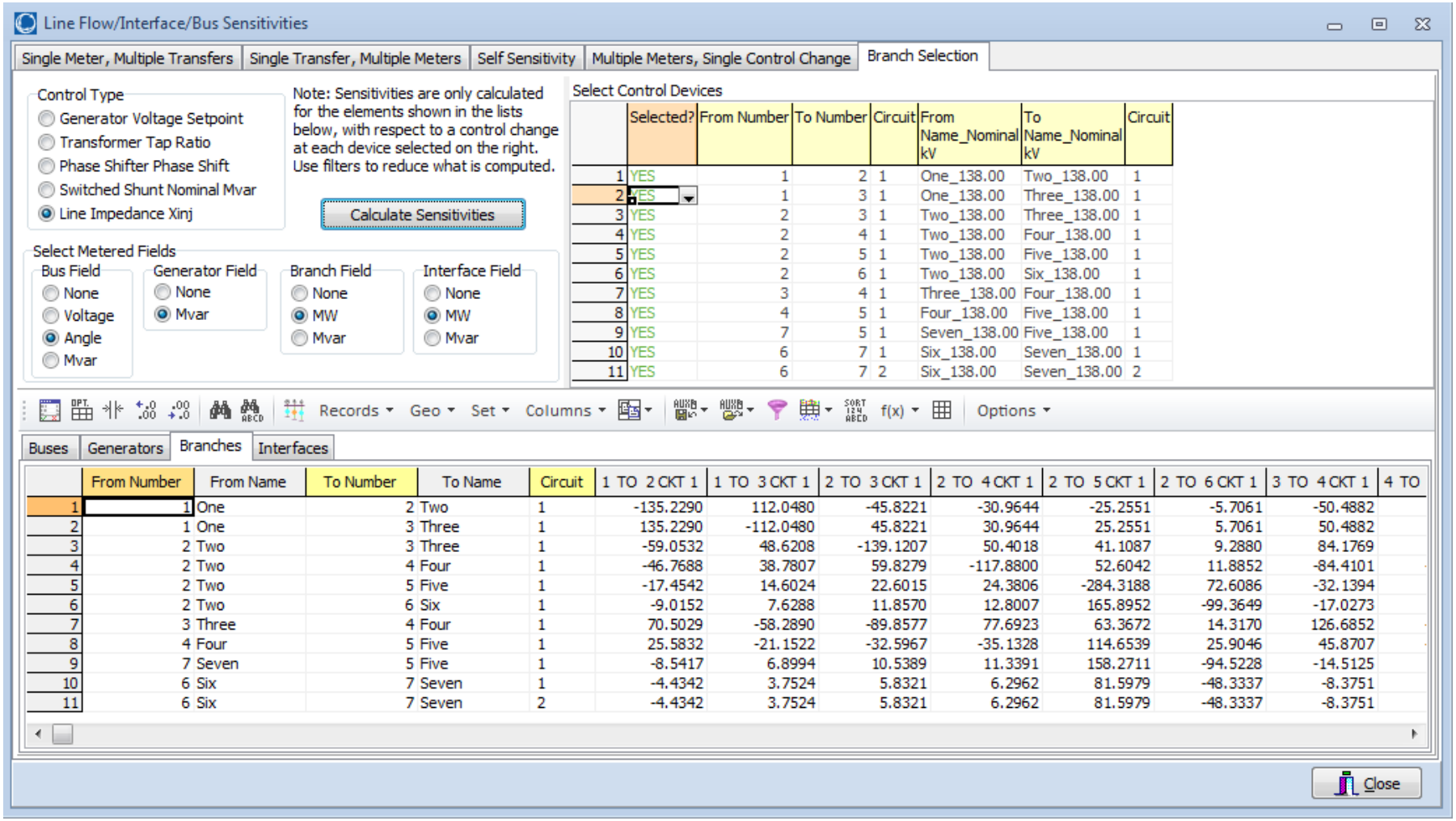
Single Control Change



	From Number	From Name	To Number	To Name	Circuit	Branch Device Type	dP/dControl	dQ/dControl
1	1	One	2	Two	1	Line	112.04796600	-33.32395172
2	1	One	3	Three	1	Line	-112.04797363	-4.23593855
3	2	Two	3	Three	1	Line	48.62076187	-7.30688715
4	2	Two	4	Four	1	Line	38.78074646	-10.88691521
5	2	Two	5	Five	1	Line	14.60239887	-3.30750036
6	2	Two	6	Six	1	Line	7.62883997	-2.33606482
7	3	Three	4	Four	1	Line	-58.28896713	-14.26168251
8	4	Four	5	Five	1	Line	-21.15219307	6.20461607
9	7	Seven	5	Five	1	Line	6.89942408	-1.84581923
10	6	Six	7	Seven	1	Line	3.75235510	-1.04953587
11	6	Six	7	Seven	2	Line	3.75235510	-1.04953587

New control to calculate Xinj sensitivities for DSR placement

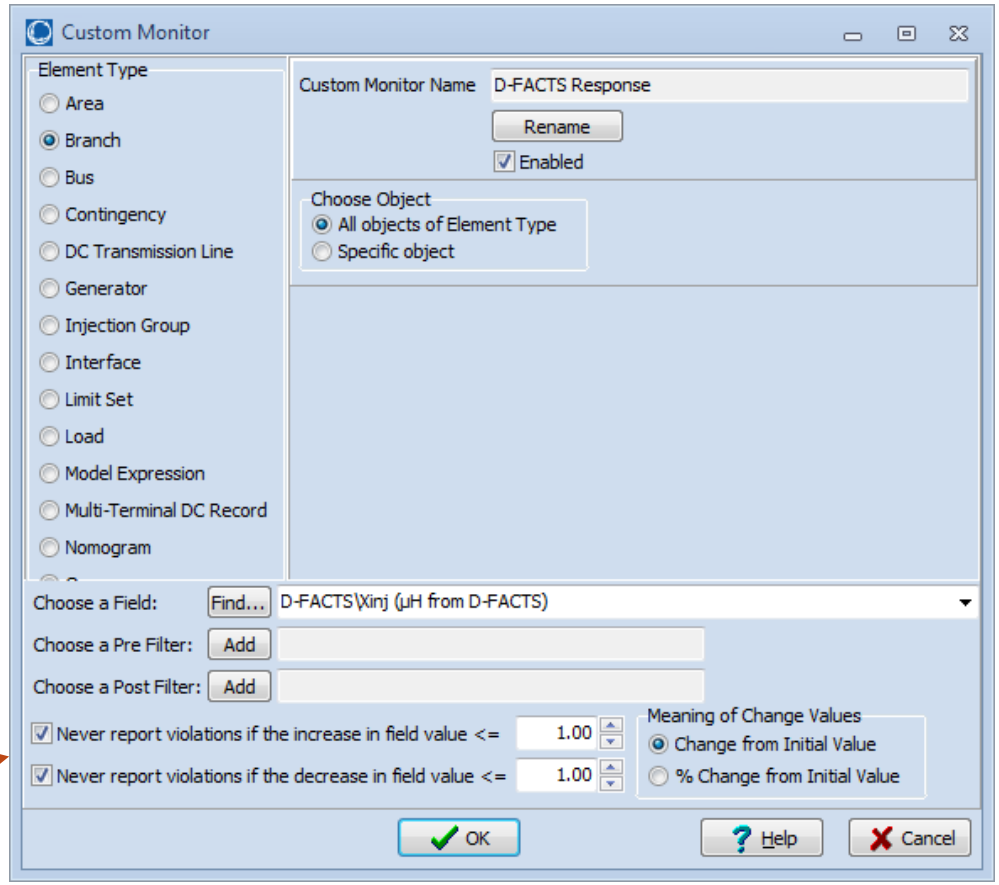
Multiple Control Change



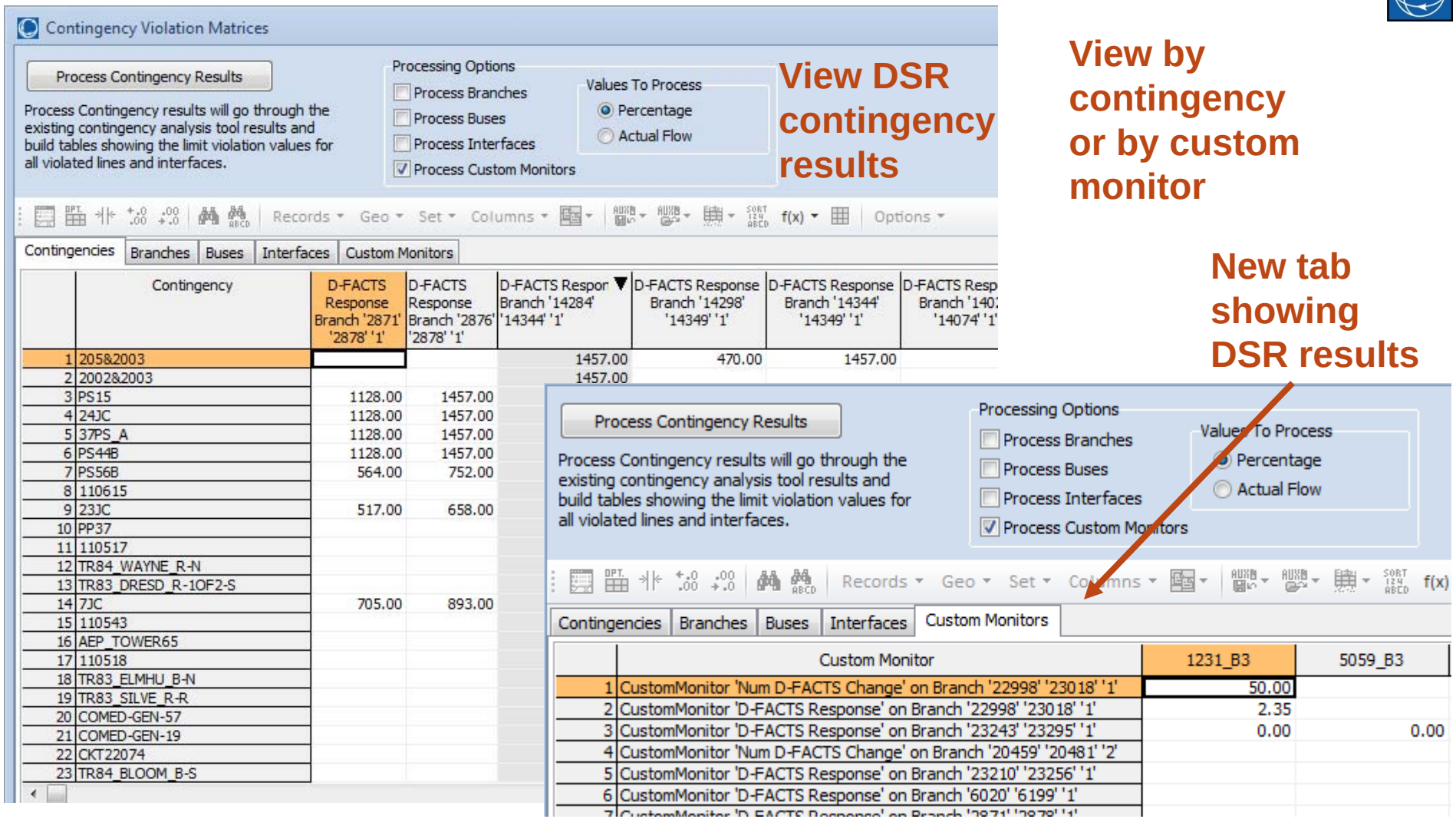
Contingency Analysis Results Monitoring

Use custom monitors to monitor D-FACTS response

Automatically limit what gets reported



Contingency Violation Matrices



Summary

- With the introduction of D-FACTS devices into operational systems, PowerWorld wants to make it possible to model their behavior in the system
- PowerWorld is taking the first steps to address this need by
  - Added D-FACTS device objects into the software
  - Implemented D-FACTS device in the power flow
  - Added feature to make custom monitoring in contingency analysis useful
  - Also working with Smart Wire Grid and DOE ARPA-E to implement D-FACTS in the OPF solution algorithm
    - Kate Rogers Davis
kate@powerworld.com
217-384-6330 ext 14